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上海生态建筑示范楼技术集成体系

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摘　要　本文介绍了上海市科委重大科研攻关项目“生态建筑关键技术研究及系统集成”的重要成果之一：上海生态建筑示范楼工程。通过研究办公示范楼各项关键技术的技术目标、技术应用和技术体系集成，探讨适合我国生态建筑的发展的生态建筑技术集成体系。

关键词　生态建筑；技术集成体系；技术目标

一、前言

21 世纪人类共同的主题是可持续发展，树立全面、协调、可持续的科学发展观已成为我国的基本国策。对于城市建筑来说亦必须由传统高消耗型发展模式转向高效生态型发展模式，生态建筑正是实施这一转变的必由之路，是当今世界建筑发展的必然趋势。

生态建筑遵循可持续发展原则，以高新技术为主导，针对建筑全寿命的各个环节，通过科学的整体设计，创造高效、低耗、无废无污染、健康舒适、生态平衡的建筑环境，提高建筑功能、效率与舒适性水平,体现节约资源、节省能源、保护环境、以人为本的生态理念，充分展示建筑与人文、环境及科技的和谐统一。

世界各国针对生态建筑的理念，并根据本国的建筑发展水平和特点，开展了生态建筑的实践与示范。建筑形式包括办公、住宅、学校、商场等，比较典型的有：英国建筑研究总署（简称 BRE）的环境楼（Environmental Building）和 Integer 生态住宅样板房；英国诺丁汉国内税务中心；德国爱森 RWE 办公楼；丹麦 KAB 咨询所设计的斯科特帕肯低能耗建筑；法国巴黎的联合国教科文组织（UNESCO）的办公楼；美国匹兹堡的 CCI 中心；德国柏林的新议会大厦等。我国在生态建筑领域也开展了积极的探索和研究，如清华大学设计中心楼（伍维权楼），北京科技部大厦、锋尚国际公寓等。这些示范建筑通过集成各项技术，充分展示了生态建筑的魅力和广阔的发展前景。

2003 年 11 月，由上海市建筑科学研究院总体负责，上海建筑相关领域 12 个交叉学科团队协同攻关的上海市科委重大科研攻关项目“生态建筑关键技术研究及系统集成”正式启动，针对上海的地域特征和经济发展水平，借鉴国内外最先进的生态建筑技术成果，通过开展生态建筑成套集成技术体系的研究、示范和推广，建立具有上海特色的生态建筑集成技术体系，建设具有国际先进水平、体现上海建筑风格的生态办公、住宅示范楼。

二、工程概况、技术目标及特点

1.　工程概况

2003.11 动工,位于上海市建筑科学研究院莘庄科技发展园区内(上海市闵行区中春路申富路口)，建筑面积 1900m^2 ,钢混主体结构，南面两层、北面三层。一楼东半部约 350m^2 大厅用于生态

建筑集成技术展示，并成为生态建筑关键技术和产品研发的实验平台。计划办公示范楼于 2004.9 建成(图 1)。

图 1 素上海生态建筑示范楼

2. 技术目标

上海生态建筑示范楼的总体技术目标将达到：

— 综合能耗为普通建筑的 1/4；

— 再生能源利用率占建筑使用能耗的 20%；

— 室内综合环境达到健康、舒适指标；

— 再生资源利用率达到 60%。

3. 主要技术特点：

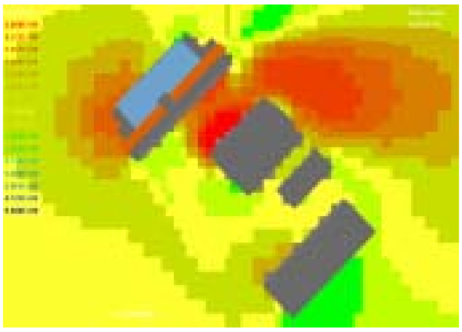
为实现项目的总体目标，同时基于上海经济发展水平，地域气候特征、周围环境特点，充分考虑示范楼建成后的使用功能需求，通过研究示范楼集成了国内外最新生态技术及产品，形成了自然通风、超低能耗、天然采光、健康空调、再生能源、绿色建材、智能控制、资源回用、生态绿化、舒适环境等十大技术特点，实现建筑一体化匹配设计和应用。

三、技术集成体系介绍

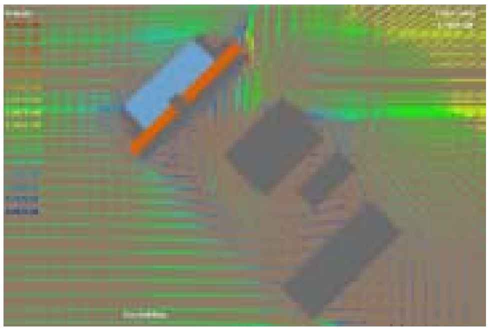
1.自然通风设计策略及气流组织模拟技术

通过室外气流组织的模拟计算及建筑物外形的风洞实验,对不同风向和风压下建筑各部分的自然通风效果进行分析，改进和优化建筑外形及房间功能。同时利用面积达 15 平方米的屋顶排风道代替排风烟囱，保证良好的自然通风效果。最后在排风道内设置 7 组加热器，在过渡季节，利用太阳能热水加热流道内的空气，产生热压，提供自然通风所必需的动力，强化自然通风。

分析过程中，通过对室内气流组织在不同风压、热压状态下的模拟计算和优化，计算各房间自然通风风量，然后比较、优化和确定自然通风的技术方案，合理组织自然通风的风道，优化自然通风口的建筑设计，实现舒适的室内风环境并减少夏季空调运行时间、节约空调能耗（图 2,3）。



a．风压图



b．风速图

图 2　室外气流组织模拟分析

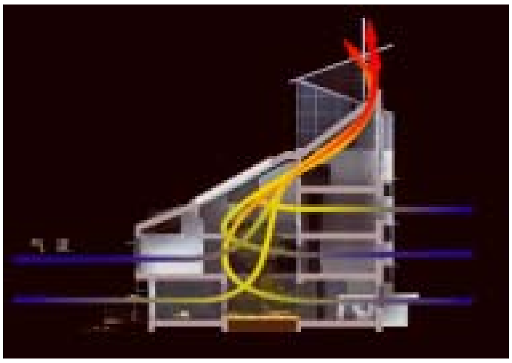


图 3　室内热压拔风效果图

2. 超低建筑能耗节能技术系统

根据生态办公楼建筑各种工况，通过能耗指标和节能效果能耗模拟分析，将多种低能耗建筑围护结构合理节能设计方案进行比较，确定适合生态办公楼的超低能耗节能技术系统：多种复合墙体保温体系（表 1）+双玻中空 LOW-E 窗+多种遮阳技术。

表 1　外墙外保温体系汇总表

序号	应用部位	保温体系主要构成	传热系数 W/(m^2· K)	热惰性指标 D
1	东向外墙	混凝土砌块(90)＋298 凯福发泡(60)＋砂加气砌块(240)	**0.32**	**4.3**
2	南向外墙	EPS 外保温(140)＋混凝土砌块(190)	**0.27**	**3.2**
3	西向外墙	混凝土砌块(90)＋298 凯福发泡(85)＋混凝土砌块(240)	**0.29**	**4.3**
4	北向外墙	XPS 外保温（75）＋混凝土砌块(190)	**0.33**	**3.2**

如东面复合外墙构造体系中采用混凝土空心小砌块或伊通砂加气砌块为主墙体，90 混凝土空心小砌块为外挂墙，中间填充发泡尿素、聚氨酯等高效保温层，构成一种隔热保温性能优异的新型复合外墙构造体系。

该体系有如下特点：①使建筑节能与使用新型墙材相结合，不使用粘土制品；②能消除热桥和墙体裂缝及渗水；③保护内结构层，延长建筑物使用寿命；④隔热保温性能优良，提高建筑热稳

定性和改善建筑热舒适性。

生态办公楼的绿化平屋面采用倒置式保温体系，保温层采用耐植物根系腐蚀的 XPS 板和泡沫玻璃板置于屋面防水层之上，再利用屋面绿化技术，形成一种冬季保温、夏季隔热又可增加绿化面积的复合型屋面（表 2）。

表 2 屋面保温体系汇总表

序号	应用部位	保温体系主要构成	传热系数 W/(m²·K)	热惰性指标 D
1	不上人平屋面	屋面绿化(600)＋泡沫玻璃(150)＋陶粒混凝土找坡层(100)	**0.31**	**3.2**
2	上人平屋面	屋面绿化(600)＋XPS(95)＋陶粒混凝土找坡层(100)	**0.31**	**3.2**
3	东向坡屋面	发泡聚氨酯(180)	**0.16**	**5.0**

外门窗采用断热铝合金双玻中空 LOW-E 窗，其中天窗采用三玻安全 LOW-E 玻璃，其表层玻璃具有自清洁功能；南向局部外窗采用充氩气中空 LOW-E 玻璃和阳光控制膜，提高外窗的保温隔热性能（表 3）。

表 3 节能窗汇总表

序号	应用部位	窗户类型	玻璃传热系数 W/(m²·K)	玻璃遮阳系数	可见光透过率（%）
1	坡屋面天窗	PET LOW-E 双中空玻璃窗	**1.82 (考虑窗框)**	**0.62**	**68**
2	各向外窗	LOW-E 中空双玻窗	**1.65**	**0.58**	**65**

同时根据该楼的建筑形式与日照规律，确定多种遮阳技术，以提高外窗的保温隔热性能。(1）天窗根据节能与采光的要求，外部采用可控制软遮阳技术达到有效节省空调能耗的作用。(2）南立面根据当地的日照规律采用可调节的水平铝合金百叶外遮阳技术，通过调节百叶的角度，即能够阻挡多余光线的照射，达到节能效果；也能使光线进入室内深处，提高舒适性。(3）西立面主要考虑到夕晒对室内的影响，根据太阳能入射角度采用可调节垂直铝合金百叶遮阳技术。

为评定各节能措施的节能效果，采用了 DEST 动态分析软件，对各种工况条件进行节能效果分析。

- 计算工况 1：不采用节能措施（对比基准）
- 计算工况 2：采用外遮阳
- 计算工况 3：采用外遮阳，采用节能窗（表 3）

- 计算工况 4：采用外遮阳，采用节能窗，提高围护结构保温隔热性能（表 1～2）
- 计算工况 5：采用外遮阳，采用节能窗，提高围护结构保温隔热性能，夜间通风

计算结果如表 4 所示。

表 4　各种控制策略的节能效果汇总

模拟工况编号	1	2	4	5	6
节能效果 (%)	—	9.0	42.6	45.5	47.8

通过以上对外墙、门窗和屋面的节能研究与综合措施的应用，仅围护结构的节能措施可将能耗降低 47.8%。

3.天然采光设计优化及模拟评价技术

采用天然采光模拟技术优化中庭天窗、外墙门窗等采光及遮阳设计，冬季北面房间可透射太阳光，夏季通过有效遮阳避免太阳直射。白天室内纯自然采光区域面积达到 80%、临界照度 100lx，在营造舒适视觉工作环境的同时降低照明能耗 30%（图 4，5）。

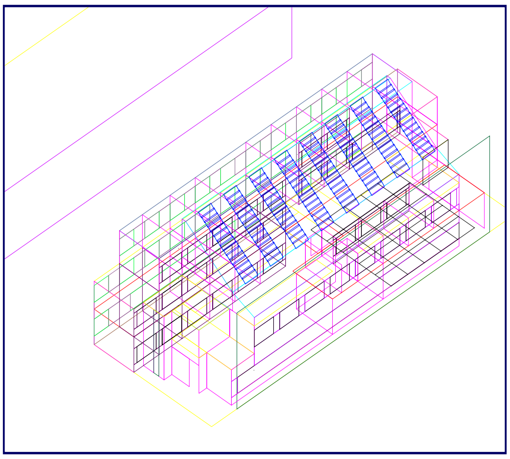


图 4 天然采光模拟优化

图 5 中庭天窗天然采光效果

4. 高效、环保、健康新型空调系统

针对现行空调系统普遍存在的霉菌问题、高能耗问题和臭氧层破坏问题，我们在示范楼里研发热泵驱动的热、湿负荷独立控制的高效、环保、健康新型空调系统：通过避免使用有凝结水的盘管，解决目前空调系统中存在的霉菌滋生问题，同时通过除湿机内盐溶液的喷洒除去空气中的尘埃、细菌、霉菌及其他有害物。

由于该空调系统同时了热泵的冷、热量，并且排风采用全热回收等技术，可以使空调能耗降低 20%左右；而且机组可以采用全新风运行，提高了室内空气品质。最后，系统通过使用绿色环保制冷工质（溴化锂溶液等），减少林氟锂昂制冷剂的使用，减少对大气臭氧层的破坏，体现生态和环保的理念（图 6）。

图 6　高效、环保、健康新型空调系统

图 7 斜屋面太阳能集热器和光电板效果图

5.再生能源利用建筑一体化

示范楼设计了斜屋面放置太阳能真空管集热器（150m^2）和多晶硅太阳能光电板(5m^2)，实现太阳能光热综合利用与建筑一体化（图 7）。太阳能真空管集热器为太阳能热水型吸附式空调和地板采暖(300 m^2)提供热源，该系统的示意图（如图 8），其主要作用是：夏季利用太阳能吸附式空调与建科院设计的溶液除湿空调耦合，分别负担一层生态建筑展示厅的显热冷负荷以及潜热冷负荷；冬季利用太阳能地板采暖系统负担一层生态建筑展示厅以及二层大空间办公室的热负荷。太阳能地板采暖系统负担的总采暖面积为 390 m^2，采暖设计热负荷 25 kW；在过渡季节，利用太阳能热水强化自然通风。生态示范楼的吸热塔顶设置了太阳能平板式集热器（4 m^2），并采用电辅助加热，可提供 300 升热水供应。

在斜屋顶下部选用光电转换效率≥14%的高效率多晶硅太阳能光电板，建立 5kw 光伏电站并采用并与电网并网。

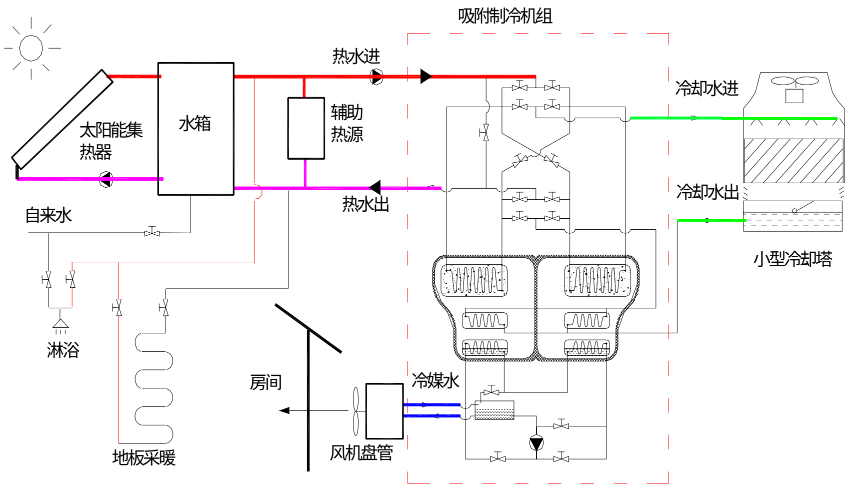


图 8　太阳能热水型吸附式空调、采暖复合系统

6.绿色建材

3R 材料（Reduce、 Reuse、Recycle）使用率达到 80%， 采用大量绿色工程材料，再生骨料混凝土多孔砖；C20 垫层再生混凝土，C30 再生混凝土，C40 大掺量掺合料混凝土（水泥用量为胶凝材料总用量的 30%）；掺建筑渣再生骨料粉煤灰商品砂浆（用作砌筑、抹灰和地面砂浆，用 25 %再生骨料替代天然砂，粉煤灰掺量大于 30%，水泥用量减少 15%以上）（图 9）；环保装饰装修材料 100%采用环保低毒产品，旧木材回收用于建筑装饰；并采用防霉、抗菌、吸声等环保功能材料。

图 9 生产再生骨料的原材料－－旧混凝土块

7.智能控制

以数据采集、通信、计算、控制等信息技术为手段，运用成套先进的智能集成控制系统，包括室内环境综合调控系统及软件(图 10)，照明及空调节能监控系统，安全保障及办公设备控制系统的集成平台和应用软件等，实现大型遮阳百页的转动控制，空调等设备的节能监控，照明采光监控，室内空气质量、温湿度、个性化通风，噪声等室内环境的动态调节，确保生态建筑运行的节能、舒适和高效。

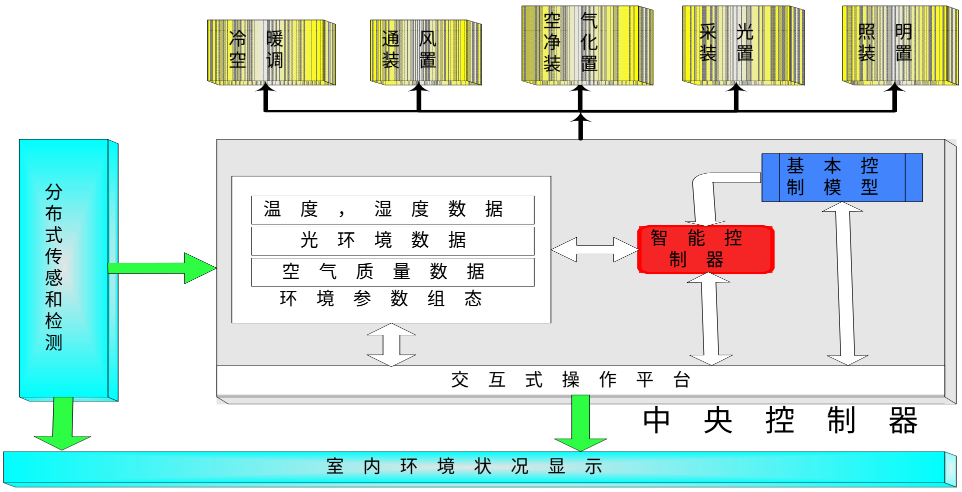


图 10 室内环境综合智能调控系统

8.资源回用

生态建筑示范楼雨污水 ICAST 回用处理系统的处理水量为 20m3/d，污水源为生态示范楼全部

建筑污水、幕墙检测中心实验用冲淋水及雨水。

该系统主要装置包括调节池、ICAST 反应池、二沉池、中间池、过滤柱及消毒池，ICAST 反应池由兼氧区和好氧区（主曝气区）组成，采用连续运行方式 。其工艺流程及连续运行方式如（图11）所示。

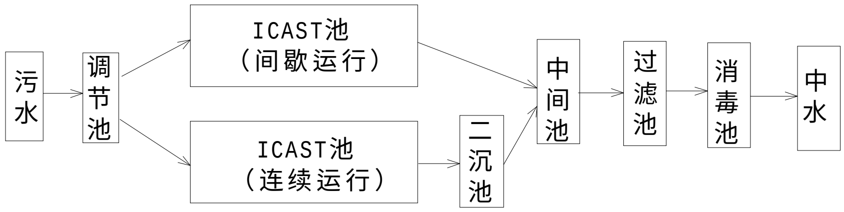


图11处理流程示意图

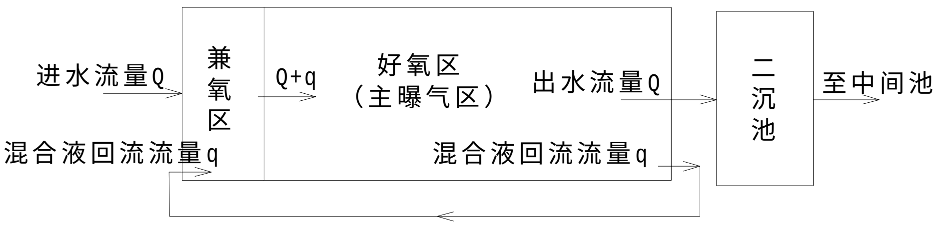


图12 连续式运行示意图

ICAST 反应池设计兼氧区目的不仅可有效地缓冲进水水质波动对好氧区活性污泥的冲击,而且可起到生物选择的作用，抑制丝状菌生长，控制污泥膨胀。运行过程中，兼氧区还可减轻好氧区部分的有机物负荷，使残留有机物更有效地去除。

此外，考虑到进水水质可能有较大波动，因此在原污水污染物浓度较大时可在中间池加入微量混凝剂。由中间池出水经过滤柱进行过滤，并送至清水池，消毒后的出水水质可达到中水回用标准（CJ/T 95—2000）。

本系统采用自动在线监测仪器对出水水质、ICAST 反应池内的运行条件以及系统设备的运行参数等进行监测，根据进水水质、水量和 ICAST 反应池内 DO 值，自动设定各工艺阶段的运行参数，使该系统处理运行安全、可靠。

将生态建筑雨污水经调节池处理后进入 ICAST 池生化处理并由过滤消毒后的出水（其水质达到中水回用标准）用于回用的系统，称为中水回用系统，一般由管道、水泵及喷嘴等组成。中水经回用系统可用于生态建筑楼顶平台浇灌绿化、景观水池用水、清洁道路等。

9.生态绿化

生态建筑示范楼在平屋顶屋面上设计了九处屋顶花园和一个室内中庭绿化，共计 400 多平方米。

屋顶绿化层包括保温隔热层、防水层、排水层、过滤层、栽培基质层、植物层。

（1）保温隔热层采用倒置式保温屋面。同时考虑到防止植物根系的侵蚀作用，保温层采用挤塑聚苯乙烯泡沫板或泡沫玻璃铺设而成。

（2）防水层采用聚氨酯防水涂料或防水卷材，并采用两道防水措施。

（3）排水层（疏水板）设在混凝土保护层上，过滤层之下。其作用是排除上层积水和过滤水，但又储存部分水分供植物生长之用。并与屋顶雨水管道相结合，将过多水分排出，以减轻防水层的负担。

（4）为防止种植土中小颗粒及养料随水而流失，且堵塞排水管道，需在种植基质层下铺设过滤层（无纺布）。

（5）种植层一般多采用无土基质，以蛭石、珍珠岩、泥炭、草炭土等轻质材料配制而成。

根据屋顶花园的大小，合理的设置活动区域、场地及设施的位置和空间大小，使之符合人的行为模式，在园路的组织、建筑小品的位置与尺度、地形的处理及植物的选择等方面，以精美为特色。植物配置宜选用小乔木、灌木、花草等 62 种植物，构成层次丰富、四季变化的景观，使人感到亲切、自然。

通过屋顶花园、垂直绿化，室内绿化和室外绿化等多种生态绿化植物群落配置技术，改善住宅的室内气温、形成生物气候缓冲带、净化空气、降低噪音、有效保护屋顶、延长建筑物寿命、减缓风速和调节风向等作用。有效改善建筑微环境、并营造视觉舒适的，实现夏季建筑外植物群落降温 1-2.5℃，夏季屋顶及垂直绿化降低室内温度 1-1.5℃，建筑周围植物群落减弱噪音能力为 1-2dB/2m 宽绿化等生态效益指标（图 13）。

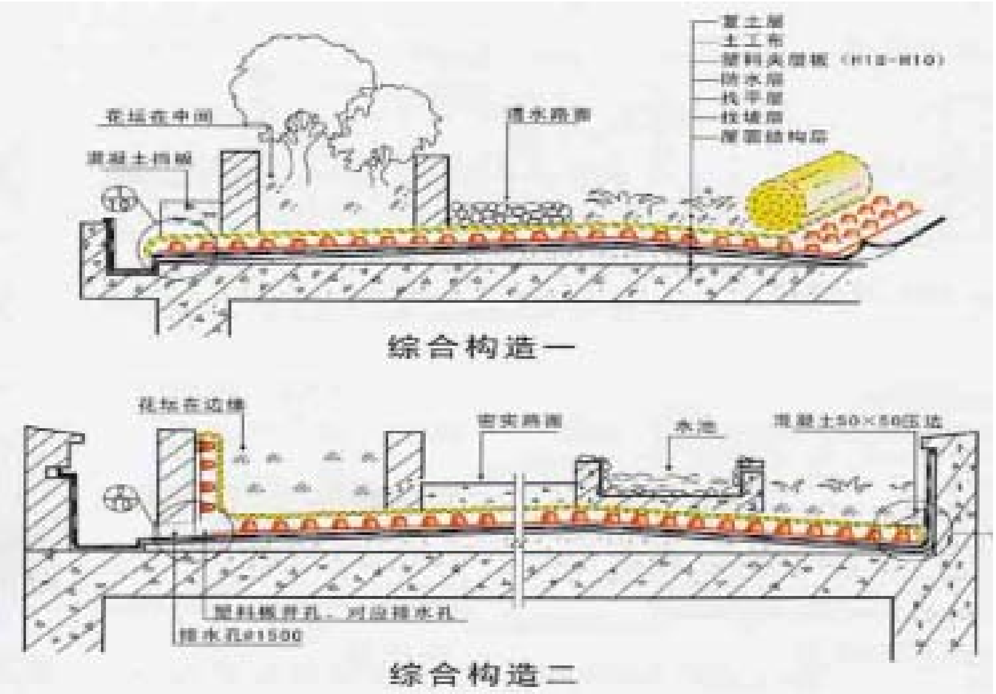


图 13　屋顶绿化层土建示意图

10.舒适环境

通过室内污染源浓度分布预评估、环保建材和室内设备的选择和新风量的控制，确保室内空气品质；通过热环境模拟评估，确定满足热舒适的空调系统运行参数和气流组织、风口的选择；通过室内外噪声调研和建筑隔声模拟，并综合考虑噪声控制与节能、通风、采光之间的协调，提出室外交通噪声、室内设备房、中庭、管道、电梯等重点区域隔声降噪控制方案；通过

光环境模拟分析，将人工照明与自然采光相结合，确定分区照明设计方案。最终通过室内环境综合智能调控系统，实现健康、舒适的室内环境控制目标（图 14）。

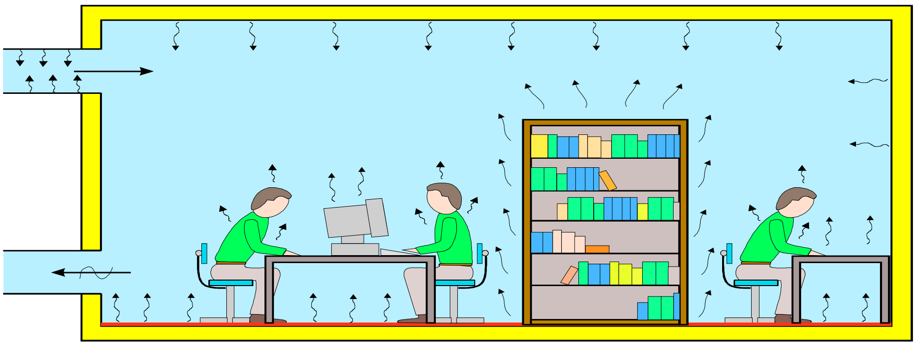


图 14　室内空气污染预评估

四、结束语

上海生态建筑示范楼的建设汇集了国内外 60 多家产学研联合体，是建筑设计师和各技术领域工程师、产品供应商及施工企业伙伴密切合作、协同攻关的产物；目前已作为生态建筑技术产品后续研发的实验平台列入 2004 年国家“十五”科技攻关重点项目“绿色建筑关键技术研究”，通过跟踪实测评价其生态技术集成体系效果，并开展生态新技术、新产品的应用研究，形成适宜推广的适用生态技术集成体系，为房产商建设生态建筑提供技术支撑，进一步推动我国生态建筑的发展。

Research into Practice:
how applied research can underpin innovative practice

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DRAFT

Abstract The construction industry is notoriously conservative and slow to change, and until recently, only the largest players have engaged in research. However, concerns over global warming and the need for sustainable development, have led to substantial investment (particularly in Europe) into the research and development of technologies and design approaches which will reduce our dependency on fossil fuels. The application of these techniques to building projects has spread around the world, in parallel with the research programmes, and is slowly becoming part of the mainstream, but there is a perceived knowledge and skills gap among construction professionals, which is seriously restricting further take-up. There is widespread understanding of the 'need', but a lack of widespread 'know how'.

The transfer of knowledge from research into practice is therefore vital. But this is difficult in an industry which habitually dislikes change, which has traditionally undervalued research and dismissed academics as ivory towered dreamers. One way of convincing critics that the 'new' technology is not necessarily also risky, is by demonstrating that it is cost effective and technically viable through its application in major projects. Attention can then be focused on the process by which innovation in low carbon buildings is achieved.

One thing is very clear: it is no longer satisfactory to rely on previous ly acquired knowledge and experience alone. In the last 20 years, major advances have been made in both our understanding, and the application, of bioclimatic design principles in buildings. Similar advances have been made in new and renewable energy devices, and their integration in buildings. Strategic thinking about these issues needs to be part of the early design pr ocess, and rigorous testing of options (using a wide range of analytic tools) is required in order to give clients the confidence to proceed with a radical solution. Not all projects can afford specialist testing and analysis, but simplified techniques exist, and this is where the 'know how' really counts.

As a research led educational institution, the School of the Built Environment at Nottingham University, has been engaged in innovative R&D and consultancy in the fields of 'bio-climatic' design and sustainable energy technologies for over 15 years. Professor Saffa Riffat has developed the concept of 'Life Labs '*(Ref)*, where innovative or experimental technologies are integrated within the school's own buildings, providing reduced carbon emissions and the opportunity to undertake experiments in a ' live' building. Professor Brian Ford has been involved in both research and consultancy in the application of bio-climatic design principles in numerous projects around the world. This paper illustrates this process of transferring 'Research into Practice' and the sometimes conflicting relationship between different measures to reduce carbon emissions from buildings.

Introduction

It is important for us to look at the scale of the task that faces us, in terms o f reducing carbon emissions and their impact on global warming. Atmospheric carbon today constitutes 370ppm compared with the pre-industrial concentration of 280ppm. The projection of future carbon imbalance indicates that ‘Business as Usual’ is not an option. A strategy of avoiding fossil fuel use entirely would re-establish global carbon balance to pre-industrial levels, but even if this may be achievable technically, this is unlikely to be acceptable socially or economically. Current proposals suggest a target upper limit of 550 ppm by the end of the century, although significant climate change is already apparent in many parts of the world, so the implications of this limit for the following century are rather alarming. For an energy strategy in buildings to be based on efficiency measures and the integration of renewables, both professional practice and education within the construction industry must change. The transfer of knowledge gained from recent research, into practice, must form part of this process. But in order for EC targets to be achieved, gaps in knowledge and skills also need to be addressed among all who work in the industry.

Energy Efficiency

In the UK, the 2003 Government White Paper on Energy proposed reductions in carbon emissions of 10% by 2010, 20% by 2020 and 60% by 2050 *(Ref)*. This is broadly in line with EC policy, but this implies a ‘step change’ in both professional practice and attitudes to the way we design and refurbish buildings.

The carbon emissions from existing service sector buildings are primarily derived from the demand for space heating and lighting. Changes in the Building regulations in the UK have begun to address this, but it is apparent that improvements in the performance of the building envelope (ie reductions in the space heating load), can potentially result in an increased cooling and ventilation load.

In the Queens Building in Leicester UK for De Montfort University (*Sneider A. 1996)*, designed 15 years ago, we reduced energy consumption for heating and lighting by 50% (from 240 kwh/m2 for a typical similar building to 120 kwh/m2). We realized that this raised the potential risk of overheating but we avoided the need for mechanical cooling by combining natural ventilation with a high thermal mass interior. The design also involved careful consideration of daylighting and solar control to the different spaces, enabling savings in electrical energy use as well. Over the last ten years the building has performed well and has consistently met energy use expectations.

The Manchester Justice Centre competition proposal by Pringle Richards Sharratt uses a conceptually similar strategy to that of the Queens building. Heating and lighting still represent the largest demands for energy. On a restricted inner city site, a five point environmental strategy was adopted: 1) Light shelves to throw light deep into the section, providing even illumination and avoiding glare. 2) The central atrium space and perimeter corridors to act as thermal and acoustic buffers to the internal courtrooms 3) naturally ventilated courts via a deep floor plenum. 4) Traffic noise is reflected back into the street. 5) Supplementary cooling is provided (when required) by borehole water.

This magistrates court resolves the necessary split between the public and the judiciary by placing the courts between the large central atrium (public) and perimeter outward looking circulation for the judiciary. Performance analysis indicated that total energy consumption would be reduced by over 50% compared with typical existing magistrates courts.

The contribution which daylight and natural ventilation can make to reducing energy use is increasingly being recognized even in large deep plan projects which had previously been entirely mechanically conditioned. Recent examples with which the author has been involved with include the Sydney Olympic Stadium, Australia (completed 2000), the Duxford AirSpace aircraft museum, UK (design stage), and the Pittsburgh convention center, USA (completed 2003).

Passive and Hybrid Cooling

In southern Europe, the combination of high ambient temperatures and internal gains will normally mean that supplementary cooling is required. **Give info on demand for cooling - Altener proposal*. If we compare the prevalence of air conditioning in existing and new commercial buildings in southern Europe, we find that air conditioning is, not surprisingly, very much on the increase. It also indicates the significance and potential value of finding energy efficient alternatives.

The I Guzzini office building at Recanati designed by Mario Cucinella *(ref)*, promotes natural ventilation at night to pre-cool the exposed floor slabs, and supplementary cooling is provided during the day by fan coil units. A certain level of control is also in the hands of the occupants to open and close windows etc as they feel fit. Of course, light is also a major driver of the design, and all office areas benefit from proximity either to the perimeter glazing, or the central light well. Orientation is carefully considered, and although the south elevation is highly glazed (and shaded) the east and west elevations are almost blank, protecting the building from low altitude solar radiation. The separate elements of the building - shading, façade, light-well, staircases, rooflights, - articulate the environmentally responsive philosophy of the project.

In seeking to minimize reliance on mechanical cooling, various ambient heat sinks have been exploited in the past. Both direct and indirect evaporative cooling has been exploited in the past, and there is renewed interest in this in conjunction with downdraught towers. The application of Passive Downdraught Cooling (PDEC - see *Ford, B 1996*) to the Torrent Research Centre in Ahmedabad, India *(Ford,2001)*, was one of the first applications of this technique. In a context where electrical energy is both expensive and unreliable, energy savings of 65% represent a significant achievement. This technique is now beginning to be applied in southern Europe. In a speculative office project in Seville, Spain *(Ford,B. 2002)*, PDEC was found to meet 85% of the cooling load, and achieve a 6% capital cost saving over its air-conditioned equivalent. Significantly, this approach simultaneously deals with problems of urban noise and pollution.

In Malta, direct evaporative cooling is only applicable for 25% of the summer cooling period, and so a hybrid cooling system has been adopted for the new Stock Exchange *(Ford,B & Diaz,C.2003)*. There are three parts to this cooling strategy: 1) When ambient temperatures are high and relative humidity is low, then PDEC operates; 2) When the internal relative humidity reaches 65% PDEC is switched off and high level cooling coils are activated; 3) At night in the summer, when ambient temperatures drop below internal air temperatures, vents are opened and air is driven through the building to pre-cool the building for the following day. Temperature traces recorded during commissioning indicate that internal temperatures within the main atrium space are stable around 23 -25^{o}C when ambient reaches 31^{o}C, although there is also stratification.

This project demonstrates that in large volume spaces of this kind air flow through the building can be driven by buoyancy (and wind) forces without the need for fans and ductwork.

The applicability of PDEC to non-domestic buildings in southern Europe has been assessed as part of two EC funded research projects: a JOULE project (ref) completed in 1999, and an ALTENER project (ALTENER Cluster 9 Ref:4.1030/C/00-009/2000 - see *Ford B & Cairns K. 2002)* which was completed last year. The Altener project has established a database on existing and new non domestic buildings in Italy, Spain, Portugal and Greece, from which estimates have been made of the proportion of the building stock to which PDEC is applicable. The greatest potential exists in Spain and Italy, where a hybrid system of the type applied to the Malta Stock Exchange, could achieve electrical energy savings of 30-50kWh/m^2 , which represents 10 - 20% of the total energy consumption of a typical office building. At a national scale, the technical potential (assuming a scale of interventions from minor to full scale refurbishment) is substantial : this approach is applicable to 70-80% of the existing commercial building stock, and in many situations will be more cost effective than comfort cooling. Of course market barriers will limit the take-up of the technology, but for PDEC the ALTENER study suggests that the national annual electrical energy savings could represent 1.5% - 2.5% by 2025.

This technique does not lend itself so easily to small cellular spaces, and at the Malta Stock Exchange cellular offices are conventionally conditioned with fan coil units. However, the 'Gravivent' system, developed in Germany, has been applied to cellular spaces, and we have also recently been developing simpler direct and indirect evaporative cooling systems using porous panels placed within wall ducts or mounted in roof vents. Results from laboratory testing indicate that we can achieve 30 - 40 watts cooling /m2 of panel. These systems also lend themselves to refurbishment projects, and are applicable both to housing and offices, suggesting substantial potential.

The use of cooling coils in conjunction with buoyancy driven air movement was part of proposals for the cooling of concourses and atria in the competition winning entry for the Singapore Management University campus by Edward Cullinan Architects. The supply of fresh air needs to be carefully controlled, but this approach is clearly viable for warm humid climates.

Refurbishment - opportunities for performance improvements.

Data on the frequency of refurbishment in different countries within Europe indicate that most commercial buildings are refurbished every 10-20 years. The scale of intervention and modification of the existing building will vary, but clearly there is a major opportunity to improve performance as well as making cosmetic improvements.

Temple Way House in Bristol was built in the late 1960s and is in need of refurbishment. Located on a noisy and polluted dual carriageway, this office building was originally air conditioned, but the system was at the end of its life, and we were asked to find an alternative to replacement. The building is predominantly narrow in section (approx 12metres wide), and although the east side is noisy and polluted, the west side is adjacent to the harbour which is quiet and clean. We therefore proposed to supply air from the harbour side and exhaust on the east side via glazed stacks which terminated above roof level. The glazed stacks were sealed externally, providing a thermal and acoustic buffer to the noisy road, while maintaining daylight penetration. CFD analysis indicated that, with refinement, the idea would work. In a sense, the glazed stacks are like a partial double façade.

Of course, overcladding with glazing to form a second façade, protects the inner façade and provides a thermal and acoustic buffer between inside and outside. However, this approach can also give rise to increased overheating risk, and consequent increased cooling load. Recent buildings by Renzo Piano Building Workshop (eg at the Parc D'Or, Lyons) have resolved the overheating risk by making the whole façade openable using automated glazed louvers. This solution is extremely expensive and also reduces the acoustic effectiveness of the 'buffer zone'. Mechanical extraction of air from the cavity can reduce cavity width, but may increase energy and maintenance costs.

An innovative porous cladding element has been developed which induces direct evaporative cooling of the air within the cavity. (See EC Framework 5 research project EVAPCOOL Ref: ENK6-CT-2000-00346). This innovation enables the external façade to be sealed (apart from small vents at top and bottom) and reduced in width, potentially reducing the cost associated with opening facades, improving noise reduction, and reducing the cooling load in adjacent offices. Cladding support systems similar to those used for current ceramic cladding systems can be used for the porous panels, with a similar loading on the façade. This idea is currently the subject of on-going research.

Integration of Renewables

The integration of new and renewable energy devices in buildings is widely heralded as the means to move from energy efficient building design to 'Zero Energy' building design. The contribution of renewables to total energy use in the UK is due to increase from 3% in 1989 to 20% in 2020.

Research and Development into building integration of renewables has been a major feature of work at the School of the Built Environment in Nottingham University. The 'Life Lab' concept has been applied to many of the schools own buildings. The 'Eco-House', incorporates a small wind turbine, solar chimney, PV roof tiles, light pipe, solar water heating, a ground source heat pump, and rain water collection. The Marmont Centre for Renewable Energy also incorporates a wind turbine, PVs, light pipes and solar water heating. The new 'Sustainable Research Building (SRB) incorporates a 5kW PV roof, …. *(expand)..* but it is the University's Jubilee Campus that gives the largest scale demonstration of an holistic approach to sustainable design in its architecture. The plan links narrow teaching blocks by atria which help to drive a novel low energy ventilation system, and incorporate PVs and other renewable energy systems. Wherever possible the buildings also incorporate sustainable materials*…..(expand)…*

The Jubilee Campus, by Hopkins Architects and Arups, is widely regarded as the world's first 'Green ' campus.

CONCLUSION

This paper has identified the pressing need to transfer research knowledge into practice, and has illustrated a number of projects in which architects, engineers and building physicists from the school of the built environment at Nottingham University have contributed to this process.

Bill McDonough, one of the pioneers of sustainable design in the US, has said that: *"Most architects who are sensitive to sustainability issues try to do more with less by designing buildings that make more efficient use of energy and resources. But is being less bad the same as being good ? Does mere efficiency meet our need to connect with the natural world or does it just slow down ecological destruction" ?* (Gissen. 2003)

It is clear that a truly sustainable built environment is not a 'goal' or an 'end point', but rather a process. And the closer this 'process' mimics the natural world the more sustainable it will be. Nature is comprised of self-regulating ecosystems which maintain a delicate interactive and dynamic equilibrium, responding to the cycles of the seasons and of day and night. Our buildings and built communities need to cultivate a similar dynamic equilibrium, contributing to rather than subtracting from our ability to be 'self regulating'. A society with these values will not mourn the passing of the fossil fuel era.

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从研究到实践：如何让应用研究支撑革新性的实践

建筑业变革进程缓慢，出了名的保守。至今，也只有少有的几家大公司开始参与研究。然而，对全球变暖和可持续发展的关注已经导致对研究的大量投资（尤其在欧洲）以及在技术和设计方法上的发展从而将减少我们对石油燃料的依赖程度。随着研究的扩展，这些应用于建筑工程项目的技术已经遍及全世界，并且正在成为部分主流技术。但是，可以感觉到，在建筑专业上存在知识和技术鸿沟，它会严重限制新技术的应用。大家都认识到需要新技术，可是大都缺乏对如何实施的认识。

知识从研究转向应用因此非常关键。但是对于一个不喜欢改变的工业，一个在传统上就低估研究，将研究者鄙视为象牙塔下作白日梦人的工业，这样的转变变得非常困难。一种说服评论家了解采用“新”技术也不一定有危险的方法是要说明将技术应用在一些大型的项目中是可靠且花费高效的。我们可以关注这么个过程，通过该过程可以达到对低 CO_2 排放建筑的技术革新。

有一点是很明确的，那就是我们不再满足于单单倚赖以前获得的知识和经验。在过去的 20 年里，我们的认知和将生物气候设计理论在建筑中应用都取得了较大的发展。在新能源和可再生能源利用及其在建筑上的集成中也取得了类似的进步。战略性的考虑这些问题应该成为设计初期阶段的一部分。为了给客户采用彻底解决方案的信心，需要使用各种分析工具对技术的选择进行严格的测试。并不是所有的工程项目都可以请得起专家进行测试和分析的，但是简化的技术也是存在的，这就是“如何实施”真正的意义所在。

作为一个教育性的研究机构，诺丁汉大学建筑环境学院在生物气候设计和能源利用技术领域上进行革新性的研发和咨询活动已经有 15 年了。Saffa Riffat 教授已经发展了“生命实验室”的概念，在这些实验室里，革新性的或是实验性的技术被集成到学校自己的建筑中去，使得建筑的 CO_2 排放降低，并且有机会在这些“活”建筑中从事一些实验活动。Brian Ford 教授致力于研究和咨询，已经将生物气候设计理论应用在世界各地的许多项目上。本文阐述了将研究转化为实践的过程和有时候为了降低建筑 CO_2 排放采取的不同措施之间存在的矛盾关系。

Government and Private Sector Actions in Improving the Environmental Performance of Buildings

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Shanghai SB04, September, 2004

There is global interest in improving the performance of buildings. Governments want to reduce the use of scarce resources and airborne emissions, owners want to reduce operating costs, and developers are finding that customers are demanding higher quality and performance. Although the achievement of this goal in different countries will require varied strategies, it is certain that all will have to make substantial improvements in the methods used to design, construct and operate buildings. This will require interventions by governments, but it will also require that designers adopt a different way of working.

The building industry is very different from other sectors with substantial environmental impacts. The performance of automobiles, for example, can be improved by working with relatively few manufacturers, but the construction industry consists of thousands of organization, ranging from very small to very large, and staffed by individuals whose levels of skills and training vary from very basic to quite advanced. Buildings are also long-lived compared to other products, and have to conform to local cultural and climatic conditions in addition to meeting functional requirements. All of this implies that initiatives for performance improvement must be addressed on a broad front.

This paper will confine itself to the range of initiatives that look promising in the large buildings sector (excluding small houses) and within market economies. In addition, the discussion will be focused on measures that apply primarily to the design and construction stages, for both new and renovated buildings. The approaches discussed are primarily based on Canadian experience, but basic strategies discussed are of broader interest.

A.Options in improving energy and environmental performance

Any discussion of building performance must recognize that designers carry out instructions provided by their clients. Thus, an appropriate focus is to consider ways through which clients might be induced to require their designers to strive for a higher level of performance. The range of mechanisms available include regulations and standards, enabling measures, incentives and market change mechanisms.

Standards and Regulations can be very effective if well enforced, but they usually define aminimally acceptable level of performance and are therefore normally insufficient to lead theindustry towards very high levels of performance.

The effectiveness of a regulatory approach varies greatly depending on the culture and traditionsof the region and country in question. In Europe, for example, demanding regulations are well accepted, and the recent EU requirement for national energy standards to be in place by January of 2006 is likely to be fully satisfied in all

EU countries. There is also discussion taking place about a similar regulation to be passed for environmental performance in the next few years.

The climate in North America is very different, and regulations tend to be resisted if they cause major changes to industry practices. Despite this, Canada has much recent experience in this area due to the development and introduction of equipment efficiency standards and the *Model National Energy Code for Buildings* (MNECB)1. Standards for equipment have been in place for several years, and are complemented by an equipment labeling program called *EnerGuide*, which provides information about the energy performance of the item under normal usage conditions.

The *EnerGuide* program is about to be supplemented by the adoption of the *Energy Star* program (originally from USEPA), which identifies the top-performing equipment in each category.

The design of the MNECB regulatory package for buildings is sophisticated, since it allows for both default minima and a simulation path for compliance, and also takes into account energy costs and incremental construction costs within a life-cycle cost formula. Studies have shown that the MNECB is approximately congruent with current good practice but, despite this, only a few jurisdictions in Canada have adopted it because of industry resistance. There is currently a move afoot to update the MNECB.

The difficulty of implementation reflects a peculiarly North American context, where regulations have traditionally confined themselves to issues of life safety and health. Any extension of the regulatory sphere is therefore considered by the North American industry to have validity only if measures reflect a strong consensus on a minimum level of action. This, combined with very low energy prices over the last decade, have made it difficult to build a consensus for strong action in the area of energy. Nevertheless, the MNECB is gradually taking root, but at a level of performance which is relatively unchallenging.

What may be called *enabling measures*, such as the development of guidance documents, design tools, and training programs, are also necessary components of a green building strategy. Such measures tend to be used by those in the industry who are already convinced of the need for high performance, and so they tend to have limited penetration, but some recent developments in design process support tools show promise (discussed later in this paper).

Demonstration projects fill a very important part in convincing the relatively conservative construction industry that modern processes and technologies can bring benefits. Where demonstrations fail, this is possibly even more useful, although there is a tendency to sweep such findings under the carpet. The C-2000 Program is currently the only available national demonstration program for high-performance buildings in North America.

Financial incentives are of interest, since a financial inducement is likely to be effective in an environment where financial return is a primary objective. One example is a program called *Commercial Buildings Incentive Program*, or CBIP. For buildings passing the threshold of 25% improvement over MNECB requirements, this program provides incentives of two times the projected energy costs savings of the building, up to a maximum of $60,000 CAD. More than 1,100 projects are now enrolled in the program and it is well received by the industry. For all the success of CBIP, however, the fact remains that to extend the program to, say, 25% of the new building production would not be feasible because of the total costs involved.

Another national Canadian program uses financial support at a more strategic level. The *Energy Innovators Initiative* was launched in 1992, and is intended to influence eight strategic sectors in the industry by providing financial support to large organizations that own very large buildings or a large number of similar buildings. The program engages corporations at the CEO level through an agreement that provides support for the development of a corporate-wide energy efficiency strategy, and also pays for part of the cost specific performance improvements in a pilot building that can be replicated in other similar buildings later. This approach is a very effective way of changing the industry, since the targeted major organizations have considerable influence in their own sector. Over the past three years, about $ 9.2 million CAD was provided to 52 organizations, resulting in an aggregate CO_2 reduction of 175 kt per year.

The *Federal Buildings Initiative* (FBI) applies the principle of energy performance contracting to buildings owned by the Federal government. In the performance contracting approach, specialized energy companies estimate the energy that may be saved in existing buildings through the upgrading of lighting, the building envelope, equipment and other energy-consuming elements. The contractor finances the work and is repaid through savings in energy costs. The FBI program uses the approach in government buildings, and has been operational since 1991. The current program emphasis is on the reduction of energy consumption, and on the use of "green" energy sources. Some 70 contracts are in place, covering about 6,500 buildings that yield an annual energy cost saving of about CAD $26 million.

The question remaining is what measure(s) might be implemented in addition to the existing repertoire of programs, that would move all or most of the industry players to reach significantly higher performance levels, and in a broader range of performance issues than just energy.

In the field of commercial building, developers and owners are very sensitive to market signals, and if measures could be developed to *affect market demand* in the right direction, they would certainly pay close attention. The first part of a solution is to convince actors on the demand side (investors and tenants) of the advantages and need for improved energy performance and reduced emissions. This will be an on-going matter of information and education, which will not be dealt with here.

The second part of a market demand solution is relevant, however. The fact is that even those investors and tenants who are already convinced about the need for high performance, do not generally possess the knowledge to define their needs in a clear way. In fact, even building professionals disagree on the exact meaning of performance, so it is not surprising that non-specialists are in an even worse position. It is clear that we need to develop mechanisms, to allow users to differentiate between buildings of varying performance levels. In other words, if an investor or tenant wants to buy or rent a high-performance building, then we must give him a way of identifying which buildings meet his needs. Methods and software (which we refer to as "tools") for performance assessment and labelling can fill this need.

B. A Closer View of Two Programs

The commercial buildings industry is driven almost exclusively by considerations of capital cost and return on investments. This fact, combined with the very low cost of energy during the 1990's, make it difficult to move the industry towards very high levels of energy performance.

Two programs from Natural Resources Canada have previously been mentioned as being of relevance. Highlights of each, as of March, 2002, include:

Program	C-2000 Program	CBIP Program
Number of projects to date	9 built or underway, 13 designed	1271 underway, 239 complete
Annual Budget	Approx. $200,000 CAD	Approx. $6 million CAD
Performance areas	Energy consumption Environmental Loadings Indoor environment Functionality	Energy consumption Greenhouse Gas emissions
Energy target	45%-50% better than MNECB	25% better than MNECB
Current incentive/support	Varies from $5k to $25 k	2 times annual predicted energy cost saving, up to $60 k
Comments	MNECB stands for the Model National Energy Code for Buildings	Average performance is 32.2% or 100 kWh/m^2 better than MNECB. Average GHG savings are 24.9 kg/m^2 per year.

Figure 1 Overview of Characteristics of C-2000 and CBIP Programs

The C-2000 Program

The C-2000 Program was designed in 1993 as a small demonstration of very high levels of performance. Even though it was aimed at a select group of clients known to have an interest in high performance, it was assumed that some level of financial incentive would be required to make the program a success. However, the extent of incentives required and the best point of intervention within the project development process was very much open to question.

C-2000 technical requirements cover energy performance[1], environmental impacts, indoor environment, functionality and a range of other related parameters[2]. It was therefore expected that incremental costs for design and construction would be substantial. After a preliminary analysis of current project costs and an informal survey of designers, provision was made for support of incremental costs in both the design and construction phase. Contributions were provided according to a sliding scale ranging from 7% in large projects to 12% in small projects.

The first two C-2000 projects received support according to this formula in the range of $400,000 to $750,000 CAD, and funding of this order of magnitude was also planned for subsequent projects. However, after the first six projects were designed and two of them had been completed, it was found that that incremental capital costs were less than expected, partly due to the fact that designers used less sophisticated

1 At the time, the energy requirement was 50% better than the ASHRAE 90.1 standard (the benchmark is now the Model National Energy Code for Buildings, MNECB). Both are North American standards for good practice.

2 C-2000 Program Requirements, N. Larsson Editor; Natural Resources Canada; Ottawa, October 1993, updated April 1996.

and expensive technologies than anticipated[3]. A careful investigation of the first two C-2000 projects constructed, Crestwood 8[4] and Green on the Grand[5], indicated that the marginal costs for both projects, including design and construction phases, was 7%-8% more than a conventional building, a rather modest increase. Even more interesting, the designers all agreed that application of the integrated design process required by the C-2000 program was the main reason why high levels of performance could still be reached. It also appeared that most of the benefit of intervention was achieved during the design process.

This turn of events led to changes in the C-2000 Program, so that financial and technical assistance was henceforth only provided for the design process, to cover costs such as the provision of a design facilitator and subject experts, energy simulations, and extra design time for the core design team. The C-2000 process is now called the *Integrated Design Process* (IDP), and most project interventions are now focused on providing advice on the design process at the very early stage. Over 10 projects have been constructed on this basis, and all have achieved the C-2000 performance requirements, or have come very close, and capital costs have been either slightly above or slightly below base budgets.. The most hopeful sign that the IDP approach is taking root is that several owners have subsequently used the same process for buildings that have not benefitted from any subsidy.

Specifically, the following C-2000 requirements have proven to be important:

· Inter-disciplinary work between architects, engineers and operations people right from the beginning of the design process;

· Discussion of the relative importance of various performance issues and the establishment of a consensus on this matter between client and designers;

· The provision of a Design Facilitator, to raise performance issues throughout the process and to bring specialized knowledge to the table;

· The provision of other specialists, e.g. for daylighting, thermal storage etc., for very short consultations by the design team during the early design stage;

· A clear articulation of performance targets and strategies, to be updated throughout the process;

· The use of energy simulations to provide relatively objective information on a key aspect of performance

· Documentation of major steps and issues raised in the process.

Simple software design support tools have been produced to help design teams enrolled in the C-2000 program. One outlines generic design steps and provides a simple way for designers to record their performance targets and strategies; another facilities the task of having the client and design team reach a consensus on the relative importance of various issues. The C-2000 IDP process[6] is now being used as a model for development of a generic international model, by Task 23 of the International Energy Agency, and

3 The conservative preferences of designers is based primarily on their perception that they might face legal liability problems if they use exotic and unproven technologies.
4 Technical Report on Bentall Corporation Crestwood 8 C-2000 Building, April 1996, CETC, Natural Resources Canada.
5 Technical Report on Green on the Grand C-2000 Building, April 1996, CETC, Natural Resources Canada.
6 See Appendix 2 for a graphic representation of the IDP process

discussions are underway with the Royal Architectural Institute of Canada (RAIC) to see if the process can be accepted as an alternative form of delivery of professional services.

The Commercial Buildings Incentive Program (CBIP)

In 1997, it was decided to launch a larger national program to move the industry towards energy efficiency. Based on the lessons learned in C-2000, it was decided to focus the financial incentives of new CBIP program on providing incremental costs for the design process. However, several changes in approach were necessary for a program intended to be delivered to a large number of clients on a "hands-off" basis. This meant primarily that the program had to be simplified so that customized support would not be necessary. Specifically, this resulted in a narrowing of objectives of CBIP to energy only and a reduction of required performance threshold to a 25% improvement over the MNECB, rather than the 50% required for C-2000. However, the philosophy of placing emphasis on supporting the design process only was retained[7].

The funding available for the CBIP Program was established as two times the predicted annual energy costs, with a maximum incentive level of $60,000. An analysis of preliminary results in the CBIP Program presented in *Advanced Buildings Newsletter*[8], showed that, as of the Fall of 1998, typical CBIP projects were receiving funding in the range of $35,000, because their performance and/or size did not enable them to reach the maximum amount. The level of typical incentive payments has increased considerably during the last year because of increasing fuel prices.

The CBIP Program has been well received, as a 1999 survey of 35 owners indicated[9]. Respondents indicated their estimates of changes in design time, design cost and capital cost, all compared to the buildings they normally construct. The estimates indicate only a marginal increase in design time and cost, while the estimate of capital cost increase was 6.2%, relatively modest considering the on-going energy savings costs. It must be recognized that estimates of design time and cost variances are bound to be relatively crude (respondents indicated an average estimate of error range to be +/- 10%); but the important thing is that 33 of 35 respondents said that they would use the program again.

As of November 2002, 1271 Expressions of Interest had been filed, and 239 buildings had fulfilled the performance requirements and received a total of $11.9 million in incentives. Owners currently report average predicted operating cost savings of about $3.62 CAD per m^2, relative to MNECB reference buildings. Through the life of the program, a cumulative total of about 36,300 tonnes of GHG emissions have been saved.

It should also be noted that the C-2000 and CBIP Programs are often combined, so that almost all new C-2000 Projects also participate in the CBIP Program. Current C-2000 projects currently receive total financial assistance in the range of $5,000 to $25,000 during the design process only, a considerable reduction from

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7 *Energy Efficiency Programs for Commercial Buildings: Summary of Discussions*, for Natural Resources Canada, by Ron Robinson, ARC Applied Research Consultants, October 1997, Natural Resources Canada, NG096

8 Preliminary Survey of the Commercial Buildings Incentive Program, Rich Janecky and Nils Larsson, *Advanced Buildings Newsletter* Number 22, September 1999, Green Building Information Council, Ottawa.

9 See Appendix 1

past support levels. However, the combination of programs results in customized support and a total maximum available financial support of up to $80,000 or $90,000 for a small number of projects each year.

Recently a third element has been added to the program mix. The *Renewable Energy Deployment Initiative* (REDI) has been established by NRCan to promote the adoption of renewable technologies, and program staff has developed software that provides an assessment of the technical and economic potential for renewable energy technologies. Both C-2000 and CBIP staff are now encouraging consideration of renewables at an early stage in their projects.

C. Performance Assessment and Labeling Systems

During the last ten years considerable research has been focused on the development of systems to assess the environmental performance of buildings. Several of these systems have gone the next step, to result in a labelling system that indicates clearly the building's approximate performance to end users. It is best to say "approximate", since building performance includes many factors, only some of which are measurable in an exact sense.

Existing assessment and labeling programs

The best-known existing system is undoubtedly the *Building Research Establishment Environmental Assessment Method* (BREEAM), developed by BRE and private-sector researchers in the U.K. This system provides performance labels suitable for marketing purposes, and has captured around 15% to 20% of the new office building market in the U.K. A spin-off system, BREEAM Canada, has been adapted to Canadian conditions, and a North American version is now being developed. Meanwhile, the LEED system has been developed in U.S.A. and is now being implemented by the US Green Building Council, with strong support from U.S. government agencies and private-sector organizations. Several other systems (largely inspired by BREEAM) are in various stages of development in Scandinavia, Hong Kong and elsewhere. There are also more specialized systems of interest that are more closely tied to Life Cycle Assessment (LCA), including ECO QUANTUM (Netherlands), ECO-PRO (Germany), EQUER (France) and Athena (Canada).

Why is there so much interest in this area? The main reason appears to be that researchers and government agencies are viewing performance rating and labelling systems as one of the best methods of moving the performance benchmarks in the marketplace towards a higher level of performance. There is a growing realization that a major jump in performance levels, at least in market economies, will depend on changes in market demand, and that such change cannot occur until building investors and tenants have access to a relatively simple method that allows them to identify buildings that perform to a higher standard.

The advantages of having a global standard for building performance assessment and labelling cannot be over-emphasized. If meaningful information about performance is to be exchanged between countries, then a uniform definition of performance parameters must be developed, even if the calculation tools providing data on, for example, energy consumption and emissions, vary between countries. Further, the rapid growth of global corporations, and their desire to work to a common standard, give this work a significant commercial importance in the medium term.

The Green Building Challenge Process

Canada is currently leading a process called Green Building Challenge (GBC), a consortium of fifteen to twenty countries that are developing and testing a new environmental performance assessment system. The GBC project is an attempt to develop a second-generation assessment system; one that is designed from the outset to reflect the very different priorities, technologies, building traditions and even cultural values that exist in various regions and countries. In order to use the system, national teams must first adjust the values and weightings embedded in the system, thereby assuring results that are relevant to local conditions. The direct output of this process will be primarily at the level of R & D; specifically, a thorough understanding of issues involved in designing such a system, as well as a continuing exchange of ideas on the subject by the best researchers in the field. However, public- and private-sector organizations will be encouraged to use the results to develop a new generation of commercial labelling systems, and this is expected to have positive practical results in the near term for industry applications in Korea, Hong Kong, Canada, Japan and several other countries. Those European countries that are already developing their own systems are using the GBC process to exchange ideas and to improve their own systems, and GBC has already influenced the recent version of BREEAM ’98.

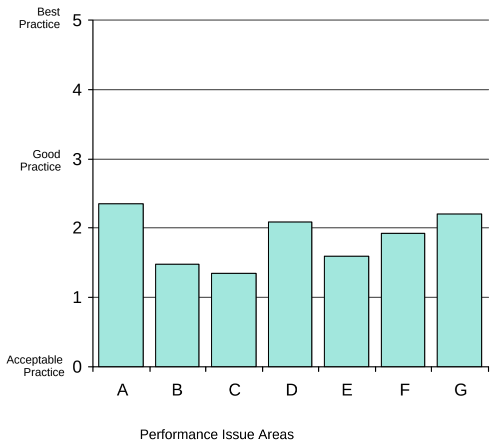
The project has consisted of three stages to date: an initial two-year process, which culminated in a major international event in Vancouver in October 1998; a second two-year process of development, the results of were displayed and reviewed at the SB2000 conference in Maastricht, the Netherlands, in October 2000, and a recent phase that culminated in SB02 in Oslo, in September 2002. Attendance at these events has climbed steadily, and more than 1000 delegates attended SB02. Each phase of research and development consists of two technical meetings per year, followed by a seminar to allow local professionals and academics to share in the work. The next SB Conference will be held in Tokyo, in September, 2005.

The assessment framework has been produced in the form of software (GBTool) which facilitates a full description of the building and its performance, and also allows users to carry out the assessments relative to regional benchmarks. Participating national teams test the assessment system on case study buildings in each country.

The GBC process was initiated and led by Natural Resources Canada during the 1996-2000 period. Although some direct financial support was provided by Canada to national teams during the first phase, Canadian contributions were limited to central coordination and system development during the second phase. Thus, each participating country is now expected to finance its own participation in meetings and for testing the system at home. As of January 2001, a new organization, the *International Initiative for a Sustainable Built Environment* (iiSBE), took over international management and development of GBC. The organization is being assisted in its work by contributions from Natural Resources Canada, the U.S. DOE, the Japan Ministry of Land, Infrastructure and Transport, and the Sustainable Energy Authority of Victoria (Australia).

GBTool 2005		Predicted performance results based on information available during Design Phase	
English Interface	Megaplex Project, Spain	Select relevant life-cycle phase in blue box at right	**Design Phase**

Relative Performance Results



Design Phase scores indicate Potential Performance as predicted by an assessment of building features and plans for construction and operation that are developed during the design process.

Key Facts About This Project

Assumed life span is set at 75 years	Amortization rate for embodied energy of existing materials is set at 2.5 percent.		
Default GBTool weights are used	47 percent of an existing structure is being re-used; this is 45 percent of the total project area.		
With current context and building data, the number of active low-level parameters is:	**80**	Max. potential low-level parameters:	**93**
The number of low-level mandatory parameters with a score of less than 3 is:	**5**	Active low-level mandatory parameters:	**14**

	To see a full list of issues go to the Issues worksheet; to alter weights, go to the Weights worksheets.	Active Weights	Weighted scores
A	Site Selection, Project Planning and Development	10%	**2.3**
B	Energy and Resource Consumption	25%	**1.5**
C	Environmental Loadings	25%	**1.3**
D	Indoor Environmental Quality	15%	**2.1**
E	Functionality and Controllability of Building Systems	5%	**1.6**
F	Long-Term Performance	10%	**1.9**
G	Social and Economic aspects	10%	**2.2**
	Total weighted building score		**1.7**

Absolute Performance Results

		By area	By area & occupancy	
1	Total net consumption of primary embodied energy, GJ	2.1 GJ/m2	0.5	GJ/m^2*maph
2	Net annualized consumption of primary embodied energy, MJ / year	28 MJ/m2	6	MJ/m^2*maph
3	Net annual consumption of delivered energy for building operations, MJ / year	81 MJ/m2	18	MJ/m^2*maph
4	Net annual consumption of primary non-renewable energy for building operations, MJ / yr.	88 MJ/m2	19	MJ/m^2*maph
5	Net annualized primary embodied energy and annual operating primary energy, MJ / year	116 MJ/m2	25	MJ/m^2*maph
6	Total renewable energy used for operations, MJ / year	8.3 MJ/m2	1.8	MJ/m^2*maph
7	Net annual consumption of potable water for building operations, m3 / year	0.6 m3 / m2	0.1	m^3/m^2*maph
8	Annual use of grey water and rainwater for building operations, m3 / year	0.05 m3 / m2	0.0	m^3/m^2*maph
9	Net annual GHG emissions from building operations, kg. CO2 equivalent per year	66 kg./m2	14	kg/m^2*maph
10	Swing range of temperature in naturally ventilated primary occupancy areas for more than 90% of occupied hours, deg. C	2.6 deg. C		
11	Proportion of gross area of existing structure(s) re-used in the new project, percent	47 percent		
12	Proportion of gross area of project provided by re-use of existing structure(s), percent	44.9 percent		

Figure 2 Results of a GBC assessment, showing absolute performance indicators in the top table and relative performance bar charts below.

Assessment and labeling programs in Canada

The description of the very active GBC process might lead to the conclusion that the GBTool system will be implemented in Canada. This is not the case, because of a variety of historical and geographic factors. First, a Canadian version of BREEAM was developed in the 1990's, and a successor system, BREEAM GreenLeaf, is used by several government departments and by the Canadian Hotel Association. The firm responsible for these systems has now developed a web-based system called Green Globes.

A second important factor is the unique situation of the small Canadian industry, adjacent to the huge U.S. market. Many would argue that the building industry is a North American one, at least in some vital sectors.

In any case, developments in the U.S. have a major impact on the Canadian industry. A case in point is the LEED assessment program[10], developed by the U.S. Green Building Council (USGBC). This program is enjoying a very rapid growth rate in the U.S., and many Canadian professionals are pressing for its delivery in Canada by a Canadian organization, as an alternative to joining the U.S. organizations. Towards this end, several governments in British Columbia paid for the development of a LEED version suited to BC conditions, and a group of professionals in British Columbia have founded a Canadian Green Building Council. Meanwhile, two federal departments and a gas utility funded the development of Canadian version of LEED, developed by the Athena Institute[11]. How quickly or to what extent the LEED system grows in Canada is not yet clear, but it is certain to have a major impact.

D. Defining Performance

We must now define the type of performance improvements that are required to make buildings more "green". Beyond the obvious issue of energy consumption and GHG emissions, other factors are normally included in a performance framework. The work of IEA Annex 31 and the international Green Building Challenge (GBC) process provide useful results for this analysis. Most of the information provided in this section derives from the GBC process.

The GBC framework includes criteria for Context factors (not rated), Resource Consumption, Environmental Loadings, Indoor Environmental Quality, Service Quality, Economics and Management. The framework follows an approach used in many other systems; to cover a broad range of performance issues in order to make it more relevant to the industry. Advances in all of these issue areas have also been shown in other assessment systems to be a necessary part of the solution, if they are to be accepted by the industry.

There is a consensus emerging amongst researchers as to the nature and exact definition of the issue areas outlined above. This may lead to the impression that there is also a consensus on the range of criteria that should be included in a working system, which is far from true. Within the GBC, for example, opinions have ranged across the spectrum, from those who would like to see only a core set of green issues included, such as Resource Consumption and Environmental Loadings.

The current assessment parameters included in GBC now include the following issues:

- Context Factors (not rated)
- Energy and Resource Consumption (non-renewable energy, land, water, materials)
- Environmental Loadings (greenhouse gas emissions, air pollution, ozone depletion, solid waste, liquid waste, effects on adjacent properties)
- Indoor Environmental Quality (air quality, thermal comfort, daylighting, lighting, acoustics,)
- Functionality
- Long-term performance
- Social and Economic Factors

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[10] See www.usgbc.org

[11] The reports can be downloaded from <www.athenasmi.org>

The current phase of work within the GBC process will extend to 2005, and the focus is on reviewing and improving the methodology, including the boundaries of the framework, and the development of better methods to establish indicators, weightings and benchmarks. The focus is now on the development of a new software tool, one that will easier and quicker to use, while providing results of sufficient detail.

Performance targets and Regional Variation

The previous section has outlined the type of system that may be helpful in increasing the market demand for high-performance buildings. However, such systems need specific performance targets to be meaningful.

The experience of all system developers has clearly shown that the relative importance of performance issues varies greatly from region to region. This is not just a matter of climate and material availability, but also links to issues of building traditions, cultural and sociology. For example, modern office buildings in Europe are often built with narrow floor plates (distance between exterior walls on a typical floor) and with natural ventilation, whereas their North American cousins tend to have very deep floor plates, sealed windows and full mechanical air conditioning. Some of this can be attributed to climate - for example, summertime relative humidity tends to be higher in continental N.A. regions relative to coastal European ones. However, it also reflects a much stronger preference in Europe for daylighting (which needs narrow floor plates) and for natural ventilation. It also reflects a willingness of office workers in some European regions to willingly tolerate more deviations from a temperature and RH comfort zone. It must also be noted that Europeans are generally willing to spend more on their buildings than are North Americans. This has a major impact on the expectations for building performance that again affects the way that it will be assessed.

To give an example, we could compare two new office buildings, one Canadian and the other Swiss. The annual energy consumption (heating, cooling and electricity) for the Canadian might be 125 kWh/m^2, while the Swiss building would probably perform better, say 90 or 100 kWh/m^2. These two different energy consumption figures mask a large number of interesting and relevant issues, with major environmental consequences. A short and partial list of examples includes:

· Strong preferences for natural daylighting leads to a narrower floor plate of the Swiss building and an emphasis on windows, exterior shading and light shelves to reduce glare. Given good lighting controls, this leads in turn to reduced use of electric lighting during the day, which reduces electrical consumption. On the other hand, the deeper floor plate (a more square shape) will give the Canadian building a shape that minimizes the surface area to volume ratio and hence makes it easier to optimize energy performance.

· Strong preferences for natural ventilation in Switzerland leads designers to use natural ventilation approaches, to the extent possible, while the North American tradition in office building design is to mechanical cooling and ventilation. A natural ventilation approach affects indoor air quality and thermal comfort, and workers in the two countries differ in their willingness to tolerate short periods of thermal discomfort.

· There will be differences in environmental impact, due to the fact that the Canadian building probably uses electricity generated by a mix of coal, hydro and nuclear sources, while the Swiss building probably obtains its electricity from generally "green" (e.g. low environmental impact) sources. Material sources will also greatly affect their embodied energy.

Do all the differences outlined above mean that the Canadian designer and builder are not as good as their Swiss counterparts? The answer is that both sides are bound by certain conditions and traditions that they have to work with, and a successful assessment system must allow local users to adjust scores through weightings, so that the different priorities can be respected in the results.

Environmental performance indicators

While regional values and differences are certainly important, the GBC process has shown that a need to make direct comparisons remains. Thus, a series of six "environmental performance indicators" have been added to supplement the relativistic assessments.

E. Improving the design process

The introduction to this paper noted that enabling measures, especially design support tools, could play a useful role in moving the industry towards higher standards of performance.

The design process is important because the initial design of a new or renovated building will largely determine, for better or for worse, the subsequent potential performance of the building over its service life. Building operators and users may degrade performance, but it is difficult for them to markedly improve the performance of a badly-designed building. Research and field experience has also shown that the greatest potential for performance improvement occurs very *early* in the design process. Current efforts are therefore largely focused on integrating the efforts of architects, engineers and others, and on providing guidance, training and support tools during the very early part of the design phase.

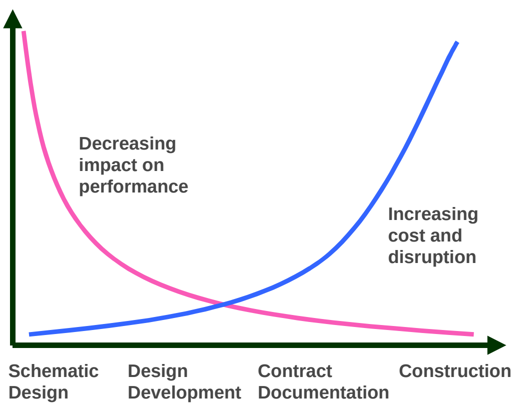


Figure 3 Graphic representation of Pareto Principle applied to intervention in the design process

Much of the work in this area is focused on technical calculation or simulation software, including tools to simulate energy performance, emissions, air quality and thermal performance. One of the areas of most rapid development is in the development of models to carry out life-cycle assessments (LCA), and there will soon be a series of such tools available to designers. The work of IEA Annex 31 has been important in identifying tools relevant to the energy aspects of building performance assessment systems, and the results of this Annex will soon become available.

There is also a high level of current interest in design tools to assist the effectiveness of the design process itself. Research in this area in Canada goes back 6 years, through the activities of the C-2000 demonstration program. The program managers were expecting that projects meeting the demanding performance criteria (including a 50% improvement in energy performance) would have to include a wide range of the latest technologies. In fact, while technologies were certainly up-to-date, all participants agreed that the most significant help in reaching the performance targets were the changes in design process required by the program. These included an integrated design process (architects and engineers working together from the beginning of the concept design stage), the provision of support specialists and the identification of performance targets by the team. These findings are now being formalized in the form of software support tools. One of these is a shortened version of the GBC tool intended for use in concept design stage performance assessment. The tool has been field tested in two projects to date with considerable success.

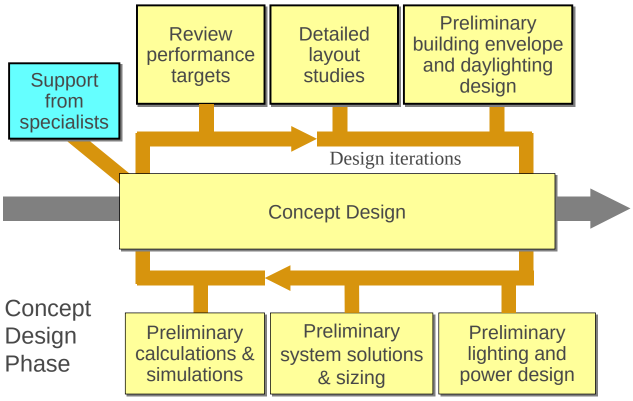


Figure 4 Graphical representation of part of the Integrated Design process in the C-2000 Program.

Canada is, of course, only one of the many countries with an interest in improving the design process. One group with an interest in integrated design is the U.S.-based Bild-IT organization, which is developing (in close cooperation with the IAI) a series of software tools to support integrated design within the HVAC industry. Task 23 of the International Energy Agency (IEA) is investigating the relationship between the design process and the adoption of active and passive solar technologies. More than 12 countries are involved in this Task, and existing design protocols are being investigated and a number of case studies documented. One product of the Task is a Multi-Criteria Decision-Making tool (MCDM-23) that is intended (as is C2k-A) for early performance assessments.

More effort is needed to develop support tools for renovation processes, and many researchers are now beginning to focus on this need. A barrier to rapid improvement in this area is that, while one can generalize about certain features of new building design, renovation projects tend to be unique. Nevertheless, there is progress, especially in cases where a significant stock of buildings share similar characteristics, such as post-war European housing, Chinese housing projects, or 1960's Canadian office buildings.

An evident need, from the practitioner's perspective, is to integrate and to simplify tools. This is, of course, at variance with the demand for tools to address an increasingly complex range of issues, but many researchers are now focusing on this problem through, for example, the ADELINE and *Building Design Advisor* platforms. In addition, the work of the *International Association for Interoperability* (IAI) is likely to result in major improvements in the ability of various software tools to exchange data with each other.

F. Regional and Local Considerations

The previous discussion has dealt with performance issues at a general level. Turning policies and programs into reality requires consideration of what implementation methods may be most effective.

At first glance it would appear that national measures, such as tax credits or national programs (the CBIP example), would require only a single and centralized point of control in a country. However, the process of building, requires consideration of climate, the site, locally-available building materials and products, local availability of skilled tradesmen, and local regulations. In contemporary terms, we may speak of very different building markets. Certainly we have found varied implementation patterns for C-2000 and CBIP in various regions of Canada, with widely different rates of program take-up and modes of application.

As we move more and more into green building, many new issues have become important, and most of these have an important regional or local component, such as information about:

- the type of regional energy sources and their emissions;
- specialist consultants in the region;
- materials and products available for re-use;
- embodied energy and emissions of materials and products in the region;
- detailed performance data on existing buildings in the region

It may be argued that information about all these issues could be gathered and retained at a national level, but the sheer volume of data, and the need to work closely with local industry representatives to gather it, would make such an approach unworkable. In addition, if a performance rating and labeling program is adopted, regional centers are required to train assessors, to undertake assessments and to issue labels.

All these factors indicate that regional or local building centers, operated on a non-for-profit basis, are likely to play a crucial role in the promotion of green building practices in the future.

G.Conclusions

Although programs have been developed to provide incentives for the industry to move towards high performance, experience shows that they are far more effective when the client is convinced that there will be a marketing advantage in following this path.

A building that has undergone a design process that results in a high level of energy efficiency is likely to be of higher quality, and will have lower operating and maintenance costs. Capital cost and design time increases are modest[12], and such buildings have been shown to attract desirable tenants. All these factors are very likely to combine to result in a higher long-term asset value[13].

For designers, use of the Integrated Design Process offers many engineers to become involved in the early design stage of buildings for the first time; and architects are learning valuable new skills. When this is combined with the incentives available, it is difficult to see any obstacles to widespread participation.

When labeling systems are widely available, more definitive proof of the importance of high performance will be at hand and poorly-performing buildings will hopefully become relics of the 20th Century.

政府和私营部门采取行动，提高建筑环境性能

尼尔森·拉森 （加拿大能源技术中心绿色建筑经理）

摘 要 提高建筑的环境性能，这是一个世界趋势，政府希望能减少使用稀少的资源，并降低空气污染物排放；业主们希望降低建筑的运行成本；开发商也注意到，购房者越来越重视室内空气品质及性能。围绕着这些目标，各国都采用了各式各样的措施。当然这些措施要取得实质性的进展，需要政府的介入、建筑从业人员（业主、设计、施工）之间的交流和不断创新的工作，才能向外界展示那些环境性能良好的建筑。

建筑环境性能评价和其他性能评价不同，举例来说，对于自动化的评价，只要看，是否在使用相对较少的制造工时，自动化程度得到提高就行。而建筑环境性能的评价却要考虑很多因素：其包括成千上万的组织结构，其建筑规模从大到小，其员工的技能水平和培训程度从最基本的合格到相当高的水平。相对其他物品，建筑要维持相当长的时间，因此，为了满足其长期的功能需求，还要考虑其是否能够适应当地文化氛围和本地的气候条件。并且，所有这些因素都要求结合建筑环境性能改进，提前周密考虑。

本文 ，将建筑环境性能因素中的规模大小考虑限定在那些有希望的受市场经济影响的大建筑方面（小的房子除外），并且，本文还讨论了对于新旧建筑，在其设计和建造阶段可以应用的具体措施，主要以加拿大的实际经验作为典型案例分析，侧重点放在其基本对策措施上。

12 *Incremental Costs in the C-2000 and CBIP Programs*; N. Larsson and J. Clark, March 2000, *Building Research and Information*.

Measuring Performance in sustainable-building design

Benson Lau – WSP Environmental

Abstract In recent years, the awareness and interest in eco-friendly building in China has increased. This is partly due to the central government's effort in promoting sustainable development, but the catalyst for the 'green shift' is mainly due to the energy shortage in the major cities of China.

In response to this problem, measures like limiting demand via pricing mechanism, introducing cooling limits and blackouts in the cities were introduced. All these measures to a degree can be effective, but one particular measure which has not been well identified and implemented is minimising energy demand through environmentally friendly building design.

Use WSP Environmental's two recent projects in China, this paper explains how environmental design can be carried out as an integral part of the design process and most important of all, how building performance can be measured.

Key Words Eco-building design；Energy Efficiency；Building performance assessment

Eco-building Architects –SRIBS in-house design team and P&T Architects and Engineer companies

Environmental Design and Engineering – WSP

可持续建筑设计措施

摘 要 最近几年中国对于生态建筑的关注程度逐渐提高。部分原因是由于政府在可持续发展方面的努力。但是“ 绿色推动 ”的主要原因是由于大城市中能源的缺乏。

通过价格来限制需求、限制空调冷量、灯火管制等措施来解决此问题。尽管这些措施在一定程度上是有效的，但是通过建筑环境设计，这种没有人注意特殊的措施，可以实现最小的能量使用。

通过 WSP 在中国的两个工程，本文解释了如何把环境分析作为设计阶段中的一部分进行实施并且如何实现建筑性能

关键词 生态建筑设计；能效；建筑性能评价

1. Introduction

In recent years, the awareness and interest in eco-friendly building design in China has increased. This is partly due to the central government's effort in promoting environmentally friendly design. But the catalyst for the 'green shift' is mainly due to the energy shortage in the major cities of China.

According to a recent article in the South China Morning Post, the Yangtze region expects massive power shortages this summer and the river delta cities have already hit by blackouts as authorities impose restrictions to conserve electricity for essentials. Shanghai and the provinces of Jiangsu and Zhejiang combined are expected to face an estimated shortfall of 10 million to 15 million kilowatts. The state media reported that overall, the mainland would have a shortage of 20 million kW in the second quarter and a shortage of 25 million to 30 million kW in the third quarter.

In response to this energy shortage, at a State Council meeting in the first week of June, Premier Wen Jiabao called for steps to ease the country's power shortage by slowing the economy and improving management to limit demand. Officials are also urging people to stop wearing suites and other formal attire in the hot summer months, so air-conditioners can be turned down and money saved. Other measures include limiting demand via pricing mechanisms, introducing cooling limits and blackouts in the cities.

All these measures, to a degree can be effective, but one particular measure which has not been well identified and implemented is minimising energy demand through environmentally friendly building design. WSP's recent joint project with the Shanghai Research Institute of Building Sciences (SRIBS) and the Hong Kong Joint User Building are two examples demonstrating how integrated environmental design approach can help designers design environmentally responsible buildings.

2. Project No. 1 SRIBS Eco-Office and Laboratory Building

2.1 Project Background

This project is a national level demonstration building comprising offices and laboratories for the Shanghai Research Institute of Building Science (SRIBS). The history of this project is unusual; WSP was commissioned to provide environmental design advice after the building foundation had started on site.

The building design was carried out by SRIBS in house architectural department. The building services and structural design were also designed by the in house engineering team with support from the Department of Building Science and Technology of Tsinghua University School of Architecture.

As a well established research institute, SRIBS has a young and energetic team comprising of scholars and engineers from different engineering disciplines. They are eager to acquire new knowledge in environmental design and willing to experiment with advanced environmental technologies.

Since this is a demonstration project, trial and error is part of the design process and experimentation on different renewable technologies will be carried on even after the building is occupied. The end goal of this project is to design a site specific natural ventilated and natural daylit office and laboratory building (Figure.1).

Figure 1   The proposed SRIBS eco-building in Shanghai (source: SRIBS)

2.2 Measuring Building Performance

Since the WSP team did not participate in the front end design, instead of re-doing the performance analysis already conducted by the SRIBS team, we identified the key areas where assistance is needed and agreed with the client to provide support on the environmental design review, daylighting and solar control analysis and environmental cost benefit analysis.

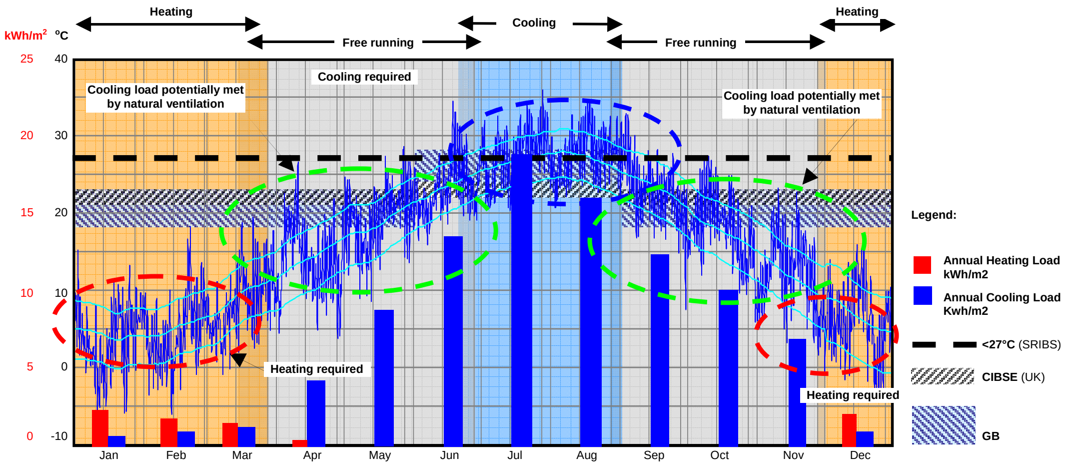
The climate of Shanghai is very different from that of London, as an external consultant, the first task for the WSP team to tackle is conducting a detailed site microclimate study to identify the environmental design opportunities and constraints. One important question we have to answer is whether natural ventilation is feasible under the Shanghai climate and if this is possible, when can this be introduce to the building.

2.2.1 Climate analysis

Shanghai has marked seasonal variations with summer season combining high temperature (up to 38ºC) and high relative humidity. The winter is cold and humid with temperature reaching -6ºC and relative humidity ranging from 30% to 100%. The prevailing wind mainly comes from south east in summer and north west in winter with wind speed varying from 2-4m/s.

Under such a humid context, developing a natural ventilation solution in the summer months is a challenge. Also setting a site specific environmental design criteria is another important task. With the help of the SRIBS team, the internal resultant temperature was set not to exceed 27ºC for more than 5% of the occupied office hours. In closed temperature controlled spaces such as laboratories and computer rooms, operational criteria were set by the SRIBS team.

Based on these criteria, it was identified that the cooling loads between March to mid-June and between August to December can potentially met by natural ventilation, thus substantial amount of energy for air-conditioning can be saved (Figure 2.1).



Seasonal Environmental Design Criteria. The histogram combines hourly ambient temperature data for Shanghai with monthly heating and cooling loads derived from WSP's thermal analysis.

Figure 2.2 The climatic analysis identifying the feasibility of natural ventilation

2.2.2 Climate analysis and Ventilation Strategy

To quantify the thermal performance of the building, WSP team conducted detail dynamic thermal analysis by using advanced simulation programme. The results of the analysis indicates that a mixed mode control strategy combining use of natural ventilation and mechanical cooling, where the mode selection is controlled through a centralised Building Management System is an appropriate environmental control strategy. Typically, natural ventilation would be used in times of the day and the year when cooling is required and the outside temperature is lower than the internal temperature. When this changes, the system would switch to mechanical cooling mode (Figure 2.3).

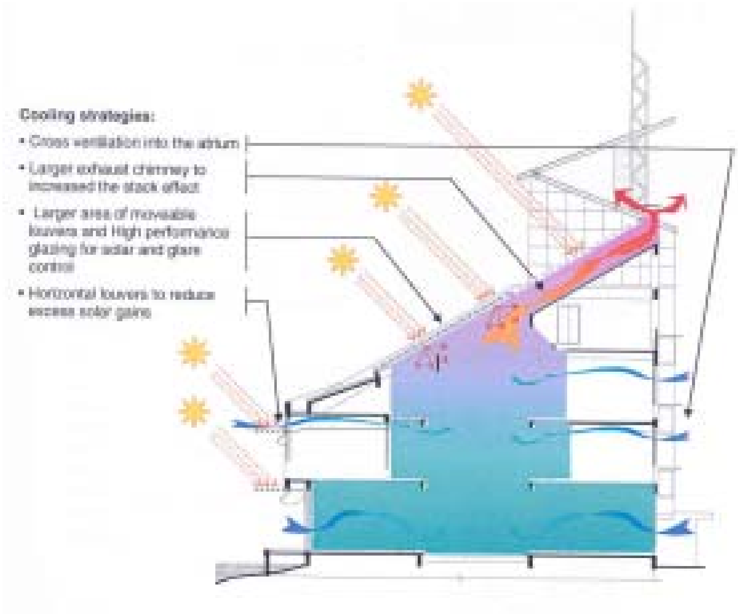


Figure 2.3 Schematic section showing the natural ventilation mode

2.2.3 Daylighting Performance Assessment

Another important aspect of the building performance analysis is the daylighting and visual comfort prediction. This is one of the areas that most building designers have not given enough attention to. Working closely with the SRIBS engineers, WSP team constructed a virtual daylighting model and carried out a detail daylighting and solar control study. The simulation results indicated that the internal atria coupled with properly sized openable windows and sun shade in the proposed building brings in adequate daylight even under overcast sky condition. As a result, the reliance on artificial lighting can be reduced and visual comfort can also be improved (Figure 2.4).

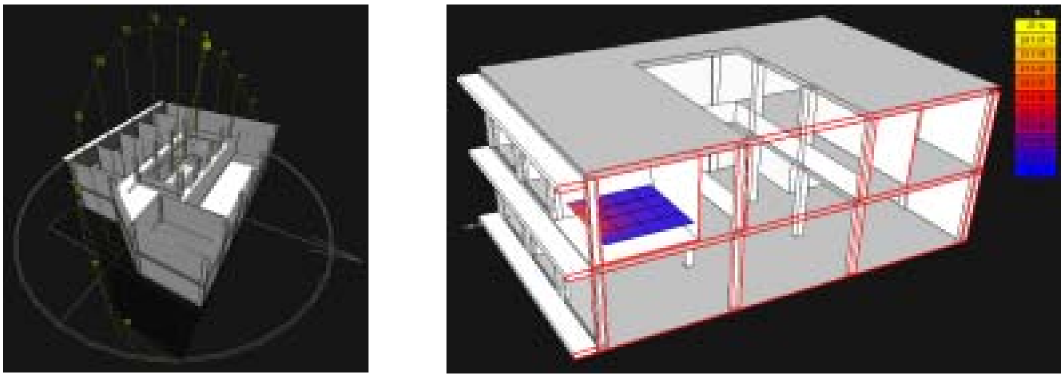


Figure 2.4 Daylighting performance analysis model

2.2.4 Environmental Cost Benefit Analysis

Apart from building performance prediction, environmental cost benefit analysis is an important component in integrated environmental design. This can inform the client the pay back period and help the client make sensible decision on the investment in renewable technology.

In order to have a realistic picture of the cost benefits, this study cannot be conducted by the WSP team alone and it has to be a joint effort because the local pricing has to be provided by the SRIBS team. The outcome of this study was that WSP team set up the basic environmental cost benefit analysis template and the SRIBS team filled in the blanks in the calculation sheets.

During the design process, we maintained close contact with the SRIBS team and conducted regular trips to Shanghai to exchange ideas and share knowledge. WSP team is committed to carry out Post Occupancy Evaluation to compare simulated results against real building performance when the project is completed.

2.3 Summary

Now this demonstration project is close to completion and the building will be occupied by the end of August, 2004. This will be one of the first naturally ventilated and natural daylit office buildings with integrated renewable technology in China (Figure 2.5).

Figure 2.5 Site photos showing the current progress of the SRIBS Eco-Building

As our first joint project with a local research institute in Shanghai, the iterative environmental design process is a valuable experience to the WSP team. Through this demonstration project, the two teams have learned from each other and a solid foundation has built up for future co-operation. The key lesson learnt from this project is that mutual respect and sharing of knowledge will contribute to mutual benefit, and never undermine the capability of your business partners in China.

3. Project No.2 Joint User Building in Rock Hill Street, Hong Kong

3.1 Project Background

This project is a joint bid led by P&T Architects and Engineers Ltd. WSP Environmental was commissioned as environmental consultant to carry out environmental design support to the design team. The proposed scheme is a mixed-use building accommodating various users and the owner of the building is the Architectural Service Department of Hong Kong.

The proposed building would have office space, exhibition galleries, multi-function rooms, youth hostel, Cyber centre, post office and car park. One of the key requirements in the design brief is to design an environmentally friendly building (Figure 3.1).

As an integral member of the bidding consortium, WSP team participated in the front-end conceptual development, providing advice on the thermal characteristics of the building envelope and to suggest strategies for natural ventilation, solar control, daylighting, and low energy cooling. The objectives of this specialist advice and analysis were:

· To assist with the design and refinement of the building envelope to achieve OTTV 18W/m^2 ^{o}C.

· To propose ways of achieving adequate natural ventilation to car park floors, terrace areas on floors 3 & 4 and bedrooms in the hostel.

· To propose and analyse alternative shading devices for the different elevations.

· To analyse the daylighting characteristics of the exhibition centre, post office, typical office, women's hostel, and typical multi-function room.

· To assess the thermal performance and predict the cooling load for the Cyber Centre (Floor 12)

· In addition, where appropriate, WSP Environmental have identified opportunities for the application of new technologies to achieve energy savings and to improve the internal environment (e.g. light/vent pipes and gravity cooling)

Figure 3.1 Exterior view of the proposed Hong Kong Joint User Building (source: P&T Architects and Engineers Ltd)

3.2 Measuring Building Performance

3.2.1 Site Microclimate Analysis

The location and orientation of the proposed building and its relationship to the surrounding topography and buildings have a significant impact on how the building responds to seasonal changes, and its resulting thermal performance. Detailed analysis has helped to refine the design proposal. This section sets out strategic issues.

Climate Analysis

Temperature

Winter

From mid November – mid April (5 months) the diurnal temperature variation is between approximately 10-25°C (Figure 3.2). This implies that most spaces could potentially be naturally ventilated during this period, although at upper levels (e.g. bedrooms in the hostel) this should be limited to prevent over cooling.

Summer

Between mid April and mid October the diurnal temperature variation is between approximately 25-36°C. Clearly natural ventilation is only possible at night (to the bedrooms) or during the day to spaces like the car parking floors, or large volume intermittently occupied spaces like the multifunction rooms (Floor 3) and exhibition space (Floor 3,4 and 5), provided supplementary cooling is available. The supplementary cooling to these areas could be provided in the form of 'Gravity' cooling walls, using chilled water cooling coils

Prevailing Wind

The prevailing easterly winds will tend to induce a positive pressure on the east elevation. This can be exploited to drive air through the naturally ventilated parts of the building. Upper levels will experience higher average wind speeds, which should be encouraged through the building in summer, but baffled in winter.

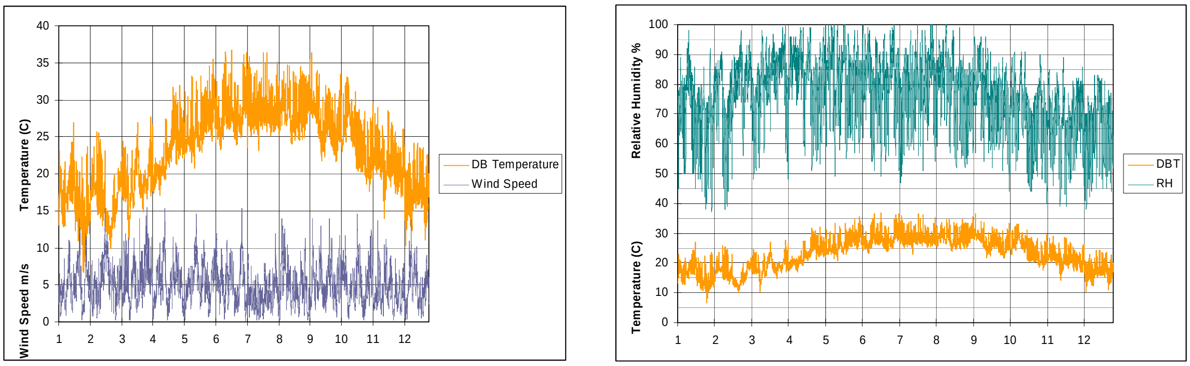


Figure 3.2 Hong Kong climatic data

Noise

An acoustic assessment of the site has revealed that traffic noise will exceed 20dB background sound level in most areas. This makes natural ventilation inappropriate in meeting and office areas.

Sun path

A model of the preliminary proposal was tested on a heliodon, and the solar exposure of different elevations was analysed for the Summer Solstice, Equinox and Winter Solstice. Obviously the sun path affects the east elevation most significantly (Figure 3.3) and the provision of external solar shading which is effective in reducing solar gain but does not obstruct views too much, is a challenge. Fixed horizontal shading with a cut off angle of 60° will restrict direct solar radiation after 10 am, and early morning glare (7.00 – 10.00 am) will be resolved with internal blinds.

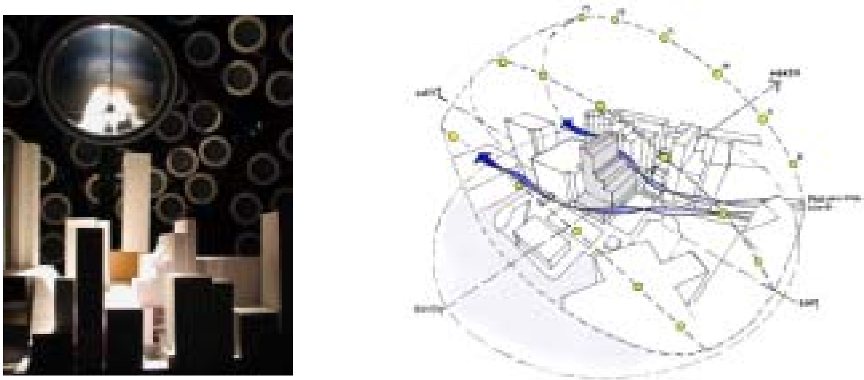


Figure 3.3 Sunlight study in artificial sky and annual sun paths in Hong Kong

Solar Radiation

Sun shading will be effective in reducing direct solar gain. However, as the solar radiation plot reveals (Figure 3.4), diffuse radiation is very significant, particularly in the summer months. The shading coefficient of the glazing is therefore very significant in reducing diffuse radiation and limiting cooling load. The combination of shading and glazing characteristics has a fundamental influence on the thermal performance of the building and the OTTV.

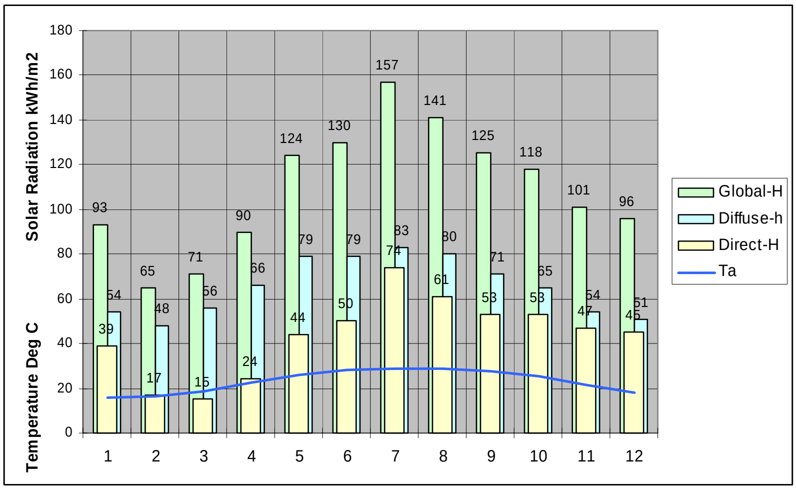


Figure 3.4 Annual global and diffuse solar radiation in Hong Kong

3.2.2 Environmental Design Strategy

3.2.2.1 Natural Ventilation Options

3rd Floor Exhibition and Terrace/Circulation

Ventilation of the open terrace area can be promoted by provision of a bulkhead over the WCs, allowing air to pass through and leave the building on the north side (Figure 3.3). Air from this passage could also be introduced to the Exhibition area, and exhausted via the high level roof glazing on the north side (Section C-C).

4th Floor Multi-Function Rooms and Terrace/Circulation

The ventilation of the circulation area can be dealt with in a similar way to Floor 3, by the provision of a bulkhead over the WCs. (Figure 3.5). There is also an opportunity to achieve cross ventilation from north to south side (adjacent to car park). The multifunction rooms could be naturally ventilated in winter via high and low level opening vents, but both spaces would require supplementary cooling in summer. We have suggested that this could be achieved by means of a 'Gravity' wall cooling system as supplied by HVAC Nederland (see Section A-A, B-B).

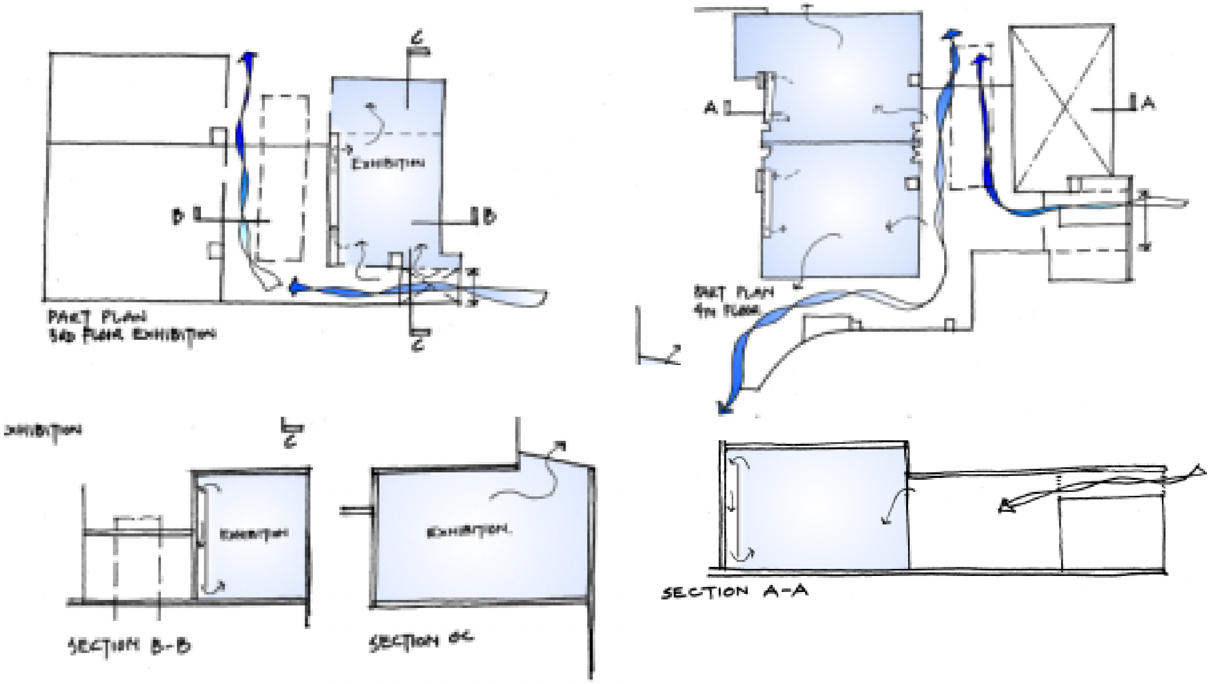


Figure 3.5 Environmental design sketches showing the ventilation strategy of the exhibition hall and multi-functional rooms

Floors 15 and 16 Bedrooms

The east facing bedrooms are shallow in plan and can be naturally ventilated from one side. In winter this could be trickle ventilation, but in summer would require high and low level vents within the façade to achieve adequate ventilation. The corridor at floors 15 + 16 can be naturally cross ventilated, induced by pressure differences between North and South facades. This requires either operable or fixed ventilators within the North and South glazed elevations at these levels. The corridor will be rather dark and gloomy in the centre of the plan, but could be enlivened by the introduction of 4 'light/vent pipes' (Figure 3.6), delivering diffuse daylight from the roof and providing enhanced natural ventilation to the central four bedrooms.

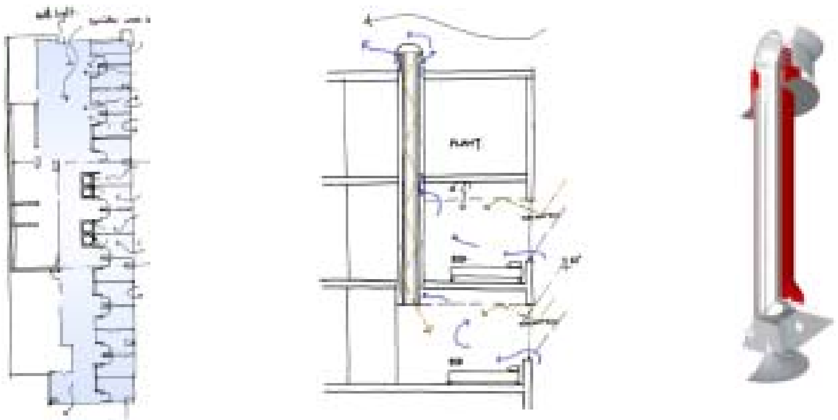


Figure 3.6 Light / Vent pipes introduced to the hostel floors for daylight and natural ventilation

3.2.2.2 Shading Options

Preliminary analysis revealed that the main east elevation is most vulnerable to solar gain.

However, it is extremely difficult to prevent any direct gain from low altitude sun. At the Equinox the sun rises from due east at 6 am to the zenith (70º altitude) at noon. The design decision to make is what solar cut-off angle will in conjunction with the glazing shading coefficient, achieve an OTTV of 18W/m² ºC or less. These options are illustrated in Sketches A-E (Figure 3.7). The use of the sunshade as light shelf has the added benefit of smoothing daylight distribution along the depth of the room. Thus, a significant improvement of the Uniformity Ratio is achieved and adaptation stress is reduced. Option B has been developed into the sunshade shown in Sketch F, which acts both as solar control device and light shelf redirecting daylight deep into the building.

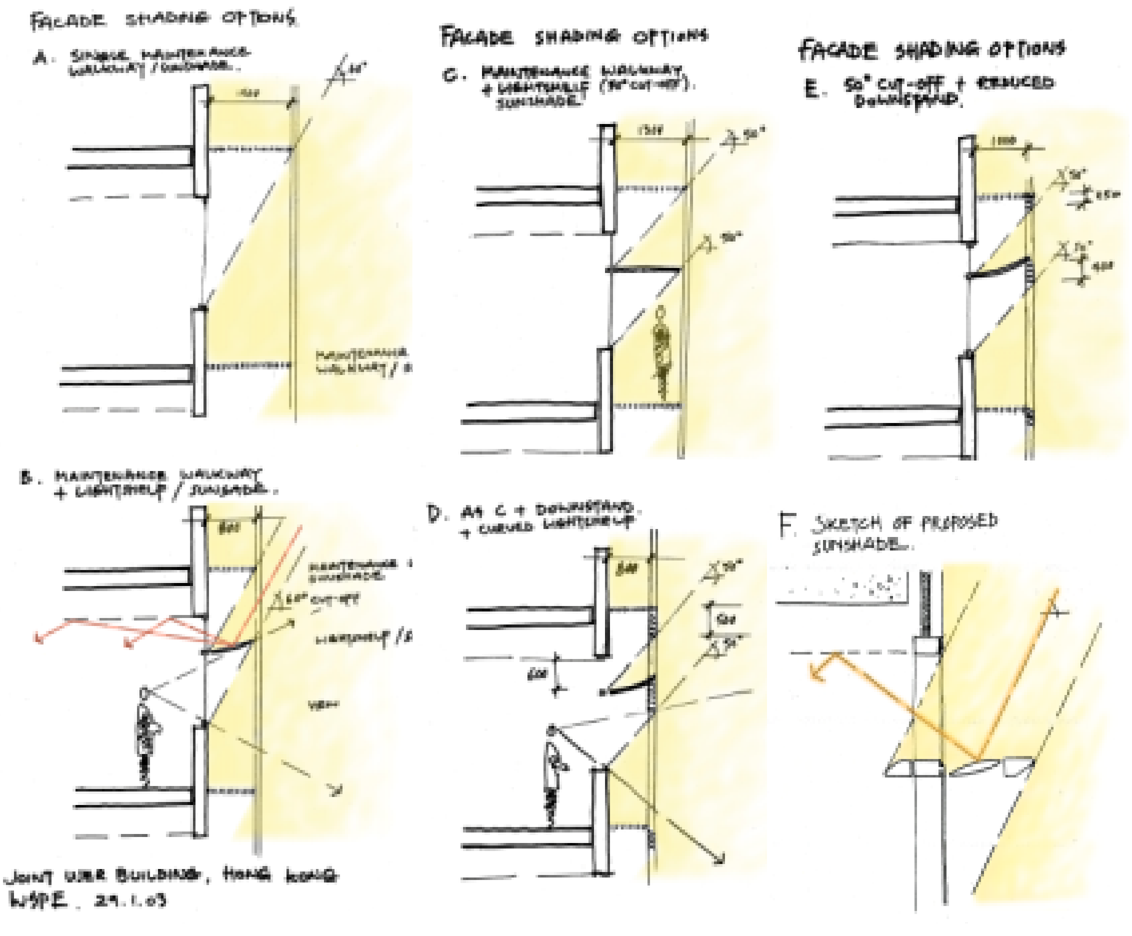


Figure 3.7 Environmental design sketches for the shading options

3.2.2.3 Daylighting Performance Assessment

A comparison of the impact of the Architectural Services Department (ASD) schematic building and the proposed building by P & T Architects in terms of overshadowing to adjacent buildings along Rock Hill Street, was investigated by computer modelling (Figure 3.8). The results revealed that due to the stepping profile of the proposed building, this achieves 12% reduction in annual overshadowing percentage. This analysis takes into account the south facades of the buildings along Rock Hill Street. The Annual overshadowing percentage to the adjacent buildings along Rock Hill Street from ASD and P & T building is as follows:

Without any building on site: 28.6%

ASD building: 48.5%

P & T building: 35.8%

The differences can be examined graphically by means of the stereographic diagrams (dark areas represent the area of visible sky arranged for a number of locations along Rock Hill Street) . This shows that the P & T building obstructs the sky significantly less than the ASD building (Figure 3.9).

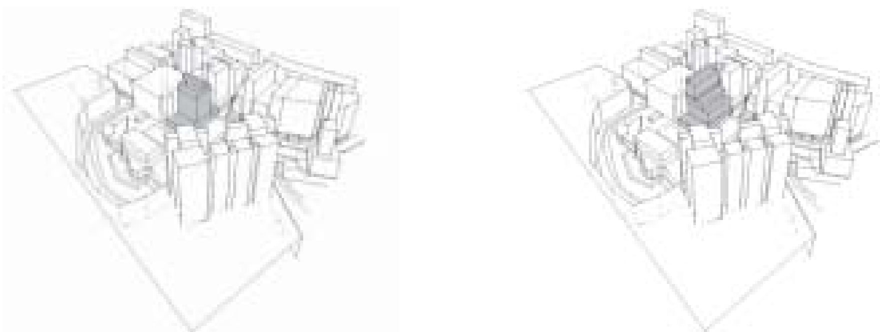


Figure 3.8 ASD Schematic Building Block and P&T Architect's proposal

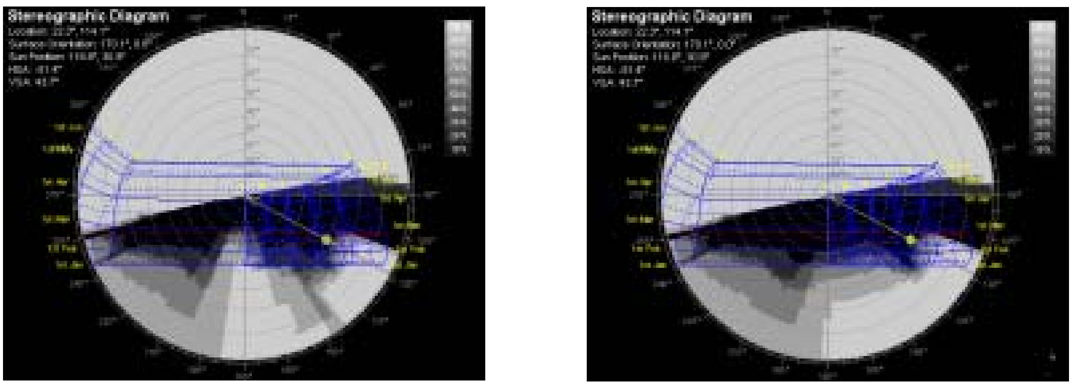


Figure 3.9 Stereographic Diagram showing the visible sky from ASD Schematic Building Block and P&T Architect's proposal

Daylighting Study - Post Office (Ground Floor)

A computer model of the proposed building plus the surrounding buildings was constructed and tested using specialist software, which accounts for the impact of surrounding buildings on daylight within the building.

The Post Office is located on the ground floor on the north side of the building. The daylight factor distribution plot shows that the areas adjacent to Rock Hill Street are well daylit, but this drops rapidly deeper into the plan (Figure 4.0). This suggests that control of the artificial lighting should be zoned and linked to the available daylight to minimise energy use. The average daylight factor is 3.6% which is less than the 5% recommended by the UK CIBSE for well lit spaces. Nevertheless, with daylight linked lighting controls, energy use for artificial lighting can be minimised.

Daylighting Study - Exhibition Corner

The Daylighting performance simulation results for the Exhibition Corner is shown in Figure 4.1. As we have identified in the Solar Exposure study by using Heliodon, both the east facade and the skylight need to be shaded to reduce the solar gain, especially in the summer months. We have introduced 2x600mm deep horizontal shade to the east facade (one on the top the Exhibition Corner and the other one in the middle of the facade in alignment with the glazing joint indicated in the East Elevation).

Without the sun shading device and the louvre on top of the skylight, the Daylight Factor (DF) is 6.3%, which indicates that this space is very well daylit and artificial lighting is not required whole year round (but task lighting is required for highlighting the exhibits).

However the fully glazed + unshaded east facade will have significant adverse effect on the OTTV value. By introducing the two horizontal shades and louver on top of the skylight, the DF is reduced to 5.5% which is still higher the 5% DF recommended by the CIBSE for a well daylit space and there is an added benefit of slightly reducing the OTTV value and improving the visual comfort in the exhibition hall.

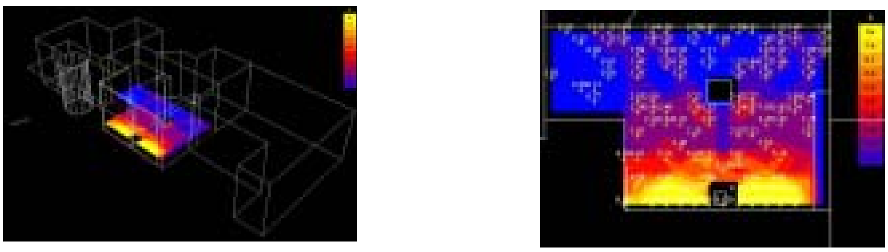


Figure 4.0 Daylighting performance assessment of the Post Office

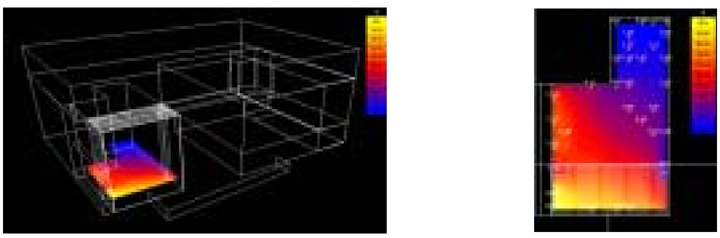


Figure 4.1 Daylighting performance assessment of the Exhibition Corner

3.2.2.4 Thermal Performance Analysis

A thermal analysis was conducted to quantify the benefit of the shading strategy proposed (see sketch F in Figure 3.7). This was carried out by dynamic thermal simulation. Dynamic thermal modelling allows an accurate treatment of the thermal effects of solar energy through the building fabric, and enables a detailed study of the effect of materials, geometry, construction and HVAC systems on performance.

The weather data used for this calculation is Hong Kong Kingspark, obtained from Meteonorm version 4 Nov 1999. The analysis was centred on the Super Cyber Centre on the 12th floor. This space was subdivided in three zones, north, central and south, as indicated in the zone diagram in Figure 4.0.

Figure 4.2 Dynamic thermal analysis model and the zoning diagram

Assumptions:

A 3D thermal model was constructed based on the architect’s drawings. The envelope specification was assumed as the façade details provided by ARUP. The internal design conditions followed the criteria outlined in part V, section 2 of the Employers Requirements:

Summer Internal air condition: 25.5°C d.b. 54%RH

Winter Internal air condition: 20.0°C d.b. 50%RH

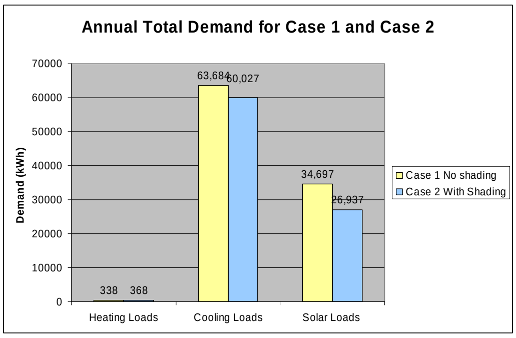
The Internal gains were based on typical office usage: lighting 15W/m2, equipment 20W/m2, occupants, 10W/m2, with an infiltration rate of 0.5ac/h.

Case 1 assumes all the glazing and envelope specification as described in the OTTV calculation, but excludes the sun shading devices. Case 2 includes sun shading.

Results:

The chart on the left of Figure 4.3 shows the total annual loads for the zones analysed. This chart shows the annual energy demand for heating and cooling in kWh, and quantifies the solar loads for the whole year. The chart on the right of Figure 4.3 shows the frequency of Dry Resultant Temperatures for the whole year.

The results show the benefit of shading by a reduction of 6% of the cooling loads and a reduction of 22% of the solar loads. The results also indicate a very small heating load (ie. heating is not required) and the Dry Resultant Temperatures are significantly reduced by the use of external shading. The resultant temperature is a more accurate indicator of occupant comfort than the air temperature, as it combines the radiant effect of the internal surfaces and the air temperatures into one value.



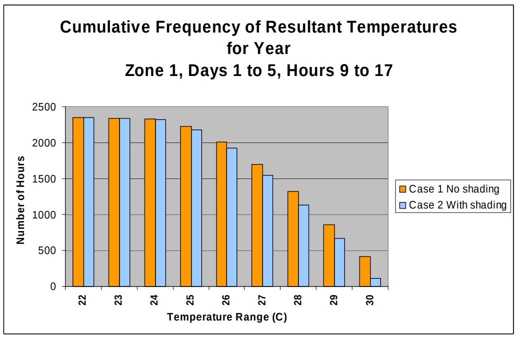


Figure 4.3 Annual total demand for different design options and the cumulative frequency of resultant temperatures

3.3 Summary

1)Site & microclimate impacts on the design of the building, which exploits the prevailing easterly wind to promote ventilation of the car park floors and the women's hostel (floors 15 & 16).

2)The solar control studies of different shading options have enabled the facade design to be optimised,including lightshelves/sunshades.

3)Natural ventilation to car park floors, terrace areas on floors 3 & 4, and the bedrooms in the hostel has been demonstrated to be viable.

4)Natural ventilation of the bedrooms is significantly enhanced by the addition of vent pipes to take air to the roof.

5)Opportunities to use 'gravity' wall cooling will be investigated in more detail in the detail design stage.

6)The design of the car park floors will meet UK Building Regulations Part F1 (ventilation).

7)Daylighting studies of the exhibition centre, post office, typical office, women's hostel (typical bedroom) and typical multi-function room, have helped to refine both the shading configuration and the glazing specification.

8)Thermal performance of the cyber centre (floor12) has indicated the reduction of cooling loads achieved by the shading devices.

9)The OTTV calculation demonstrates that the building design proposed achieves an OTTV of 17.76 W/m² ^{o}C.

4. Conclusion

The two building precedents in this paper show that building performance can be measured and they demonstrate that integrating environment design into the design process is feasible. This process is also beneficial to both the clients and the end users because the design outcome is a more holistic environmentally responsible solution.

Building performance simulation, daylighting simulation, thermal modelling and CFD (Computational Fluid Dynamic) analysis are rapidly expanding methods of design and verification throughout the construction industry. The main benefit to the client is the added value that these techniques can bring to the project by optimising the design in terms of energy consumption and the quality of the working environment, leading to reduced capital and running costs and increased productivity.

By predicting accurately the peak loads and annual energy consumption of the building, this method helps the engineer to optimise the plant sizing and system design, reducing the associated carbon emissions. In addition, the environmental design features can also add a new dimension to architecture.

“Sustainable City” More that just the buildings

Peter Sharratt – WSP Environmental Ltd.
Camilo Diaz – WSP Environmental Ltd.

Abstract Finding viable models for sustainable urban development in China is essential if the recent unparalleled economic growth rates are to be sustained and if public welfare programs are to continue. Increasing urbanisation has put enormous pressures on the environment whether it be for resources such as water and energy or simply absorbing the by products of our society: waste and pollution.

Peter Sharratt and Camilo Diaz argue in this paper that creating an integrated, sustainable infrastructure for cities is not only feasible but also viable.

Taking as a recently competed case study, the 200,000 people urban extension of Miyun, north east Beijing which uses 50% less water and is powered by 100% renewable energy sources; the conceptual design of the water, waste, power and transportation infrastructure will be described including the key issue in balancing supply and demand through resource efficient design and integrated utility supply.

Key Words Resource Efficiency;Inter utility dependency ;Renewable Energy ;Cradle – to – Cradle concepts ;Supply and demand management

摘 要 如果中国保持近几年空前的经济增长率，且公共事业不断发展的话， 中国寻求城市可持续发展可行的模式是很有必要的。城市化进程对环境产生了巨大的压力，无论其是为了水和资源或只是简单地吸纳我们社会的付产物：废物和污染。

Peter Sharratt and Camilo Diaz 在这篇文章中介绍了一个切实可行的整合的可持续发展的城市组织系统。

通过一个典型的例子进行讨论，北京东北的密云县城市人口扩增到 20 万，但只使用不到 50%的水，而其电能是由 100%的再生能源产生的，来描述水、废弃物、动力和交通设施的概念设计，包括通过能效设计和完整的能源供应达到供需平衡的关键问题。

关键词 能耗；内在利用依从性；再生能源；发源地—发源地概念；供需管理

Masterplanning Architects – William McDonough and Partners

Environmental Design and Engineering – WSP Group

1.0 Introduction

The Beijing Rising Century Real Estate Co. Ltd. in association with China Housing Industry Association and China-US Centre for Sustainable Development commissioned William McDonough & Partners to prepare a conceptual Strategic Development Master Plan for the extension of the city of Miyun, Northeast of Beijing, China. The design was founded on William McDonough and Partners ‘cradle to cradle’ principles of sustainable development.

WSP acted as specialist consultants to William McDonough & Partners on the sustainable master planning and infrastructure strategies. WSP had previously worked with WMP on the strategic master plan for the Science Museum’s Creative Planet, in Swindon, UK.

This paper summarizes the recommendations for sustainable infrastructure covering four main areas:

- Water
- Energy
- Transport
- Biodiversity

The sustainable infrastructure design seeks to optimize the benefits to the environment and society by:

- Managing resource demand
- Freeing up land otherwise used for infrastructure
- Optimizing materials used in construction
- More effectively engaging resources used in operations
- Leveraging capital investments
- Leveraging investment in existing infrastructure
- Overarching design objectives

The proposals for Miyun therefore seek to maximize the use of existing environmental and social capital, creating solutions within the confines of the site boundary wherever possible. The strategies developed are aimed at:

- Creating a neutral balance between water and energy demand and supply
- Managing demand for potable water by recovering and reusing waste waters onsite
- Managing the demand for energy by maximizing energy efficiency within the infrastructure and the built environment
- Maximizing the supply of renewable energy in the form of solar thermal and bio energy
- Managing the demand for automobile trips by creating a transport hierarchy that promotes alternative modes of transport
- Seeking integrated solutions between all infrastructure elements

The proposed extension of the city comprises 556ha of residential units and 2858ha of mixed use development including office accommodation, retail/restaurants, leisure, community uses, commercial, service pods and industrial buildings. In total it is envisaged to provide housing accommodation and employment for 40,000 people.

2.0 Water

Water is a precious resource in China, and the William McDonough & Partners Cradle-to- Cradle Design Protocol proposes that the new development meet all water demands within the footprint of the site and eliminate the burden placed on existing infrastructure systems in Miyun and the surrounding area.

There were two principal areas of investigation:

a) Surface water (storm water)

b) Potable water and wastewater

Analysis of annual rainfall indicates near drought conditions for most of the year, except June, July, August and September when 95% of total arrival rainfall occurs. This is typical for a monsoon climate type and the peak surge makes soil erosion in existing watercourses a potentially serious issue. Collection and long-term storage of rainfall using traditional infrastructure is not thought to be feasible due to cost implications, e.g. large diameter pipe work and storage tanks would be required to be sized to the maximum demand but only rarely used to capacity.

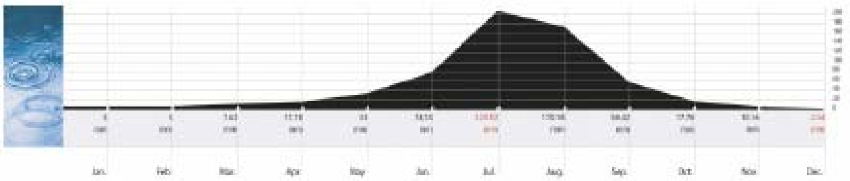


Fig 1 Annual rainfall patterns

Due to local flash-flood type weather patterns, the best hope for ground water recharge is to allow water to collect over large areas and percolate into the soil to the greatest extent possible while draining excess water. This would require an engineered approach that considers percolation in tandem with drainage.

Cradle-to-Cradle Approach

Ideal water cycles: Surface water that runs through the site leaves cleaner than when it entered, in distribution patterns and rates that mimic the unbuilt site. Potable/ drinking water is provided, using natural processes that reuse wastewater streams constantly recycling the water within a closed loop system. Valuable organic and inorganic nutrients are captured from the wastewater streams and are available for returning to the soil.

Surface Water

Policy: Domestic and industrial wastewaters will be segregated and treated according to the volumes and needs for water treatment giving the potential for multiple water treatment standards.

Goal: To collect, absorb and cleanse storm water on site, as much as possible, while encouraging groundwater recharge and evapotranspiration.

Surface water Strategies

1. Use existing drainage patterns. Preserving and restoring these zones reduces erosion, and creates mature soils that slow and absorb surface flow.

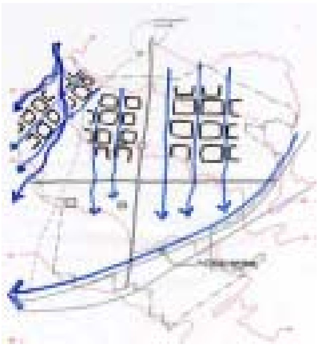
2. Use natural drainage flow and topography. Large, vegetated zones for surface water conveyance running north/south serve to capture, hold and slowly convey storm water while providing biological treatment, allowing infiltration/ground water recharge, and removing non-point source pollutants.

3. Create primary interceptor along rail line. In heavy rain events, this will serve to capture and convey overflow from the conveyance zones.

4. Use vegetated buffers as secondary interceptors. Vegetated buffers surrounding developments serve as temporary surface water retention during heavy rain events.

5. Employ sustainable drainage technologies at the neighbourhood level. These include green roofs, porous/permeable pavements, vegetated swales and other infiltration devices.

The surface water strategy utilizes the natural contours of the ground, which lie predominantly in a southwest direction. This gives Potable/Waste Water can be utilized. The proposals include a series of primary swales interconnected with infiltration zones-the 'green spaces' alternating on plan with the primary circulation routes.



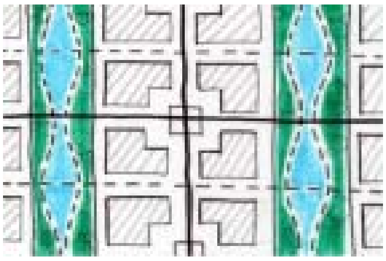


Fig. 3: Storm water swales are integrated within the development pattern, and are designed to encourage infiltration, retention and groundwater recharge

Fig 4 Swales swerve multiple functions, such as grey water processing, storm water retention and transit in the form of bicycle and walking paths

Fig 2: Development pattern honours natural drainage flow and topography.

Fig 5: Building specific strategies, like green roofs, can help optimize storm water infrastructure. (Rouge River Ford Plant, WMD+P).

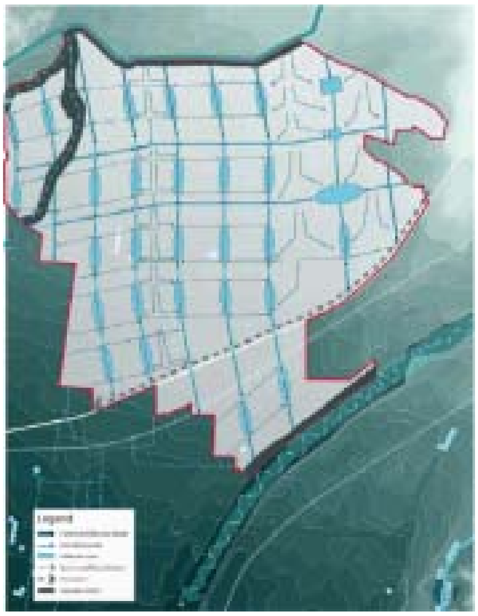


Fig 6 Proposed surface water strategies

Potable/Waste Water

Goal: To optimize the use of potable water by reducing demand where possible, reusing grey water as much as feasible, recapturing organic and inorganic nutrients from the wastewater stream and reducing potable water usage. Targets of reducing water demand by 50% and recycling 75% of all water used on the site have been set. Water supply and demand are balanced by use of dual potable and non-potable water standards.

Potable/Waste Water Strategies

1. Employ water-efficient fixtures, equipment and processes. Reduce water demand from the outset of the project.

2. Exploit ground water reserves. Establish the viability of deep aquifer boreholes for supplementing potable and non-potable water demand.

3. Provide a separate grey water collection and supply system. Recapture grey water and use it for non-potable uses like toilet flushing and clothes washing.

4. Use grey water or borehole to keep public green spaces green. Grey water for irrigation reduces overall potable water needs and recharges groundwater.

5. Use processes that recapture organic and inorganic nutrients from wastewater stream. Capturing solids for biogas production also returns nutrients to the soil.

Distribution at City Level

The existing potable water and grey water supply networks feeds the commercial and residential development areas, shown in green and blue arrows on Figure 9. It has been assumed that a potable water connection will be possible with the existing network. However, grey water recovered from site uses will be returned for use onsite thus minimizing demands for potable water from off-site sources.

The proposed system also shows where gravity and pumped wastewater zones will be required in order to recycle the water. This dictates the location and number of illustrated pumping stations required. Also, illustrated on the Figure 9 is the primary stormwater interceptor drain which will be located adjacent to the railway line and will enable the waters from the northern and central parts of the site to flow under gravity to the sewage treatment works for either full or partial treatment and disposal or reuse when conditions permits.

Distribution at District Level

Wastewater discharged from the building units can use one or two approaches to recovery and treatment depending on building type. Water recovery and treatment can occur on-site or can connect to the site network for treatment at the sewage treatment works. For example, residential wastewater will be comparatively clean wastewater compared to industrial wastewater and therefore simpler to connect straight to the site-wide distribution and recovery network. Conversely industrial wastewater will be better managed with its own systems only discharging partially treated wastewaters to the network for further refinement.

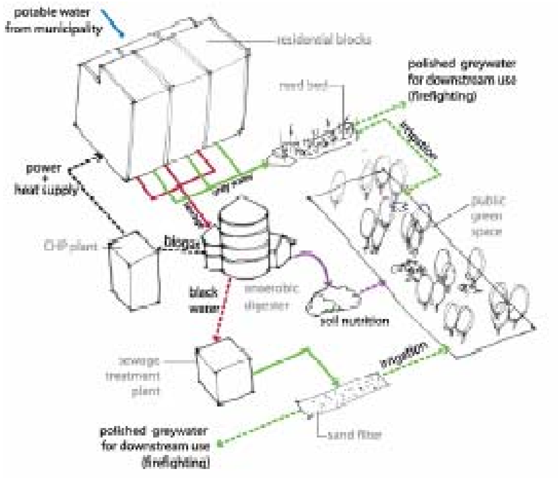


Fig 7 District water recycling

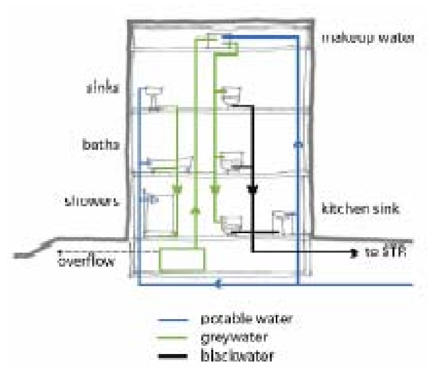


Fig 8 Building grey water

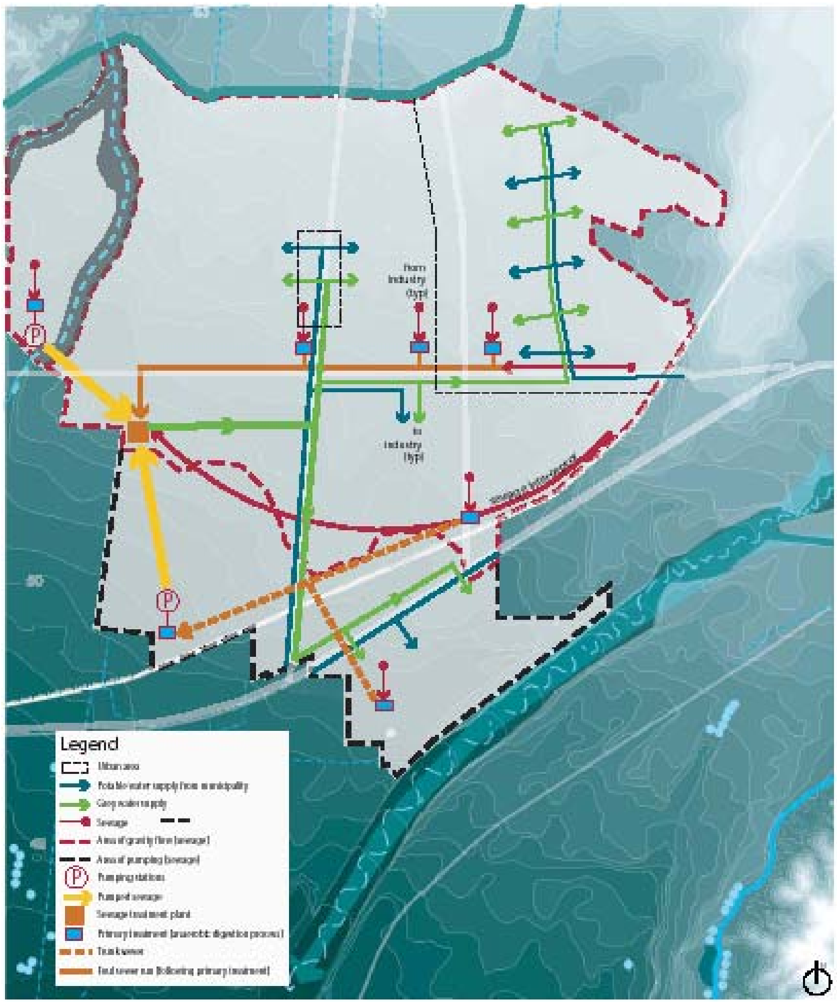


Fig 9 Proposed surface water strategies

Water Consumption Estimates

In order to assess the specific infrastructure options a preliminary load analysis was carried out based on generic building area by building use, population and number of dwellings. An assumed use of 200 litres/person/day has been used based on previous experience in subtropical climates and modern water demands. This figure exceeds current estimates for average water consumption for China, (100. 1p/day) but given the quality of the developments it is reasonable to assess future demands based on modern international demands. Comparable consumptions figures are:

- US: 300L/P/Day
- UK: 220UP/Day
- China: 100L/P/Day

Note that the total estimated daily demand for Miyun Development *(excluding* industry process water demands) is 120,000m3/ day. This figure is without water efficiency and recovery technologies recovery technologies that could reduce this by as much as 50%.

Projected Loads

Total supply requirements are as indicated; these figures assume no water saving or sustainable systems are used. With grey water recycling for non-potable uses, potential reductions in water demand could easily save 30%. For wastewater, there are potentially five streams:

Industrial

- Black water 35%
- Grey water 15%
- Process water 50%

Urban

- Black water 70%
- Grey water 30%

The adoption of sustainable water management systems and processes will provide whole life cost savings. A simple comparison on the reduction in demand and treatment requirements highlights that the approximate 15-25% increase in construction/implementation costs can be offset by the reduced scale and operational costs of water infrastructure. For the anticipated 45% reduction in demand and 55% reduction in treatment volumes, adoption of sustainable water systems could be cash positive within four years in comparison to conventional techniques.

3.0 Climate / Energy

Energy production and energy use will be the primary focus for initial development. However, infrastructure design also seeks to anticipate evolution towards a 100% solar powered future as capital costs reduce over time. This section is divided into two parts:

A) Energy demand

B) Energy production and distribution

Cradle to Cradle Approach

Ideal energy cycles: All energy is produced on site as close as feasible to where it used, and is derived from renewable sources. Further, energy use is optimized to such a degree that the development becomes a new exporter of clean energy.

Policy

Screening protocol and guidelines will be developed for industries regarding air quality, energy use and carbon emissions. Overall goals for optimizing energy and maximizing the use on site renewable energy sources will be incorporated into decision making at all scales.

Overall Energy Goals

- Model eco-effective," green" building design .Reduce peak demand profiles
- Use an energy technology hierarchy to meet residual

Demand Side Management Goal

Optimize energy performance through demand management in order to meet a greater percentage of energy needs from clean sources.

Strategies

1.Maximize benefits from "passive" design. A key component of the passive solar design strategy is orientation of the individual buildings and the primary circulation routes and street patterns. The proposed town grid is rotated ten degrees toward the east from true north/ south and blocks are elongated east/west to optimize solar exposure. Large south exposures are ideal to capture solar gain in the winter to control heat gain in the summer, and to optimize the use of daylighting. Elongated blocks allow for cross-ventilation, reducing active cooling needs. Deciduous planting and other shading strategies can also reduce active cooling needs

2. Use high-performance systems, and optimize their scale. Seek out strategies like ground source heat pumps that optimize their performance by relying on local assets, such as the constant temperature of the earth.

3.Meet envelope performance targets. Well-insulated buildings such as those that use strategies like envelopes that absorb heat during the day and release it at night can reduce diurnal swings and moderate energy use. Strategies like green roofs can provide the additional benefits of reducing the amount of energy needed to maintain human comfort.

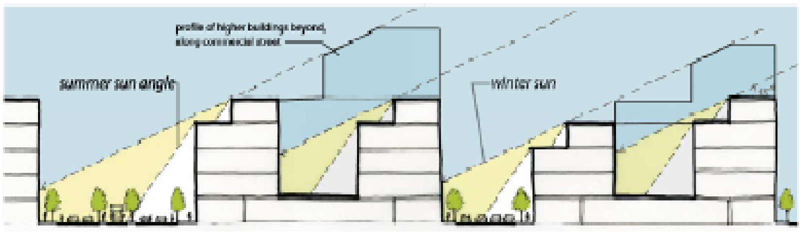


Fig 10 Mixed-use commercial buildings. Massing and orientation for solar access

Supply Side Management

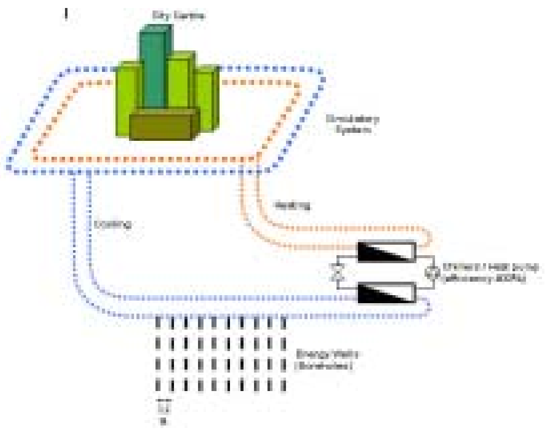
Experience has shown that significant savings can be made in the cost of energy infrastructure by reducing the demand at point of use. (For the purposes of this study the energy demand of industrial processes has been ignored until greater clarity on the type of industry has been defined). It is essential that these measurements be factored into design guidelines, energy codes or the core building specifications as the design progresses.

Primary power is distributed between the commercial and the residential areas. The system connects to the existing steam plant with the proposed addition of a combined heat and power with additional cooling equipment. A key component in the integrated energy strategy is a combined heat and cooling (CHC) plant connected to both residential and industrial users. The proposed CHC plant would work as follows:

The chillers/heat pump has four main components: the condenser (warm), the evaporator (cold), the expansion valve and the compressor. The cooling system is connected to a number of boreholes 180 m deep. The boreholes function as energy wells. They provide free cooling storage over summer and as a heating storage during wintertime.

The warm side of the machine can supply heating for different purposes: space heating during winter, hot water for industrial process and domestic hot water for nearby residential users.

Energy demand and supply can be managed using various alternative technologies. The proposed strategies outline two main options for energy production:



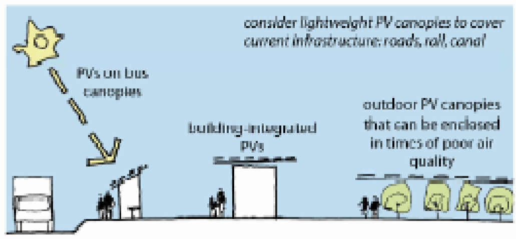


Fig 12 Opportunities for integration of photovoltaic into the urban structure.

Fig 11: Combined heat and cooling CHC plant diagram.
Primary power is distributed between the commercial and residential areas. The systems connects to the existing steam plant with the proposed addition of a combined heat and power plant with additional cooling equipment.

Energy Management Strategic Options

In developing the integrated energy strategies for the site, two options were considered:

Solar City

The concept of solar city envisages the use of photovoltaic technology and solar thermal methods to supply all energy demands. Although there is enough solar power available to meet this energy demand issues of cost effectiveness and practicality need to be considered. It appears, given current trends, that solar derived energy may be cheaper than new coal power within 15 years and certainly within 20 years. The city of Miyun can anticipate this event and provide planning to accommodate it.

Hybrid City

This option assumes the use of a combination of energy technologies available to the site to provide a more rational supply of energy. It assumes a minimal grid connection, which will be used to provide peak loads, if required, and will optimize the onsite infrastructure around embedded energy options.

Technology	System / Mechanism	Production: Electricity		Production: Heat	
		Electricity (GWh/yr)	Req. Area (M2)	Heat (GWh/yr)	Req. Area (M2)
PV		439	2,930,000		
Solar Thermal	Solar thermal with seasonal heat storage			397	800,000
Total		439		397	
Demand		439		397	
Balance		0		0	

Fig 14 Energy balance for the 'Solar City' scenario

Fig12. Energy balance for the 'Hybrid City' scenario

Wind power options have not been considered at this time, given the available wind resources, but could provide additional options for the hybrid city solution. However, renewable energy systems such as PV's and solar thermal collectors have a vital role in providing environmentally clean energy to the site. PV's and solar panels can be integrated into the design of many of the buildings and other urban structures.

Technology	System / Mechanism	Production: Electricity (GWh/yr)	Production: Heat (Gwh/yr)
PV		404	
CHP	Biogas sewage	5	7
	Biogas industrial sewage	20	40
	Gas Sterling	10	38
	Redesign of coal ired steam plants to CHP	Optional	
Circulatory System	Waste heat from coal plants		270
Wind Power		Optional	
Solar thermal with heat/ storage			42
Total		439	397
Demand		-439	-397

Fig 15 Energy balance for the 'Hybrid City' scenario

Photovoltaics

PV's can be applied as either integrated or as stand-alone systems. Building Integrated Photovoltaic Systems (BIPV) offer a number of advantages over stand alone systems including: making effective use of roof area, saving on construction costs (cladding, roof lights, shading, etc.) and increasing visibility with consequential educational and demonstrative benefits. Furthermore, grid connected systems offer the advantage of not requiring battery banks for electrical energy storage and will produce AC electricity, when combined with inverters, or direct DC, both of which can be used directly to meet the building's electricity demand.

Among the various types of photovoltaic modules, monocrystalline PV modules represent the most commonly installed type and now have a proven track record for reliability and sustained performance over time. These modules currently have an average efficiency of 14 -16% and their cost has dropped considerably in the last decade. Prices are now at a level that makes them cost-effective option with when compared with quality building envelope finishes.

Solar Thermal Collectors

Similarly to photovoltaic systems, the energy output of solar thermal collectors can be maximized through appropriate roof integration. The two principal systems taken into account are evacuated tube solar collectors and flat plate collectors. Evacuated tube collectors are more efficient on an area basis compared to flat plate collectors and have a more constant energy output throughout the year that could be more beneficial in offsetting the space heating demand during especially during the winter months and in the climate of northern China. However the cost of the latter technology is extremely competitive and China is a world leader in production of these systems, making them a preferred solution when roof areas are not limited.

Figure 17 provides preliminary energy balance has been undertaken to assess the potential applicability of the different technologies already discussed to meet the energy demands of the development. Figures 14 and 15 give detailed energy supply estimates for the Solar City and Hybrid City options. Both options are based on modern international building design standards and do not account for energy savings from the adoption of high performance envelope design which could substantially reduce space heating demand. Adopting significantly higher standards for envelope performance will reduce the cost of energy production infrastructure and is a priority for investment.

Projected Loads, Costs

The development will remain grid connected to allow for the export of renewable energy to the rest of Miyun when supplies a re generated or provide top up supply or meet peak demand.

Figure 16 provides a simple cost comparison for various technologies to illustrate the benefits and limitations of each according to scale of implementation. The cost comparisons given are based on international systems. The assumption is that the municipality of Miyun will construct and operate the on-site generating facilities. It is also assumed that the renewable energy technologies are sourced from China and are not reliant on imported goods from Europe or the US. Further work needs to be carried out defining viable cost.

In summary, by adopting the C2C principles discussed above the energy strategy will meet all the energy demand for the site, within the boundaries of the site, and avoid placing a burden on existing energy generation infrastructure else where. How this is achieved will have wider relevance to China, where 68% primary energy comes from burning low-grade sulphur rich coal with the remaining from hydro, nuclear and other sources. The implications for the wider Chinese market are that the scheme will be compliant with the 10th 5 year plan which aims to increase market competition by separating energy supply from distribution and reduce the domination in the market by centralized coal and hydro electric power production.

Technology	Cost per kW Installed electric capacity	Heat/Power ratio	Size	Notes
CHP solid fuel (coal, waste and biomass)	$ 2,000 US/kWe	65/35	> 10MW	Traditional Steam Process
CHP turbine biogas, natural gas	$ 10,000 US/kWe	60/40	> 4MW	Volvo Aero + licensed manufacturers
CHP small gas turbine	2,500 US/kWe	60/40	,4MW	licensed manufacturers
CHP gas motor anaerobic digester	1,000 – 1,500 US/kWe	55/45	< 1MW	use gas motors not turbines
CHP landfill gas	850 – 1,200 US/kWe	55/45	< 1MW	discuss with authorities the availability of landfill sites
CHP gas Stirling engine	2,500 US/kWe	80/20	1-30 kW	Block / domestic

Fig 16 Cost Comparison: CHP Technologies

	Housing				Commercial			Industrial	Totals
	High	Med	Low	Mix	Office	Retail	Leisure	Industrial	(GWh/yr)
Number of units	11892	11107	15242	7424	-	-	-	-	
Area (m²)	-	-	-	-	2438260	1561320	273100	9569000	
Density (persons/unit)	3,5	3,5	3,5	3,5	-	-	-	-	
Population	41622	38876	53348	25984	-	-	-	-	
Electricity demand (Gwh)	35	33	46	22	119	76	13	95 (lighting)	**439**
Heating demand (Gwh)	59	55	76	37	97	62	11		**397**

Fig 17 Projected energy loads for development

4.0 Sustainable Transportation

The project presents a unique opportunity to create a truly integrated and sustainable transportation system that will be unique and a first in China. The proposed transportation system has been designed to maximize mobility options, equally facilitate travel by all modes, and fulfil the three primary transportation objectives of accessibility, permeability and sustainability.

Policy:

Develop a hierarchy of transportation networks that promotes a sustainable mode of transport, manages the use of private vehicles, promotes the use of public transport whilst not infringing on people's mobility and access.

Goal:

To develop mobility options that are the preferred choices over automobiles for speed, convenience and delight.

Strategies

1. Develop pedestrian and bicycle network. The north/south greenways are used as a distribution network for pedestrian and bicycle traffic, connected to the town by two east/west greenways. The network is separated from high-speed truck and car traffic.

2. Provide for, and give preference to, mass transit. Transit loops and dedicated bus lanes are designed to operate within the primary distributor network. Other strategies to "showcase" mass transit include:

- Using clean fuel buses (such as electric, LPG and hybrid technologies)
- Implementing active bus priority at traffic signals
- Providing real-time passenger information at bus stops
- Providing improved waiting facilities (shelters, seating, etc)

All of these strategies result in improved operation reliability, which leads to improved perception by users and faster travel times than automobiles.

3. Introduce Park and Ride sites. Strategically locate sites to intercept traffic, and ensure they are served by bus routes that benefit from priority measures while providing secure parking for both cars and bicycles.

4. Separate local access from through movement, and limit unnecessary access. A clear hierarchy in road type and use optimizes, transit infrastructure, which in turn reduces travel speeds (where appropriate), increases safety, and reduces waiting times.

5. Develop a system of multi-modal transport hubs. Places of intersection between modal types become places for commercial and social activity, where people can wait for the bus, catch a train, hire a green car, and/or rent a bicycle.

6. Develop roadway standards that reduce road width. Secondary roads and intersections should facilitate pedestrian movement and safety.

7. Maximize potential for implementation of "intelligent transport systems" such as real-time traffic information, variable message signing, dynamic car park control and optimized traffic signal networks.

Modal Priority

1. Walking
2. Cycling
3. Buses

4. Rail
5. Cars

Highway Network Design Recommendations

- Optimize, not maximize, carriageway space
- Adopt a demand management approach.
- Develop stringent design criteria that avoid excessive carriageway space and over-design. Reducing carriageway space reduces speed and enhances highway safety.

Typical Hierarchy

1. Primary: three traffic lanes each way, central reserve plus segregated cycle lanes either side (2.0 meter min).
2. Secondary, two traffic lanes each way, central reserve optional, cycle lanes either side (2.0 meter min), optional segregation.
3. Local: single lane each way, no central reserve, cycle lanes either side (2.0 meter min), no segregation.
4. Access road: single lane each way, no cycle lanes.

Secondary and lower intersections are designed around pedestrian and cycle movement, no private cars. Pedestrian crossing distances are optimized and pedestrian desire lines are satisfied, as necessary with additional crossing facilities.

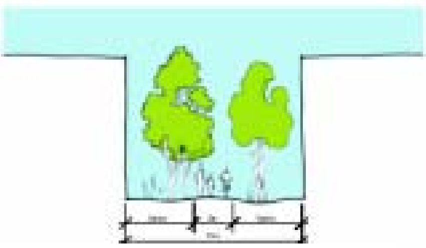


Fig 18 Landscaped pedestrian routes

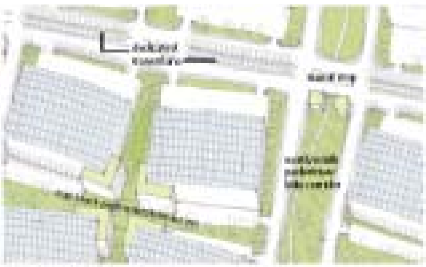


Fig 19 Mobility networks at

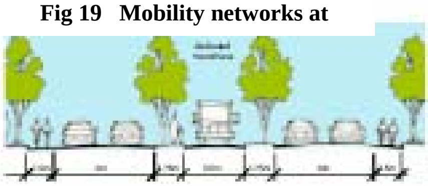


Fig 20 Street section at mixed use showing transit lanes

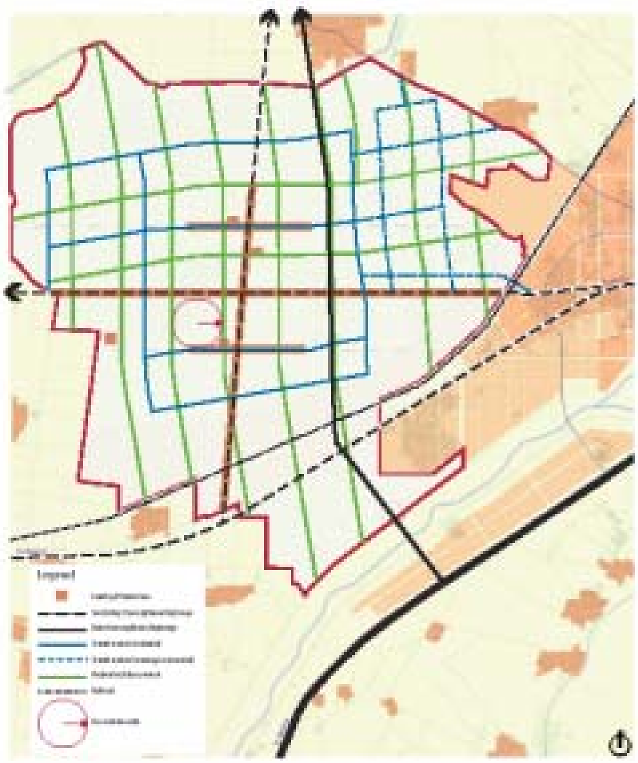


Fig 21 Proposed road hierarchy / mobility

5.0 Biodiversity / Well-being

Goal: Create a framework for environmental regeneration.

A detailed assessment of the site needs to be made to develop the choices of native plants to be reintroduced to the site for each of the specific site conditions. Nitrogen-fixing legumes and deep-rooted native species can be favoured during regenerative phases. Native plants will already be adapted to the climate of Miyun, so that after a period of establishment, they will not need additional water or supplementary nutrition in order to flourish.

Strategies:

- **Provide habitat corridors through the site.** North/south 60 meter strips of vegetation running the length of the site are opportunities to increase biological diversity by establishing self-sustaining habitats. The corridors create important ecological connection to the regional eco-system and provide habitat and migration for wildlife.
- **Implement highway, rail and road buffers.** The concept plan shows buffers ranging from 5Om to 200m. Within some of these buffers will be storm water conveyance swales to capture storm water. These areas can be planted in native grasses and herbaceous plants that can withstand periodic, but short-term flood. The rest of these buffers constitute great opportunities to advance reforestation. In contrast to some of the highway tree planting that is presently occurring in China, these buffers should be planted in a mix of native tree species to reflect the composition of the local forest ecosystem.
- **Re-vegetate buffers along watercourses.** This will reduce erosion and runoff during storm events. Revitalizing these areas provides a quiet, continuous zone for fauna to migrate.
- **Use native and drought-resistant species in landscaping.** Landscapes can grow to maturity with less irrigation; Miyun can become the nursery for native species for this region of China.
- **Implement building-specific habitat creation strategies, like** green roofs. Green roofs provide multiple benefits: they create habitat, produce oxygen, provide insulation, retain storm water, and mitigate urban heat island effect. Seek out similar opportunities to create habitat when designing buildings.

6.0 Conclusions

WSP were specialist consultants to William McDonough & Partners on the sustainable master planning and infrastructure strategies for the city extension of Miyun. This paper summarizes the conceptual plans and recommendations for sustainable infrastructure. By developing the conceptual strategies for sustainable infrastructure based on a good understanding of the project requirements, the local environment, the site and the microclimate, WSP has demonstrated that creating an integrated sustainable infrastructure for cities is not only feasible but also viable.

The strategic scheme for sustainable infrastructure proposes the potential saving of 50% of the water use through water conservation strategies and the supply of 100% of the energy demand by renewable energy sources. The scheme also includes the conceptual design of the water conservation systems, and highlights the key role of buildings in balancing energy supply and demand. The infrastructure strategy proposed underlines

the concept of integration of the various infrastructure components and the master plan and recognises that integration is vital in order to provide a holistic and cohesive response to the projects requirement.
Currently a solar powered city remains a long term goal, as photovoltaics do not yet present a cost effective solution due to the high initial investment. However the proposed conceptual plans for infrastructure provide intermediate steps that will allow the city to anticipate a viable solar power future. If present trends continue, it is expected that solar energy will be the same cost as coal-fired electricity by 2006. Building a town that embodies these concepts provides a replicable model as China prepares for a massive campaign aimed at housing 400 million people over the coming decade.

让绿色生态住宅走向市场

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摘　要　当今的住宅建设随着经济的发展、人们生活水平的不断提高而曝露出诸多问题，如传统的采暖制冷方式弊端多、房屋能耗大、空气质量差、隔音不好、不节水等等。因此发展绿色生态建筑成为必然趋势。但在目前国内还主要是在技术研究和部品开发方面进行探索，大规模建设生态建筑还未蔚然成风，北京锋尚国际公寓的开发成功走出了一条在市场经济环境下开发绿色生态建筑的可行之路，那就是必须以适应资源短缺的国情为前提，以科技创新为手段，以满足使用者对健康舒适更高的追求为目标，重视建筑全寿命周期内的综合经济分析，即满足人们对住宅的更高、持续的健康舒适要求并且消耗自然资源最少，为消费者创造具有满足可持续发展需求的全新住宅，这同时也是房地产置业投资的基本原则。

关键词　高舒适度；低能耗；绿色生态住宅；节能 65%

发展绿色生态住宅是客观要求

当前，我国所面临的环境恶化、能源短缺的情况已经非常严重。就拿能源情况来说，我国目前国内民用建筑的能耗已经占国民经济总能耗的 28%，随着经济的发展、人们生活水平的提高，建筑能耗还将逐年增加，采暖、空调能耗目前已经占到建筑能耗的 55%，而中国人均占有能源不足世界平均水平的一半；

据有关统计资料显示，以上海电力供应为例：高峰时负荷为：13.62GW，午夜时电力负荷仍居高不下：13GW，而上海自有发电能力只有 9.22GW；全国来看：19 个省市严重缺电，2003 年全国各地区累计拉闸限电超过 14 万条次，累计限电量 19 亿千瓦时，空调用电负荷占 40%以上；

北京在 2004 年 7 月 20 日即入伏第一天就创用电新的最高记录近 900 万千瓦，比去年创造的历史最高记录增加了 60 多万千瓦，仅数天以后就又创新高到了 946 万千瓦，直逼北京供电能力 950 万千瓦的极限；

另据联合国统计，中国人均年水资源拥有量仅为世界平均水平的 1/4，被联合国列为 13 个最贫水国家之一，在全国 600 多个城市中有 400 多个供水不足，其中 110 个为严重缺水城市。北京人均年水资源拥有量仅是全国平均水平的 1/8 世界平均水平的 1/30；北京各个水库（包括非水源保护水库）水位几年来持续下降已经到了危险的地步，今年从 8 月 1 日起，居民生活用水价格由每立方米 2.9 元上调为 3.7 元，工业、商业用水由 4.4 元上调为 5.6 元，洗浴业用水更是大幅上调为 61.5 元；8 月 4 日北京市政府紧急发出了关于倡议节水节电的《致市民公开信》号召每家每天节省“一桶水一度电”，以此号召市民共度难关。

这些数据都表明客观环境已经显著影响到了我们的日常生产、生活，而且必将会越来越严重，当今的建筑发展尤其是占主要部分的住宅的建设必须走绿色生态也就是可持续发展之路已经是越来越多人的共识，作为房地产开发企业也应该走开发此类产品，不仅为社会同时也是为客户长远利

益着想，为客户也就是为开放商自己的利益着想，因为消费者会逐渐认识到它的重要性并左右自己的置业方向。

发展趋势明显 效果不甚理想

另一方面，大的政策环境和社会环境已经具备了一定的条件和趋势。早在数年前北京市在申办2008 年夏季奥运会时就打出了“ 绿色奥运 ”的旗帜，要借奥运会的东风将北京建设成为一个绿色生态的城市，但至今北京的大气质量要想持续改善已经开始面临着很大的困难。确实在有限的条件下仅靠多种树搞绿化对大气质量的改善程度有限，应该重视污染的源头之一--建筑耗能所对大气的污染因素，否则全社会将付出更多的代价去治理；

从今年 7 月 1 日起北京在全国首先开始实行节能 65%的强制标准，表明了政府的决心及发展的需要，但能否真正达到目的还需要做很多的工作；另据建设部领导最近讲话：现在的住房面积约有400 亿平方米，而能达到节能标准的只有百分之零点几，新建的也只有 15%达到节能标准。说明目前我们连低标准的节能水平都没有普及，还谈什么建设绿色生态建筑？这充分说明开发绿色生态住宅还缺乏足够的动力。

同时，国内外种类繁多的有关绿色、生态的标准、技术评估体系在国内传播广泛、有关生态技术的研讨会开的是如火如荼，但能够系统化实施的房地产项目却凤毛麟角，有人说是经济水平不高制约了绿色生态建筑的发展，可北京、上海等各大城市早已经是“ 豪宅 ”遍地了，看来经济不是发展绿色建筑的制约因素。因此迫切需要寻找一条切实可行的发展之路、能够在市场环境下按照经济规律去发展的道路。

在满足市场更高需求的前提下发展绿色建筑

在市场经济条件下，商品的价值只有在交换中才能体现，好东西未必被市场普遍认可与接受也是普遍存在的客观事实。虽然我国能源及各种资源的短缺客观上会促进绿色生态建筑的发展，但目前如何处理长远利益和近期利益需要寻找更好的解决办法。

一方面需要政府在宏观政策体现更多的鼓励政策法规，另一方面房地产开发企业迫切需要有关绿色生态建筑的成熟设计、施工、部品集成即系统的产业化要求。虽然各个方面正在努力、发展，但还不够成熟还没有形成规模效应，对于绿色生态建筑的发展形成了制约因素。

因此，在目前还没有普遍具备这些条件的情况下，开发难度是可想而知。锋尚的开发商看到了未来的发展趋势及市场上产品的同质化和存在的不足，通过大量的国内外调研及分析寻找到一个新的开发模式来作为立业之本即建设高舒适度低能耗住宅。高舒适度就是追求更高的健康舒适程度是包括室内热舒适度在内的综合因素，即按照国际标准ISO7730和世界卫生组织（WHO）对健康住宅的要求，应该具备人体健康所要求的合理的温度（20℃—26℃）、湿度（40%—60%RH）、空气质量、光环境质量、噪声环境质量、卫生条件等。住宅要实现这些，就要增加成本、就要消耗更多的能源，国情决定了今后的建设必须消耗各种不可再生资源要少，如一次能源、水资源、土地矿产资源及其它资源等等，否则住宅的使用者就会付出高昂的使用成本。还要同时具备健康舒适的居住条件来满足人们普遍追求的更高目标，这就是要走高舒适度低能耗住宅之路即可持续发展之路。

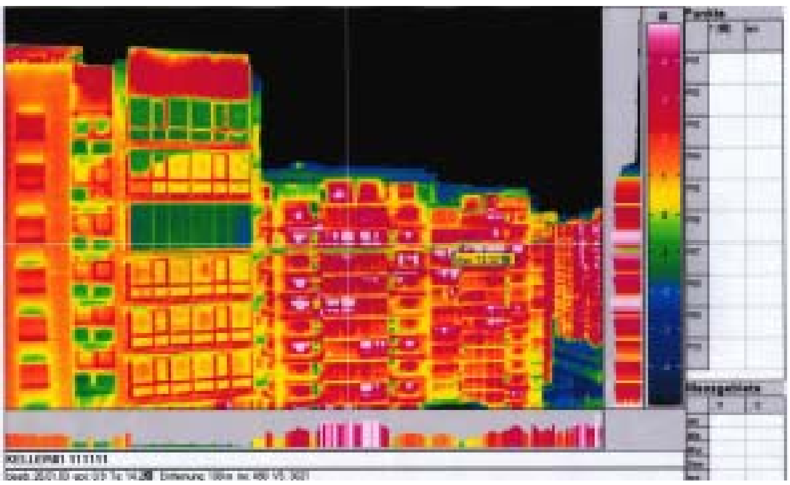
锋尚的绿色建筑技术体系要点

北京锋尚国际公寓，是根据中国的国情按照可持续发展的要求由国内房地产开发商在市场机制下自主开发完成的房地产项目，在我国住宅产业化水平不高的今天通过艰苦地努力方得以完成并在中国住宅领域开创了多项第一，经过国家建筑工程质量监督检验中心长达一年的跟踪检测证明完全达到高舒适度低能耗的设计目标。

锋尚是由四座 18 层的塔楼和二座 8、9 层的板楼组成，总建筑面积 10 万平方米，占地 2.6 万平方米，容积率为 3.0；锋尚的技术集成不仅体现在低能耗等的绿色技术上而是围绕住宅普遍所存在的问题提出一种系统化的解决方案。

一、复合外墙系统—高适应性的具有强保温隔热双重功能的外墙系统

锋尚采用复合式外保温隔热系统，即在结构（剪力墙）外侧依次为粘贴 100 毫米厚聚苯板（EPS）、100 毫米厚可流动空气间层、瓷板干挂幕墙。外墙综合传热系数 $K=0.3w/m^2k$。这套系统在国内高层住宅上是首次使用。



它解决了增加保温层厚度与外饰面难做的矛盾使外观能够方便的持续保持清洁、解决了湿气在保温层内的出路并具有隔热作用（否则，几年以后保温材料内含水率增高将使保温效果大幅降低），而且改变了寒冷地区（如北京）的建筑通常没有隔热的功能，使夏季的室内舒适度明显提高并节约能源。并且，这种隔热做法也能够适应我国华东（如上海）、华南（如广州）地区的气候条件。

二、组合外窗系统—窗户诸多功能的综合解决方案

锋尚外窗采用断桥铝合金节能窗；再配上高透型低辐射率（Low-E）中空玻璃，内充惰性气体氩气（这在国内高层住宅是第一次应用），外窗的平均传热系数 $K=2.0w/m^2k$；

并在国内高层住宅上首次应用了铝合金外遮阳卷帘，这种遮阳方式比遮阳板、室内百叶帘的遮阳效率要高的多（遮阳率可达 80%以上）。

窗户是节能的关键和难点，需具有采光（夏季还要防止强光）、视线（通透性）、通风、气密性、水密性、隔音性、保温性等功能。

该系统全面解决了这些问题。

三、屋面地下系统—让顶层的房屋同样具有良好的保温隔热能力

锋尚屋面做了 200 毫米厚的聚苯板保温层，平均传热系数 K=0.2w/m^{2}k。并局部实行屋面绿化，让夏季太阳辐射尽量少地影响室内热环境，让顶层房间同样具备良好的热工性能。

另外，锋尚将外墙 100 毫米厚的保温层一直做到地下 1.5 米深处，因为北京地区冻土层厚 0.8 米，这样就能够防止冷热从地下散失，从而将建筑处于完全的保温隔热状态；女儿墙均做完全的相同性能的外保温；同时所有部位均采取措施避免热桥产生。

通过以上三个方面的措施，使得锋尚的采暖制冷设计负荷均降到 15w/m^2 以下。建筑能耗水平为 12.4w/ m^2，而北京市从 2004 年 7 月 1 日起实行的节能 65%的要求是 14.65 w/m^2（锋尚各项指标与中外的对比见表：1）。

这样锋尚的建筑外围护结构就具有了相当地抵御外界气候变化对室内热环境影响的能力。这套系统针对我国南方广大夏热冬冷地区和夏热冬暖地区在经过性能调整后同样适用，并准备用于锋尚在南方地区即将要建设的项目中。

同时，以上三个方面为建筑采用更健康柔和的采暖制冷方法创造了有利条件。

四、混凝土采暖制冷系统—一种以柔和辐射方式传热的天棚采暖制冷技术

该系统将水管（聚丁烯管也叫 PB 管）现浇在钢筋混凝土结构楼板中，夏季流入≥20℃的水，冬季流入≤28 ℃的水，通过低温辐射的方式均匀地控制室内的温度于夏季≤26℃、冬季≥20℃左右。该系统对于锋尚来讲仅是辅助性的采暖制冷措施，在冬季的许多时间不需要供热或仅供很少的热量，因而更柔和舒适、健康并节能。

在 2003 年底至今当室外气温高于零下 2℃时就不需要给系统提供热量而室内温度稳定保持在 21℃左右。这套系统在高层住宅上应用在世界上是首次。其优点是：室内舒适度高，人不会有上热下冷、下热上冷的感觉；设备负荷小，节约能源；室内无传统的空调机和暖气片及管线，增加了室内有效使用面积。

锋尚采暖制冷系统在全年控制室内温度在 20-26℃的情况下运行成本仅为 30 元左右/平方米（建筑面积）。如果按照北京现行的采暖标准，仅在采暖季主要居室满足 18℃其他房间 16℃运行成本 8 元/平方米就够了，北京现行的燃气采暖收费标准是 30 元/平方米，由此可见锋尚的节能效果十分明显。

需要强调的是该系统采用的PB管的标准是：70℃水温、10Bar压力下连续使用50年。在锋尚应用的环境下（低温、不受紫外线影响、被混凝土保护起来）计算寿命可达到或超过100年，而我们一般住宅的结构设计寿命才50年。

同时，该系统配套的制冷机组的功率比传统建筑小很多，4.5万平方米仅配了180冷吨的制冷机组（包括新风的负荷）。

五、健康新风子系统—提高新风的利用效率快速排除空气中的主要污染物

锋尚采用集中的置换式新风系统，具备过滤、加湿除湿、全热交换、加热功能，该系统将处理过的新风以比室温略低（低2℃）的温度输入室内，新风自然沉积在室内下部，遇到人体、家电等

热源就会上行，这样人呼吸新风概率比传统的方式要大许多，同时对风机的功率要求小。

城市居民有90%的时间是在室内度过的，而城市空气质量比较差，因此改善室内空气质量变的非常重要。尤其是在我国北方的大多数城市，主要污染物为可吸入颗粒物，这套系统基本解决了空气的污染问题。

该系统的优点是：节能、噪音低、健康，解决了北方地区冬季空气寒冷、干燥，夏季空气高温、潮湿及春季的风沙等问题。对于南方来讲有助于从根本上解决室内空气的湿热（霉雨）等不利于人体健康的因素。该系统是首次在高层住宅上应用。

六、垃圾处理子系统-创造良好居室及社区环境卫生的有效措施

锋尚将住宅生活垃圾按照存在的形态分为三类：

第一类为食物类垃圾，在厨房经食物垃圾处理器经粉碎后用水冲走，这种完全密闭的方式彻底解决了食物油污等最易污染环境的垃圾，保障了居室及社区环境卫生条件的良好，同时减少了厨房排水管线易被堵塞的可能；

第二类为粉尘类，经中央吸尘系统低噪音无二次污染地吸走，能够有效减少室内的可吸入颗粒物，比传统家用吸尘器优点明显。中央型吸尘系统用于高层住宅锋尚是国内首次；

第三类为固体垃圾，如废弃纸箱器皿等，因便于分类回收再次利用，由业主自行拿到小区可分类垃圾回收箱。

以上措施同时能有效减少物业管理公司的保洁人员数量，对降低物业管理成本有积极的作用。并且按照垃圾在室内和住区内存在形态来分类比按照以回收利用、处理的方式（如塑料、电池、纸张、玻璃等）来分类可操作性更强，更易为消费者接受且对居室和住区的卫生环境更有利。

七、防噪音子系统-安静居住环境保障

锋尚通过以下措施系统化的解决噪音对室内环境的影响：

1、具有较强隔音能力的窗户、遮阳卷帘来隔蔽外界噪音；

2、通过在楼板垫层里加橡胶隔音垫来减少楼层之间的噪音影响；

3、通过具有减噪作用的 PB 管、高密度聚乙烯管来减少给排水系统的噪音；

4、隐藏式水箱及同层后排水系统将使楼上住户的洁具冲水噪音不再影响下层住户。

通过国家建筑工程质量监督检验中心对锋尚的外窗、楼板、分户墙、室内噪声级的检测，均超

过或达到国家标准的最高要求。

八、水环境子系统-节约水资源

该系统分为 4 个方面：

1、中水系统，采用生物膜反应水处理技术，处理废水的成本很低，不算设备折旧率的话仅 0.7 元/吨左右，而北京现行水价为 3.7 元/吨，仅将中水用于园林绿化、景观湖补水等，该系统日处理水 120 吨，每年可以节约水费 130 万元以上。因此用该系统节水明显、占空间且不用占室外绿地，同时能降低物业管理成本也就是降低了业主的物业费用支出。

2、采用高密度聚乙烯楼宇排水系统，仅用一根排水管同时解决了异味及噪音问题；加上同层后排水技术，将座便器与隐蔽式水箱分开设置，水箱内各种密封圈为能抗 250 万次拉伸，经久不坏，座便采用挂墙式，使卫生间无卫生死角。更重要的是同层排水杜绝了穿楼板的管线，减少了楼上楼下邻里之间的噪音、漏水、装修等影响，并且使洁具的位置具有可移动性。

3、屋面虹吸式排水技术，用 1 根水管可以取代传统的 8 根雨落水管，靠虹吸作用加大雨水管的排放效率，减少室内空间被雨水管占用或使外立面更美观。

九、其他方面

1、无土基质草坪的采用

锋尚园区内的草坪采用耐践踏的无土基质草坪，不仅人们可以步入而且有利于保护耕地。因为我国目前的草坪生产基本上都是用良好耕地的表层土壤来培育草坪，待草长成后再用铲卷机连草带土铲成草皮卷，每次铲走土壤层 3cm 厚左右，数年后就使得良田变成低洼地，耕作层丧失，土壤沙化，对农业生产和生态环境的破坏是无法弥补的。因此采用在无土的营养液内培养的草坪是保护耕地的一项有效措施，该措施甚至引起了温家宝总理的关注。

2、“ 绿色 ” 消防通道的设计

锋尚园区里有一条特殊的消防通道，较窄而且一般见不到机动车辆。因为锋尚将机动车道及停车场设计在地下。使得地面上的消防通道平时专为居民步行使用，仅考虑在有业主搬家时或紧急情况下方便消防车及救护车的通行。因此，平时园区内没有了汽车也没有了由此引起的不安全因素和汽车噪音、尾气的影响。

同时，锋尚将消防通道路面硬铺装部分设计成 2.5 米宽，其余部分均铺设草坪，而把硬路基依然做成 4 米以上的宽度，这样一方面满足了大型消防车的通行，一方面又增加了可绿化面积并且方便雨季地表雨水的下渗。

锋尚的消防通道设计时我们也与北京市消防局的有关部门进行多次探讨并许可这种非常规的做法，甚至有关领导还表扬说这是“ 绿色 ”消防通道，在紧急情况下能够让消防车快速到达指定地点。

锋尚的有关检测报告

从2002年冬天至2004年春，国家建筑工程质量监督检验中心与清华大学联合对锋尚进行了有关热工及舒适度等的长期跟踪测试，主要测试数据如下：

1、建筑热工性能测试结果为：

·外墙主体部位传热系数　K= 0.37（W/m^2K）

·墙体平均传热系数　K= 0.53（W/m^2K）

·外窗系统传热系数　K= 2.17（W/m^2K），当卷帘关闭时K＝1.89（W/m^2K）

2、按照ISO7730建筑舒适度测试结果为：

· 在冬季的测试时间段内，被测房间的室温可达20℃以上，基本在20～22 ℃范围内波动；被测房间都有着较高的热舒适度。PMV平均值为－0.3，处于轻微凉的适中状态，与此对应的人群预测不满意百分比PDD仅为 8%，达到了国际公认的最佳舒适状态；

·夏季被测房间的室温平均在 24℃左右，上下波动约1 ℃，PMV的平均值为-0.42,PDD为9%，被测房间都有着较高的热舒适度；

·室内相对湿度较低，一般在 50%～60%间波动，室内无结露现象；

·室内无吹风感，新风的出口风速小于 0.3米/秒，而且衰减很快，在地板附近形成　均匀层流，沿热源或墙面爬升；

·建筑物夏季实际制冷负荷为 14 W/m^2。

3、关于空气质量的报告：

锋尚是精装修的成品房，室内采用了大量的成品橱柜、固定家具和木地板等，为了让业主在收

房时对室内的空气质量有所了解，我们在 2003 年 3 月份交房前对项目进行了正式的空气质量检测，检测分别按照国家标准《民用建筑工程室内环境污染控制规范》（GB50325-2001）和《室内空气质量标准》（GB/T18883-2002）对抽样房间空气中的氡、甲醛、苯、氨、TVOC 以及温湿度、新风量、二氧化碳、二氧化硫、二氧化氮、一氧化碳、臭氧、甲苯、二甲苯、苯并[a]芘、可吸入颗粒物等指标进行了检测并全部合格，并将正式的检测报告提交给所有的业主。这在北京也是首个对精装修房进行空气质量检测并向业主提交报告的住宅项目。

4、关于噪音的检测报告：

锋尚因为在隔音消音方面进行了诸多设计，因此在业主入住以后对项目的隔音水平进行了测试，下面是测试数据：

·分户墙的计权表观隔声量： 55dB

·楼板（地面铺实木复合地板）的计权标准化撞击声压级： 52dB

·楼板（地面铺地毯）的计权标准化撞击声压级： 28dB

以上 3 项检测结果达到《民用建筑隔声设计规范》GBJ 118—88 中住宅建筑的一级隔声标准。

·带窗外墙的计权隔声量： 41dB

该检测结果达到《民用建筑隔声设计规范》GBJ 118—88 中旅馆建筑的特级隔声标准（住宅部分没有此项指标）。

满足市场需求 发展绿色生态住宅具有光明前景

由以上数据可以看出锋尚实践的结果是真正做到了高舒适度低能耗，而且力争其它资源的消耗水平也不同程度地去减少，在某种程度上可以说就是绿色生态建筑。

锋尚在设计初期也曾在可再生能源的引入方面下了很大精力，如果能够实施将会具有更理想的效果。但是经过考察分析发现，太阳能热电系统因为塔楼屋顶面积有限又有绿化新风设施因而没有条件采用；水源、土壤热泵在当时条件下因场地限制不能满足打井要求而无法有效实施。这也成了锋尚的遗憾，但同时也表明做生态建筑需要因地制宜、需要更成熟的技术及部品集成，否则有可能成为哗众取宠的摆设。

锋尚在建设成本上的投入比传统住宅是大一些，由于新技术及设备的采用而使投入一次性增加了 15%左右（约 800 元/平方米），但在与周边项目（毛坯房，均价 7000 多元/平方米）的竞争中，价格从 9000 多元涨到 14000 元/建筑平方米仍然在半年左右的时间里销售一空。锋尚的实践证明低能耗带来更健康更舒适的居家环境是市场所需要的，它证明了这种建筑具有在中国发展的良好市场前景。

因此，我们国家需要大力发展住宅的科技进步与创新，让住宅不仅是绿色生态的也是健康舒适的，并且客观上需要我们做的比欧美国家更好，这是因为与世界同纬度地区相比，我国大部分地区冬季气温偏低5-18℃，夏季气温偏高2℃，而且冬夏持续时间长。目前北京一年中需要采暖的期限

已接近5个月，需要制冷的期限达到4个月。北京地区采暖期与非采暖期相比，空气中总悬浮物高1.2倍，氮氧化物和一氧化碳高1.7倍，二氧化硫高1.6倍。而且，随着我国经济和社会的快速发展，各类房屋的建设仍将保持较高速度增长，所以只有象锋尚这样才能在有限资源条件下不断满足经济发展、生活水平提高的需要，才会受到市场的欢迎。

另外，从置业投资的角度讲，什么样的房子能够具有良好的经济适应性是越来越多的人所关注的问题，今后房子使用费用的增加将会明显降低置业时的预期收益。因此不仅要看一处地产的位置，还要看其周遍及内部环境状况和未来发展变化情况；不仅要看面积的大小还要看其功能是否齐全；不仅要看置业时投入多少还要看其今后若干年运营费用多少；不仅要强调必须节约各类资源而且还要满足人们生活条件的改善和不断提高的生活标准。

所以，锋尚这样的住宅从经济性、居住的健康性、环保性上具有良好的发展空间，我们也会继续坚持将这种理念的房子盖到全国各地，并且希望更多的开放商和有关科技工作者共同位发展适合中国国情的绿色生态建筑。（完）

表 1　锋尚与国内外建筑围护结构传热系数标准的比较表

国　　别			屋　顶	外　墙	窗　户
中国	北京	按热工规范	1．26	1．7	6．4
		按节能 50%标准	0．8，0．6	1．16，0．82	4．0
		按节能 65%标准	0.6	0.6	2.8
		锋尚设计标准	0．2	0．3	2．0
	哈尔滨	按节能 50%新标准	0．5，0．3	0．52，0．4	2．5
瑞　典	南部地区（含斯德哥尔摩）		0．12	0．17	2．0
加拿大	（度日数相当于北京地区）		0．23，0．31	0．38	2．86
丹　麦			0．2	0．3，0．35	2．9
英　国			0．45	0．45	双玻窗
美　国	（度日数相当于北京地区）		0．19	0．32，0．45	2．04
日本	北海道		0．23	0．42	2．33
	东京都		0．66	0．87	6．51
德 国			0．22	0．5	1．5

注：1、表中传热系数的单位是 w/(m^2·k)。

2、国外数据为该国现行标准规定的限值。

科技与绿色校园建筑

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科技一直以来皆为健康生活带来贡献，在科技城市与建筑方面，同样为环保概念带来新希望。作为一个世界性的城市，香港在引进高科技的绿色建筑絶不逊色,这些年来，可持续建筑在香港的发展一日千里，全赖科学与建筑设计结合之成果；为实践以至拓展更多的可能性，可持续建筑已进一步扩展至校园设计，位于香港大学的仪礼堂新闻系多媒体教学实验中心以及九龙湾之香港大学专业进修附属学院便是其中的表表者。

仪礼堂（Eliot Hall）

仪礼堂为一项利用环保技术来实现生态、文化和经济持续发展的实验性工程。这是香港首次以科技元素注入历史建筑来进行绿色改造，成功把文物建筑更新改造，继而逹至文化可持续性的新尝试。设计以智能技术来满足功能和科技上的新需求，整个计划完整的表现了科技与建筑设计共冶一炉而创造环保建设的最大成效，其中所运用的智能技术包括：被动式日照设计、地板送风空调系统、人工照明调光系统、能耗数据采集和分析、智能建筑控制和室内环境监察等，冲破科学对环境造成破坏的一贯思想,体现了被动能源设计及节能建筑服务系统的成效。科学更为仪礼堂带来高效的建筑材料，功能与耐用性随之而提升，对建筑物的可持续性之帮助不容置疑。

图 1 仪礼堂

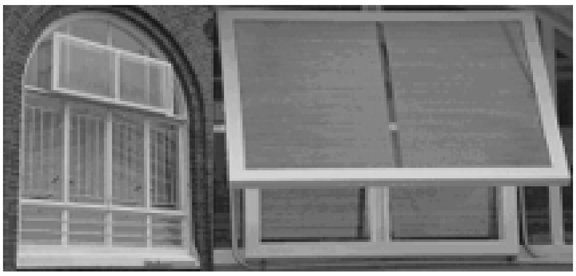

图 2 澳大利亚昆士兰科技大学研究以激光准确切割的透明反光板

日照设计

人工照明在建筑物内占总能耗的 20%到 25%，减却此等能耗对节能将起显著的作用，激光切割透明日光照射板及计算器操控系统便成就了这方面的发展。

与港大合作的澳大利亚昆士兰科技大学的研究者设计了这项简单及低成本的日光引进方法，以激光准确切割透明反光板用以增加自然日照，这面透明矩形丙烯酸反光板于澳大利亚按建筑物之地理位置设计，以激光切割后连接安装在原建筑的窗框上，便可根据太阳的角度来调整窗户的倾斜度以捕捉

最有 x 利的日光，系统内设有六个光照感应器作为监控，操作窗帘的开合，在背对窗户的房间内，屋顶上亦悬挂由哑光白木板作成的反光板以接收和反射日光到内部份房间。

计算器操控系统同样是工程中可持续技术不可缺少的一项。日照设计的节能省源及人工照明装置皆由计算机操控，见证着科技对健康建筑之成果，除照明系统外，仪礼堂内所用之电耗系统包括办公室设备、衡温系统、媒体实验室相邻的图书馆皆受到电力消耗监测，由数字电表和计算器程序来操作，进一步确保所消耗之能量達到最低点。

空调系统

仪礼堂是首个在校园内使用地板送风空调系统的装置，絶对能体现高科技注入校园的成就。由于媒体实验室的需求接近办公室的使用，采用地板送风这套系统便最适合不过了，系统允许多条应用线的调整和简易的服务重置，亦同时避免使用管道和导管,省却大量配置和空间，此外，计算器系统也能被容纳其中，减少建设时间和费用。另一方面，把出风口置于地面的送风系统亦解决了冷凝水的问题。一般系统中，暖气上升到高层空间时，会在高置的冷风出风口附近会产生冷凝水，有机会导致 SBS 病楼综合症，对健康构成影响，如今用科技把送风的位置改良，既能除去天花板的管导空间，亦能改善健康问题，为可持续发展的一大跃进。

图 3 地板送风空调系统

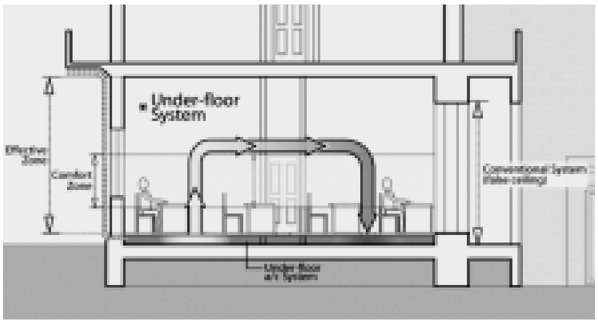

图 4 地板送风空调系统之气流示意图

用户交互式控制

随着计算器技术的进步，建筑服务系统的运行通过过鼠标点击即可，为使各种设备利用简易程度作为监控，仪礼堂正计划以用户交互式控制作为管理设计的概念。计划中地面风机(CAM)将连接着实验室中各计算器的调制解调器，数据通过软件用直接监控， 地面风机的计算器传输，再连接特殊事件如高低湿度警报系统， 并以 e-mail、传真甚至 SMS 信号等形式的输出作为示警，大量提高监控的准确性，并进一步的减低人力资源。

计算器的监控并不止于各类警报系统，照明系统同样可以通过调光器用同样的计算机监控，用户和系统之间的数据可以透过互联网、自动控制和可编程序功能实现远程控制和状态监监控，既省时，又省力。

电力消耗监测

仪礼堂内的用电管理皆计划使用电力消耗监测系统控制，以准确地了解该范围内的实际用电量。这不但提供了有效用电的途径，还为研究者对可持续发展建筑技术和设计提供了数据，作为日后发展及改善的凭证。

系统主要由数字电表和计算器程序操作，通过四种用法监测和显示所有办公室电器、照明系统、通风系统等之电力消耗。在计算器程序的支持下，用户可以实时查询以往，现时及至所有阶段的电力使用量统计图， 以便进行管理，预算，及至进人步的研究省电策略。由此观之，科技令环保建筑的能源效益推到更高峰。

使用后之主观评占

计算器虽能把室内之状态随意调整，然而要提供一个最有利的环境给特定使用者，则先要从他们的主观感受着手。利用一个较有效的科学方法，就是抽取部份使用对舒适之室温与光线作问卷调查，以评占各人的主观反应，再对仪礼堂的室内状态作出调整，力求符合使用者的需求。

在二零零四年六月，九个建筑系学生便被挑选在仪礼堂新闻系多媒体教学实验中心进行廿五分钟之主观感受测试，他们随即亦被安排到邻近图书馆进行相同性质的测试以作比较，需时亦为廿五分钟，然后再对他们作问卷调查。为提高整个测试的可靠性，问卷的内容是参考欧洲对办公室内最有利空气质素及能耗的审计方案而设计，再针对各人对不同温度的地下通风空调系统及自动光暗调节系统的主观感觉，最后把得出的结果转化为统计图进行分析， 以根据这些结果调节最有利的温度及光线，達到舒适及节能的效果。

地点	多媒体教学实验中心	图书馆
平均温度 (°C)	23.0	23.6
平均湿度 (%)	56.7	51.4
平均照明度 (lux)	908	660
开始时间	14:45	15:10
持续时间 (mins)	25	25

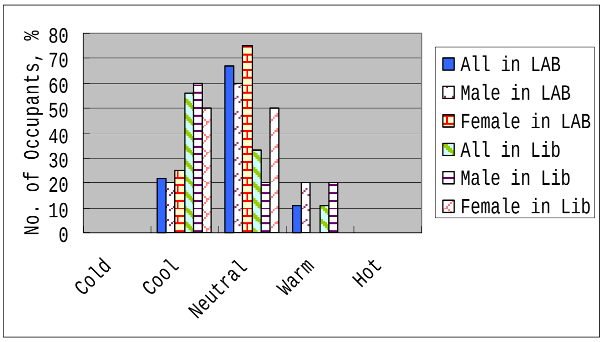

图 5 仪礼堂多媒体教学实验中心 POE 初步调查结果

香港大学专业进修附属学院 (HKU SPACE Community College)

为推广专业设计以及提高教学环境之质素，住于九龙湾的香港大学专业进修附属学院新校舍以科技注入多个设计层面，迈向成为一所可持续建筑的新校园。新建的校舍占地超过 2,000 平方公尺，总楼面面积逾 15,000 平方公尺，楼高 13 层，覆盖率達 85%，位处市区内，邻近大型屋苑， 在设计上与社区融为一体，在建设上则力求融入科学方法以提高环保设计的可行性。

能源效益设计

此项设计中最突出的科技应用为屋顶之太阳能光电板，计划中这些光电板将设于屋顶中庭的住置，收集日光所释放的能量，再进一步使之演变为电能，供应中庭内电灯泡的使用，令建筑物的电耗大大减少。

除此以外，建筑师亦为学院设计了新创制的透明胶板，作为日光反射之用。这些反光板皆准备由多个块状的亚加力胶组成， 连接的手柄可令板内的条块自由转动以调教角度，这样日光便可适当地反射至中庭内，以收最大的天然光线照明，由于各地之太阳反射角度会随着时间和地点而和有差异，反光板的角度亦会因应不同地方而有所变更，那便能同时应用于其它城市，这种新物料的应用乃建筑师的首次尝试，可见科学智能对可持续建筑起了很大的帮助。

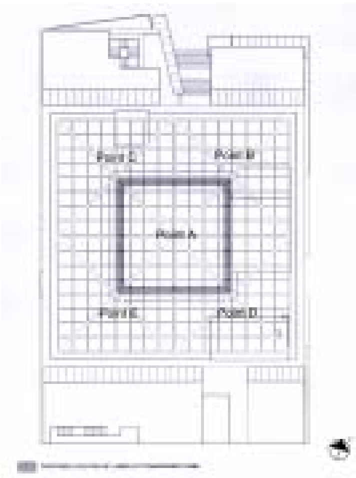

图 6　香港大学专业进修附属学院之屋顶反光板位置平面图

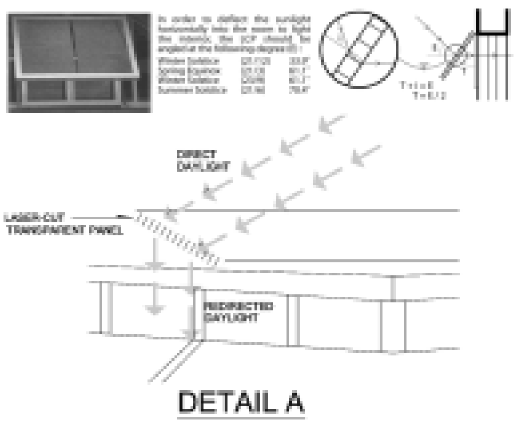

图 7　反光板对自然光反射角度示意图

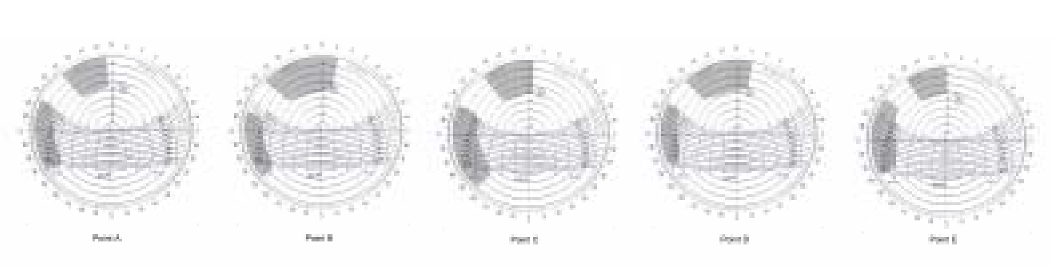

图 8 屋顶不同位置的日光追踪分析

节约能源的设计絶不止于在照明方面的应用，可节省能源的水冷式空调系统也设置于在建筑物内，以减低能耗及使用其间的应用成本。

通风设计

加强建筑物通风效能的最大贡献者莫过于中庭的设计，在剖面的中心点一直贯通十多层的中庭，利用科学中风拔的原理，把自然风由下而上抽出，有助空气流通，让各层皆可達到自然通风的效果，

减低空调的使用量，同时四周被围着的中庭设计可阻挡过量阳光的进入，不至产生温室效应的情况，由此使能降低冷气的使用量。而空中花园的采用，不但有助绿化，同时亦能加强被动式通风。

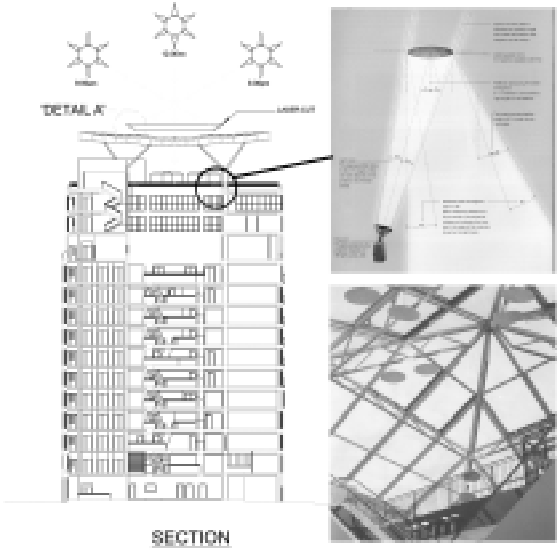

图 9 香港大学专业进修附属学院剖面图及反光灯罩示意图

噪音控制

学院周边所产生的道路噪音高達 85dB，造成学院开放式设计的一大障碍， 若要建为有效的学习环境，按香港环保署有关教育设施的要求，把噪音水平控制至 65dB 或以下，甚至是低于 55dB 是必然的事， 那么附近由行人及车辆所制造的噪音必需得到调整或阻隔，隔声板的应用正好对此起了很大的帮助。

院内之隔声板皆经过精心设计，成为不同角度的反射及吸收噪音设施。为进一步减低成本，建筑师正计划放弃使用传统的三层玻璃，取而代之的是激光切割的亚加力板，这种物料对吸音功效更为显著，亦可令自然光自由进入室外， 对学院的优质学习环境的塑造起了很大的帮助。此外，院内同样运用到可控制噪音的双重玻璃，进一步减低噪音造成的影响。

总结

利用科技以推进绿色建筑，最大的优点在于其效率与可行性。由于欧、美及日本等地的科学发展皆极速进行，这正好成为各项设计概念化为事实的凭据，很多设计再不单单止于理念，而是有机会得到实践。为环保建筑更推上一层依赖科技把效率无限扩大，以往在建设时所欠缺的人力、资源，在现今社会中不再构成障碍，在人力及资源在削减的情况下，低成本、低能耗的建设便能成就发展。

在建设方面，我们亦应注意到可持续建筑并不泛指新兴的建筑物，真正的环保建筑亦可从固有的历史建筑着手。历史建筑之更新，改造，重用是一项大胆的尝试，它把古旧建设重新利用，再把它按现有的需要而更新，这不但能把文化遗产保留下来，亦能符合现今的需要，这类建设对保护环境及文化皆有很大的帮助，设计者应把这种概念多加利用，发展在更多的历史建筑中。

以科学方法推动环保已有一定的成效，但在最新的可持续建筑中，环保概念已不再是只从设计方面作出考虑。由于建筑物的使用对象为特定的使用者，他们在正式利用时是否感觉舒适才是关键所在，因此设计者便开始注意使用者的主观感觉，以有效地把室内情况调整至最舒适及有利的状况。这种方法是把环保概念伸延到建筑物管理层面上，将被动科技环保设计再推上一层，令能源利用達到最佳化。仪礼堂所所实验的主观评占便是一个很好的例子，这将可作为日后环保建筑的参照。

当人们发现环境逐步受到污染及破坏时，大家便开始关心人与自然的关系。人类的每一个动作对自然皆能产生一定程度的所影响，因此在设计每一项建筑时都应考虑周详，对环境作出最大的保护。现今社会中，能源危机及温室效应等问是正逐步受到正视，环保建筑相继涌现，科技为可持续发展带来了无数的新希望，假若能把这些已有的经验交流，再把科学准确而有效地融入其中，更多的绿色建设便能成就发展，为环保创造新的里程碑。

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自然通风技术在生态建筑中的应用研究

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摘　要　以在建的生态建筑示范楼为对象，对自然通风技术在生态建筑中的应用进行了分析。通过数值模拟，计算了在设置排风烟囱时不同的烟囱高度对自然通风的影响以及比较了改烟囱为屋顶大面积排风口后不同的自然通风效果。通过分析得出，与设置专门排风烟囱以加强自然通风的做法相比，采取保证生态建筑足够的排风口面积和开窗面积能够对加强自然通风起到更加明显的效果。

关键字　生态建筑；自然通风；数值模拟

Natural Ventilation Analysis In one Green Building

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Abstract　The natural ventilation technology used in one green building of Shanghai is analyzed. The natural ventilation effect of chimneys of different heights, and big exhaust airway instead of the chimneys is studied by numerical simulation. The conclusion is presented that reinforcing the natural ventilation by designing special chimney is not suitable. It is more effective to reinforce natural ventilation by realizing adequate area of the exhaust airway and windows than designing special chimneys.

Keyword　Green building，natural ventilation

1　引言

上海经过 10 年的高速发展，人均 GDP 已达 4500 美元。人民居住水平亦有了显著的改善。到 2001 年上海人均居住面积已达 12.4 平方米，比十年前增加了 85%，较成功地解决了住房困难问题。随着人民群众对生活质量需求的不断提高，城市建设面临生态转型。上海市政府已规划用 5 个 3 年的时间实现生态城市的建设目标。在此背景下，近年来生态建筑方面的研究逐渐得到了各方面的重视。

近十年来，不少发达国家根据各自的特点，已在生态建筑方面进行了不少的研究和实践，提出了很多建设生态建筑的技术措施。由于采用自然通风不仅可以改善室内空气品质、提高环境舒适性，而且可以缩短空调系统的运行时间，减少空调能耗，所以在已建设成的生态建筑中，人们对自然通风的应用已经做了很多尝试。但是自然通风技术往往也和生态建筑所在地的气候、建筑形状等息息相关。本文将结合上海市建筑科学研究院有限公司在莘庄建设的生态建筑示范楼，对自然通风在该生态建筑中的应用进行分析。

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本课题得到 2003 年上海市科委重大科技攻关项目资助。

2　研究对象和主要问题

本文所分析的在建生态建筑示范楼总建筑面积约 2000 平方米，为一座南面二层半、北面三层的斜屋面建筑，内部主要为办公房间，其中建筑东半部和西半部各有一个中庭。设计之初，参考了国外一些已建成的生态建筑组织自然通风的设计方法，初步方案为在将建的生态建筑的北屋顶设置 5 个排风烟囱（如图 1），希望通过这些烟囱对自然通风起到明显的强化作用。

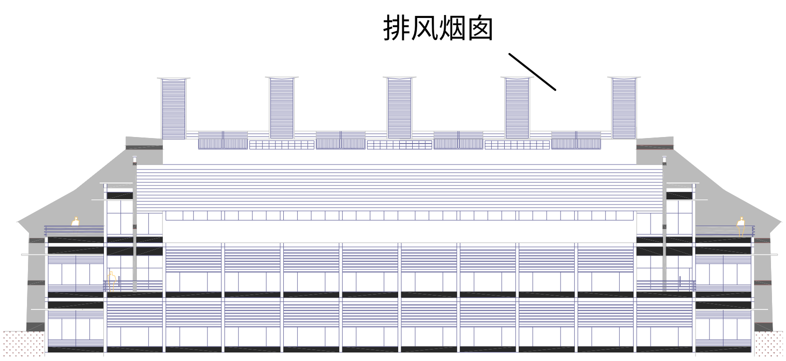

图 1　生态建筑示范楼的初始设计

但是设计之初我们对这些烟囱是否必要；如果必要，需要设计多高；对自然通风能起到多大的强化作用并不清楚；为此，下面本文将主要针对这些问题进行分析。

3　主要分析方法及主要结果

自然通风的推动力有风压和热压，已经通过分析发现，在当地的室外主导风向下，通过风压作用，本生态建筑能达到比较好的自然通风效果。本文主要对热压作用下的自然通风进行考虑。

在下面的分析中，考虑室内温度 30℃（作为自然通风条件下人体维持舒适条件可以接受的最高温度），室外温度 28℃，以室内外 2℃温差时造成的热压作为自然通风的推动力。利用区域模型（zone model）和流体网络理论，分别对两种情况下整个生态楼各房间的自然通风情况进行模拟分析：不同的烟囱高度对自然通风的影响；将烟囱改为大面积的排风口，比较两者的自然通风效果。下面分别介绍相关的计算结果。

3.1　不同烟囱高度对通风的影响

考虑生态建筑外窗有效通风面积 1.7 m^2，内窗有效通风面积 1 m^2，所有内、外窗全开。生态建筑设计 5 个自然通风用的烟囱，每个烟囱的断面尺寸 0.64m^2，生态建筑典型区域在烟囱高度分别设计为 0 米、5 米、10 米时不同的自然通风效果如表 1。

表 1　不同烟囱高度下生态楼典型区域的自然通风效果比较

	0 米烟囱		5 米烟囱		10 米烟囱	
	通风量（m^3/h）	换气次数（次）	通风量（m^3/h）	换气次数（次）	通风量（m^3/h）	换气次数（次）
东中庭	18328	16.6	18809	17.0	19194	17.4
西中庭	8209	10.4	8424	10.6	8596	10.9
演示室	1704	8.6	1742	8.8	1773	9.0
104	1106	9.9	1131	10.1	1152	10.3
203	419	4.0	353	3.4	292	2.8
304	1189	11.1	1164	11	1144	10.6
烟囱排风	13939	/	16360	/	18478	/

从表 1 的计算结果可以看出，和排风烟囱的设计初衷相反，设计 5 个高出屋顶的排风烟囱对强化自然通风的效果并不明显。即使设计 5 个高出屋顶 10 米的烟囱，东、西中庭和一层的演示室、104 等典型房间的自然通风量仅比烟囱高度为 0 米时（即只在屋顶开同样断面积的 5 个排风口）多 5%左右。

这主要是因为屋顶本身高度有近 17 米，设计高出屋顶 10 米的烟囱并不能成倍地增加空气热压，同时流量只近似和热压的 0.5 次方成正比关系，所以即使设计很高的烟囱也并不能对自然通风起明显的强化作用。

最后，表 1 中随着烟囱高度的增加，第二层房间（203）和第三层房间（304）的自然通风效果反而恶化，主要是原来整个建筑自然通风的中和面在第二层房间的窗户以下，随着烟囱高度的增加，中和面上升导致二、三层房间的通风效果反而恶化。

3.2　不同的屋顶排风口面积对自然通风的影响

生态建筑外窗有效通风面积 1.7 m^2，内窗有效通风面积 1 m^2，所有内、外窗全开的条件不变，取消初始设计中高出屋顶的 5 个 0.64m^2 排风烟囱，但增大屋顶的排风口面积，在北屋顶设计一条长 34 米，宽 0.5 米，断面积为 17 平方米的大面积排风口。同样设定室外 28℃，室内 30℃时生态建筑各典型区域的自然通风效果和前面设计 5 个 5 米高的烟囱时相比的结果如表 2。

表 2　将烟囱改为大面积排风口后生态楼典型区域自然通风效果的变化

	5 米烟囱		17 平方米排风口	
	通风量（m^3/h）	换气次数（次）	通风量（m^3/h）	换气次数（次）
东中庭	18809	17.0	23507	22
西中庭	8424	10.6	13594	17
演示室	1742	8.8	2035	10
104	1131	10.1	1326	12
203	353	3.4	519	5
304	1164	11	939	9
屋顶排风	16360	/	42263	/

从表 2 可以看出，在屋顶设计大面积排风口后，生态楼的自然通风效果与原来设计 5 米高的排风烟囱时相比有了非常大的提高。例如东中庭的自然通风量增大了近 25%，而西中庭的自然通风量增大了近 60%。

3.3　主要结果

从上面的分析可以得出如下结论：在强化生态建筑自然通风的效果上，用增大自然通风各通风口有效通风面积的方法要比设计烟囱或者增加烟囱高度等方法好得多。为此，在将建的生态建筑中，对原设计进行了修改，取消了初始设计中的 5 个排风烟囱，而在北面屋顶设计了一个 17 平方米的大面积排风口以强化自然通风。修改后最后的建筑如图 2 所示。

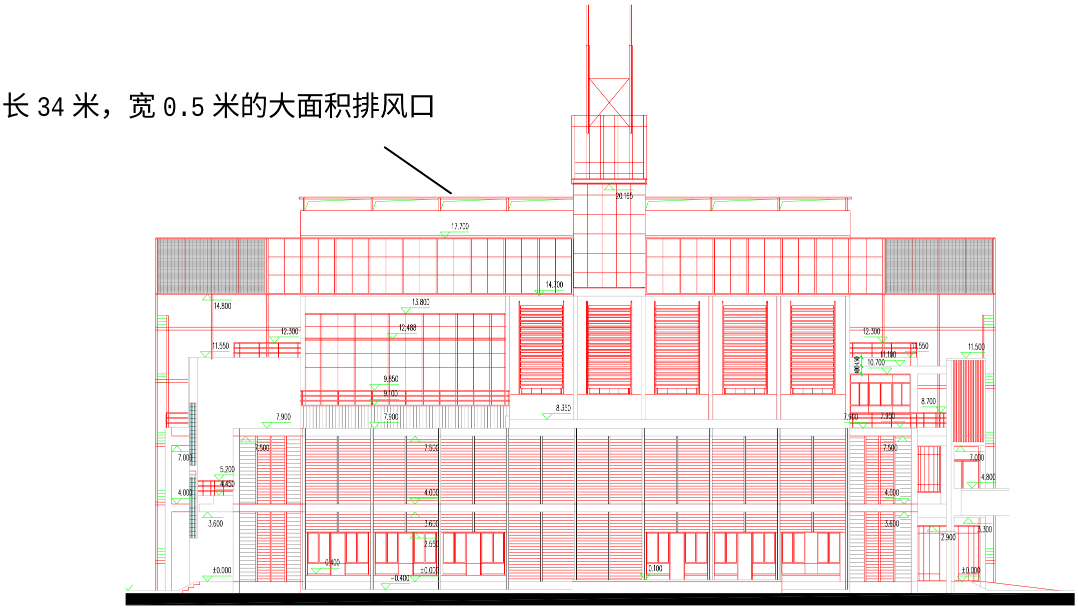

图 2　最终的生态建筑示意图

最后，利用区域模型（zone model）和流体网络理论，同样可以对建筑的内、外窗应该设计多大合适；办公室外窗的开、关将对本建筑最重要的区域东、西中庭的自然通风效果产生多大影响等问题做类似的分析，在此不再做进一步讨论。

4　结论

通过对在建的生态建筑示范楼自然通风效果的分析，得出在生态建筑中照搬国外某些生态建筑的模样，通过设计专门排风烟囱以加强自然通风的做法并不可取，而保证生态建筑自然通风流向上足够的有效通风面积对强化自然通风更加有利。

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Natural ventilation of high-rise residential buildings Plan

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Abstract Nowadays in big cities with high building density, more and more high-rise building are being built. It is important to take the interference effect among adjance buildings on pressure coefficient (Cp) distribution on the building envelope into account when natural ventilation is available in a building design. In this paper, pressure coefficient difference (Cp′) is studied by numerical simulation to understand the interference effect of natural ventilation of high-rise residential buildings.The results show that natural ventilation of downstream buildings is influenced by upstream buildings significiently, especially for normal wind direction and small space between buildings. Increasing wind angle of incidence, enlarge the space between buildings and lower the hight of upstream building would improve natural ventilation of downstream buildings obviously. Also, natural ventilation of downstream buildings is better when the buildings are in rang with others than that when the buildings are staggered.

Keyword interference effect, pressure coefficient difference,Natural ventilation

摘 要 目前，越来越多的高层建筑正在建筑密度高的大型城市中兴建。当在建筑进行自然通风设计时，考虑建筑围护结构上的压力系数分布在相临建筑之间的干涉效应是很重要的。本文将利用数值模拟的方法压力系数差，从而了解高层住宅建筑群自然通风的干涉效应。模拟结果表明，下风处建筑的自然通风受到上风处建筑的显著影响，尤其对于垂直风向、间距较小的建筑群来说，更是如此。提高风的入口角、增大建筑间的距离。另外，建筑群排列方式为顺排时下风处自然通风的效果好于建筑叉排方式。

关键词 涉效应；压力系数差；自然通风

1 Introduction

Recent investigation shows the population increase and concentration mainly occurs in the megalopolises of Asia. China has a population of 1.25 billion at present and remains the most populous nation in the world. Population increase lead to concentration of residential buildings.

With the development of economic and urbanization in the past two decades, high-rise residential buildings appear rapidly in china. The percentage of building energy consumption to total energy consumption is becoming much higher than before [1]. In 1999, building energy consumption took 27.6% of total commercial energy consumption in the whole country, which including energy consumption for air conditioning, heating, lighting, cooking and domestic hot water etc., and air conditioning and heating are the main parts. Investigation shows that the possession rate of household with air conditioner in south

China is increasing at the speed of 20% every year. The target for energy-efficient building in China is to reduce the energy consumption of A/C and heating while keeping comfortable indoor thermal environment.

As known, natural ventilation has the potential to become an efficient way to ventilate building and provide a comfortable and healthy indoor environment as well as save energy. Natural ventilation can be used not only for cooling in spring and autumn but for removing indoor air pollutants. However, it is very complicated when natural ventilation is involved even in a simple design, because it is influenced by many factors. Air flow from one opening to another is caused by pressure difference built up by wind. The higher the pressure coefficient difference ($Cp'=Cp_{Max} - Cp_{Min}$) is, the higher the flow rate will be. Accordingly, a detailed study on airflow around building and pressure distribution on building envelope is a must for well-ventilated building design. However, the determination of the external pressure caused by wind and buoyancy effect, especially by wind in hot climate, is very complex, since the pressure distribution depends on incoming wind speed and direction, building size and shape, the size and location of building interior openings and so on [2]. Buildings are rarely isolated from others, especially in high urban density cities like Hong Kong, so it is also important to account for the effect of upstream obstructions, which can considerably affect the pressure coefficient distribution on the external of buildings available for natural ventilation. Therefore, the accuracy of natural ventilation design depends on the accuracy of the pressure distribution information.

Although many of the developed countries have successful experience in natural ventilation research, design and operation, it is not practical for China to simply copy their experience. Natural ventilation of buildings in developed countries is usually involved with low building density and low-rise style. And the climate in those countries is probably different from that in China.

In natural ventilation field, experiment in wind tunnle is a traditional way to simulate and measure the airflow around buildings to determine natural ventilation. Although the experimental approaches provide reliable information concerning airflow in and around buildings, the available data is generally limited due to the expensive and time consuming experiment. Nowadays numerical simulation has become a new trend for determining natural ventilation. The present study shows, with the help of CWE (Computational Wind Engineering- a branch of CFD) technique, the external pressure distribution can be worked out with reasonable precision [3]. Hereby, in this paper, CWE method is used to study the wind pressure coefficient (Cp) on the building envelope to determine the effect of adjacent buildings.

2 Numerical Simulation

Since the wind distribution around buildings is very complex, the influence of adjacent buildings can’t be ignored. Therefore, the computational area for outdoor airflow should be large enough to study the impact of surrounding buildings. If the simulation area is modeled after an actual small-scale buildings area, it has to include a large area with an enormous number of calculation points, which makes the actual calculation very difficult. However, small-scale buildings areas often have a similar style, which consists of rectangular buildings separated by straight paths. If they are extremely simplified, they become areas with regularly aligned square buildings of constant size. This simplified small-scale buildings model can easily be numerically simulated. For it can reduce the space for simulation, computer memories and calculation time. In this paper, the small-scale buildings are expressed by nine and eight regular aligning buildings respectively.

For simplicity, this investigation used Fluent to calculate the pressure coefficient difference distributing on the envelope of the buildings. Ideally, the calculation should be performed for different wind directions under constant wind speed. In order to correctly take the impact of the surrounding buildings into account, different space between buildings and various height are investigated. Some CFD models can be established, one of them(model 1) as shown in Figure 1.

Recent literature shows that there are numerous turbulence models ranging from simple algebraic models to highly sophisticated models like Reynolds-stress transport models (RSTM). Among them, the original k-e model (standard k-e model) proposed by Launder and Spalding almost three decades ago [4] and large-eddy simulation (LES) are receiving continuous attention in wind engineering. Standard k-e model seems to be still the most widely used in the building aerodynamics community for their simplicity, robustness a d reasonable accuracy [5]. While, LES model can provide the accurate flow description. However, it also appears that LES is of limited application, due to the prohibitive computing costs and time consume. In this project, what we want to know is the information on time-average pressure coefficient, so standard k-e model is used to simulate the flow field around the small-scale buildings.

3 Results and discussion

The numerical simulation results indicate that the Cp′ of buildings is affected by wind direction, space between buildings and height of upstream buildings greatly.

3.1 Wind direction

Fig.2 shows the simulated wind directions related to model 1, and Fig.3 shows the Cp′ of the nine buildings for various wind direction. From Fig.3 we can see the Cp′ of downstream buildings is influenced by upstream obstructions deeply. When θ equals 0º (normal wind direction), the Cp′ of upstream buildings is obviously higher than that of downstream buildings. For example, the Cp_{b5}' of 0.166305 is only 5.76 percent of Cp_{b1}' which is equal to 2.88476. In this case, natural ventilation for most buildings is unacceptable except for upstream buildings.

When θ equals 30º or 45º, the Cp′ of upstream buildings is a little lower than that of 0º, but the Cp′ of downstream buildings increase obviously. The average Cp′ of downstream buildings with a θ of 30º is almost eight times higher than that of 0º. That is to say, the average Cp′ of buildings for angled wind (θ=30º or 45º) is higher than that for a normal wind direction.

3.2 Space between buildings

The above-mentioned simulation shows that the Cp′ of all buildings with normal wind direction for model 1 is lower than that of the other two angled wind. And then the space between buildings is adjusted to improve the natural ventilation of all buildings for normal wind direction. In this study, the physics models with 9 buildings (model 1, Fig.2) and 8 buildings (model 2, Fig.4) are involved. The space between buildings (L) is set to be 0.5, 1, 2, 3, 4, 8 and 12 times of building width (B) respectively, which is representative in reality.

Figure 5 shows a small Cp′ increase of downstream buildings for model 1 when L increases from 0.5B to 2B. But in the case of L equal to 3B, the Cp′ of downstream buildings increase obviously. For example, $Cp_{L=3B}'$ is equal to 4.7 times of $Cp_{L=0.5B}'$ for b7 and $Cp_{L=3B}'$ is equal to 3.9 times of $Cp_{L=0.5B}'$ for b8. As expected, the effect of L on the Cp′ of upstream buildings can be negligible. The reason is that downstream buildings are in the wind wake of the upstream buildings with a small L, and the effect of upstream obstruction will become weaker in the case of large L. Fig.6 shows an obvious Cp′ increase of downstream buildings as L increases from 0.5B to 2B for model 2. That is to say, building distribution in model 2 is better than that in model 1 for natural ventilation utilization. The flow field of model 2 is shown in Figure 9.

3.3 Building height

We notice that natural ventilation of downstream buildings is poor with small L. But sometimes in practice there is no enough area for arranging buildings with large space. In this part, we try to study the effect of building height on natural ventilation of downstream buildings with small building space. The models with 9 and 8 buildings in the same height (model 1 in Fig.2 and model 2 in Fig.4) and the models with 9 and 8 different height buildings (model 3 and 4, Fig.7) are established. In the simulation, L of 2B is involved.

Fig.8 shows the Cp′ of downstream buildings for model 3. There is a great Cp difference along the vertical surface of downstream buildings. And when the upstream buildings height is lowered, the Cp′ of downstream buildings increases significantly in comparison with model 1. Similarly, the Cp′ of downstream buildings in model 4 is higher than that in model 2(see Fig.9). The Cp′ increase of downstream buildings in model 3 is much more than that in model 4. That is to say, the effect of lowering upstream buildings height in model 3 is greater than that in model 4.

4 Conclusions

Form the study, it is obviously that natural ventilation of downstream buildings is influenced by upstream buildings greatly, especially for normal wind direction and small space between buildings. Increasing space between buildings and lower upstream obstructions height would improve natural ventilation of downstream buildings. Also, natural ventilation of downstream buildings is better when the buildings are in rang with others than that when the buildings are staggered.

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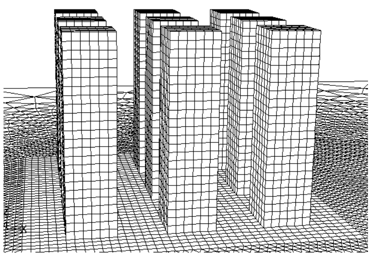
ILLUSTRATIONS



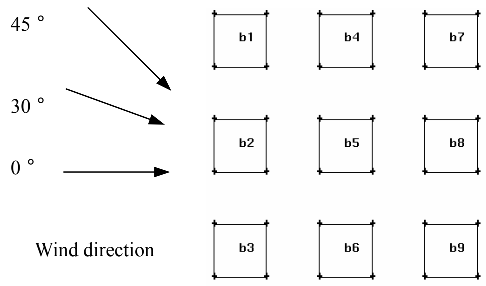
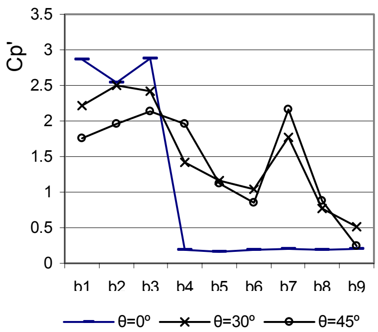


Fig.1 Physics model 1

Fig.2 Different wind direction for model 1



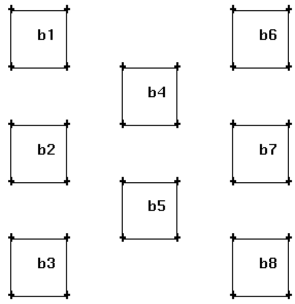
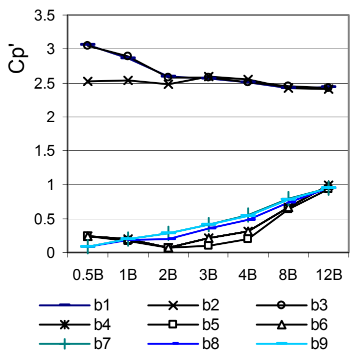


Fig.3 Cp′ of buildings under various wind direction

Fig.4 Physics model 2



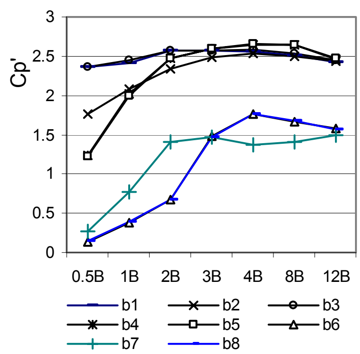


Fig.5 Cp′ of buildings with various L of model 1

Fig.6 Cp′ of buildings under various L of model 2

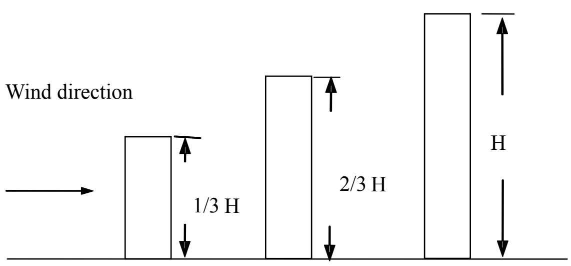


Fig.7 the model with different height buildings

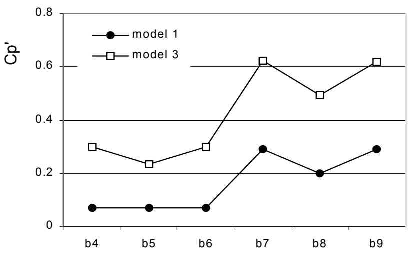


Fig.8 Cp′ of downstream buildings in model 1 and model 3 (h=1/2H)

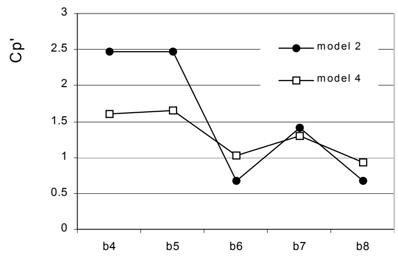


Fig.9 Cp′ of downstream buildings in model 2 and model 4(h=1/2H)

A Study of Subtropical Louver Designs to Optimize Daylight Usage

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Abstract In lack of natural resources, Taiwan has to import 97% of the required energy. Buildings take up 31% of the total electricity consumption, in which artificial lighting accounts for around 1/3 of the electricity. The effective reduction of artificial lighting is to maximize the usage of day-light, which may cut-off 50% of the lighting electricity. The study seeks to maximize the usage of daylight through the light-reflecting function of louvers. The focus is to examine the optimum tilt angle and the depth of the blades in the upper part of a louver. Through RADIANCE simulations, this study evaluates the impacts from different tilt angles and depth of louver blades on the average illuminance, daylight factor, and uniformity of illuminance for different seasons. It has been found that the 0 degree tilt angle achieves the highest average illuminance during summer and the 30 degree is good for the other seasons. It has also been observed that the 45mm blade depth has better total performance for subtropical region, on illuminance, daylight factor, and uniformity of illuminance.

Key words energy saving, daylighting, redirection

In Taiwan building takes up 31% of total electricity consumption, in which artificial lighting accounts for about 1/3 of the electricity usage. For energy saving, the effective way is to maximize the usage of day-light and it can reduce the electricity consumption of lighting by 50%. This study is part of a series of research works on the development of a new window type, which integrates redirection of day-light, shading, anti-glare, and ventilation. The focus of this study is on the design of the louver at the upper part of window, which is able to re-direct day-light. The goal is to investigate the dimension and the tilted angle of the blade for an optimum day-light application.

This study evaluated the impacts from different dimensions and tilted angles on average indoor illumination, day-light factor, and uniformity for four seasons, through RADIANCE simulations. The considered depth of the blade is 90 mm, 45 mm, and 15 mm. The tilted angles are 0^{o}, 30^{o}, and 45^{o}. Four typical days, 3/21, 6/21, 9/23, and 12/22 are chosen to represent each season and 9:00, 12:00, and 15:00 are three monitored time spots for each day.

It has been found that the blade depth of 45 mm has better performance on high illumination, day-light factor, and uniformity. It has also been observed that the tilted angle of 30^{o} is good at equinox for better day-light re-direction, and 0 is chosen at summer solstice for better shading.

INTRODUCTION

In lack of natural resources, Taiwan has to import 97% of the required energy. Based on the Energy

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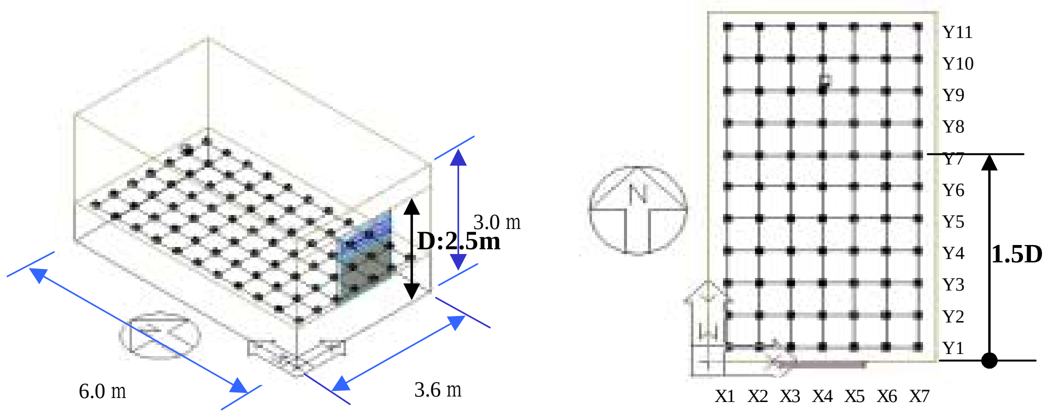
Conference of Taiwan in 1988, it concluded that to promote energy conservation and to increase energy efficiency are major goals to fulfill and the target for energy saving is to reach 4,187x10^4 KLOE till 2020. To reach the target, sectors of industry, transportation, residence/office, and power are assigned to take 31.6%, 16.4%, 19.9%, and 14.9% of the total saving, respectively. For the sector of residence/office, there are four approaches to reach the quota. They are (1) to raise the efficiencies of appliances/equipments; (2) to establish indices of energy consumption for building enclosure; (3) to set-up monitoring methods for building energy assessment; (4) to enforce total building energy consumption allowance. Among the four approaches, the third one is a supporting task, for which no saving quota is assigned. The rest approaches are assigned respectively to 40.3%, 16.1%, and 43.6% of the saving allocated to the residence/office sector.

According to Taiwan Power Company, the electricity consumption of the residence/office sector has been increasing steadily since ’70’s and reached 31% of the entire electricity consumption in 2000, in which artificial lighting accounts for about 1/3 of the electricity usage. The effective reduction of artificial lighting is to maximize the usage of day-light, which may cut-off 50% of the lighting electricity. This study is part of a series of research works on the development of a new window type, which integrates the functions of light re-direction, shading, anti-glare, and ventilation. The study seeks to maximize the usage of daylight through the light-reflecting function of louvers. The focus is to examine the optimum tilt angle and the depth of the blades in the upper part of a louver.

METHODS

This study evaluates the impacts from different tilt angles and depth of louver blades on the average illumination, daylight factor, and uniformity of illuminance for different seasons through RADIANCE simulations. The simulation set-up, examined parameters, and assessment methods are illustrated as follows.



(a) (b)

Figure 1 Space for simulation

Table 1 Optical properties of materials for simulations

	color and material	surface reflectance	light transmittance
ceiling	beige paint	0.71	0
upper part of interior wall, 0.9 3.0m in height	beige paint	0.71	0
lower part of interior wall, 0.0 0.9m in height	wood	0.317	0
floor	brownish-yellow paint	0.337	0
window glazing	clear Low-e	0.056	0.795
window frame	anode aluminum	0.79	0
upper blade for light redirection	polished aluminum	0.85	0
lower blade for shading	light-colored aluminum	0.7	0

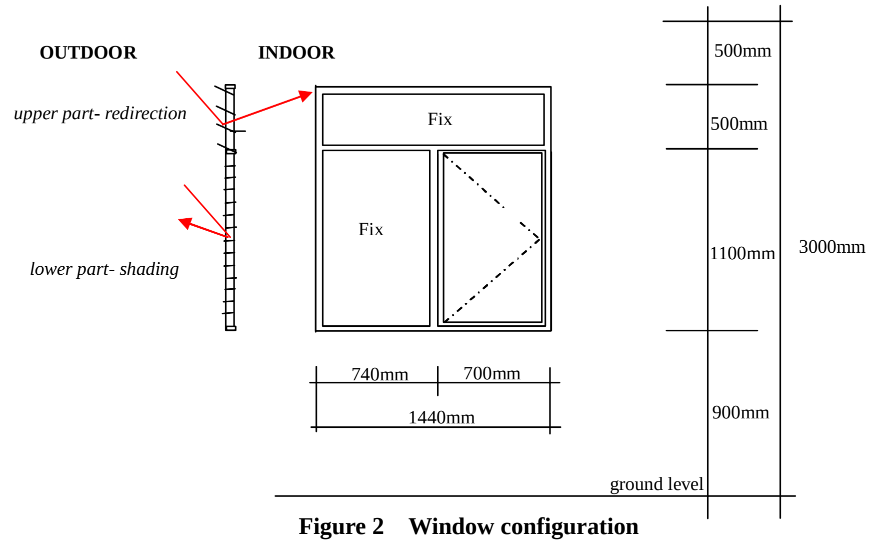


Figure 2 Window configuration

Simulation set-up

This study selects a rectangle space with one south-facing window, shown in Figure 1, for carrying out simulations. The window contains two parts, the upper part with the height of 0.5m for the function of light redirection and the lower part of 1.1m for shading (Figure 1(a) and Figure 2). The configuration of the window and the louver blades at the upper and lower level are shown in Figure 2.

This study considers three different blade depths of 15mm, 45mm, and 90mm for the upper level louver and one blade depth 15mm for the lower level. The simulation plane is selected at 0.8m as the height of desk-top. The plane and the mesh system are shown in Figure 1. The material, surface reflectance, and light transmittance for the interior surfaces and window are listed in Table 1.

Taipei, situating at 25 degree north and 121 degree east, is taken as the climate for simulations. According to the classification of IES (Illuminating Engineering Society), this study considers two weather conditions of clear and overcast. The simulation takes four typical days representing the four seasons, which are 3/21 as spring (SP), 6/21as summer (SM), 9/23 as fall (FA), and 12/22 as winter (WT). For each day three time spots are chosen, which are 9:00, 12:00, and 15:00. The tilt angles of the upper blades are 0, 30, and 45 degree while the lower blades are remained horizontal- 0 degree.

Assessment methods

This study takes illuminance, daylight factor, and uniformity of illuminance as three indices to assess the performance of the tilt angles of louver blade. According to the study of LBNL (Lawrence Berkeley National Laboratory, 1997), the practical depth of a day-lighted zone is typically limited to 1.5 times the window head height. With a reflective light shelf, this zone may be extended up to 2.5 times the head height. For a deeper penetration of daylight, this study thus takes the inner part of the simulated space, beyond the 1.5 times head height, at the height of 0.8m for the evaluation (Figure 1) through calculating the average illuminance. A higher value of an average illuminance denotes better performance.

The daylight factor (DF), expressed in Equation (1), is defined as the ratio between the illuminance measured indoor at a reference point and outdoor global illuminance on an unobstructed, horizontal surface. In Equation (1), E denotes indoor illuminance and E_s outdoor reference illuminance. This study takes the plane at 0.8m above the floor of the simulated space (Figure 1) for the evaluation by calculating the average daylight factor. A higher value of an average daylight factor denotes better performance.

$$DF = (E/Es)*100\% \qquad (1)$$

A poor illuminance distribution causes visual discomfort. The uniformity of illuminance is expressed as the distribution level of light spreading over a space (Lawrence Berkeley National Laboratory, 2001). Since sun is a variable light source, the uniformity of illuminance due to sun light is calculated based on the statistical approach of standard deviation and mean-value (Lin, 1998). The average uniformity of illuminance is expressed as Equation (2), in which Stdevp denotes the standard deviation and E_m as mean-value. The standard deviation is shown as Equation (3), in which N is the sample and x is the corresponding illuminance of the sample. This study takes the plane at 0.8m above the floor of the simulated space (Figure 1) for the evaluation by calculating the average uniformity of illuminance. A lower value of the average uniformity of illuminance denotes better performance.

$$AU = Stdevp/E_m \qquad (2)$$

$$Stdevp = ((N\Sigma x^2-(\Sigma x)^2)/N^2)^{0.5} \qquad (3)$$

RESULTS AND DISCUSSION

This study takes the illuminance index as the first priority to be investigated. The point is that daylight is expected to penetrate deeper into a space as possible.

Illuminance assessment

This paragraph investigates for each season the optimum tilt angle and blade depth to achieve the highest average illuminance. Figure 3 illustrates the impacts of various tilt angles (0, 30, and 45 degree) and blade depths (90, 45, and 15mm) on the average illuminance during morning and afternoon for four seasons. It has been found that 30 degree tilt angle for all three blade depths achieve the highest average illuminance value during spring, fall, and winter. For summer the preferred tilt angle is 0 degree.

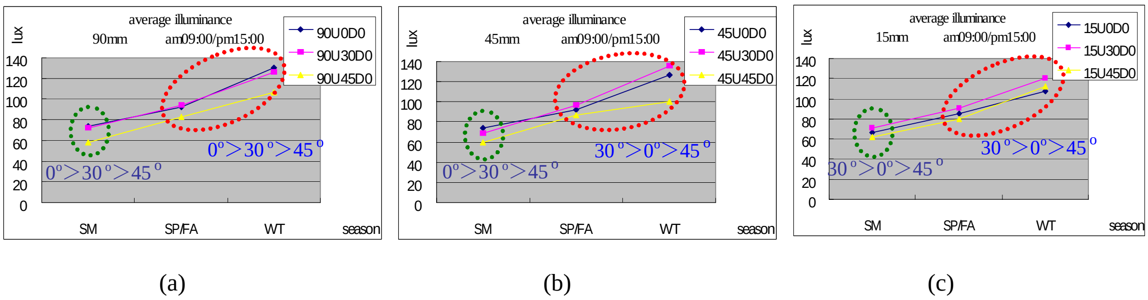


Figure 3 Impacts of various tilt angles and different blade depths of (a) 90mm; (b) 45mm; (c) 15mm on average illuminance during morning/afternoon for four seasons

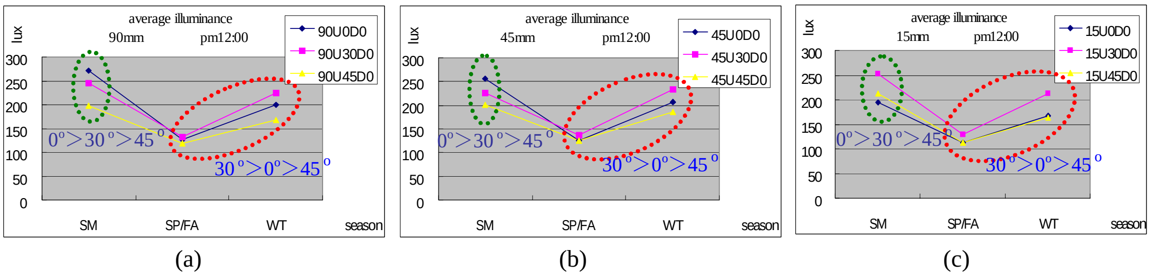


Figure 4 Impacts of various tilt angles and different blade depths of (a) 90mm; (b) 45mm; (c) 15mm on average illuminance during noon time for four seasons

Figure 4 illustrates the impacts of various tilt angles (0, 30, and 45 degree) and blade depths (90, 45, and 15mm) on the average illuminance during noon time for four seasons. It has been found that 30 degree tilt angle for all three blade depths achieve the highest average illuminance value during spring, fall, and winter. For summer the preferred tilt angle is 0 degree. From Figures 3 and 4 one can conclude that 0 degree tilt angle is good for summer and 30 degree is optimum for the other seasons.

Figure 5 illustrates the impacts of various blade depths with 0 degree tilt angle on the average illuminance during different times of a day for four seasons. It has been observed that both 90mm and 45mm blade depths achieve higher average illuminance values for all four seasons. Figure 6 illustrates the impacts of various blade depths with 30 degree tilt angle on the average illuminance during different times of a day for four seasons. One can observe that both 90mm and 45mm blade depths achieve higher average illuminance values for all four seasons.

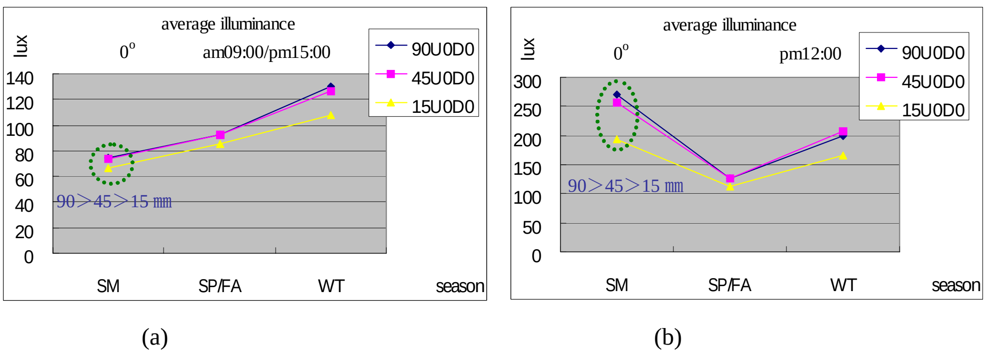


Figure 5 Impacts of various blade depths with 0 degree tilt angle on average illuminance during (a) morning/afternoon; (b) noon time for four seasons

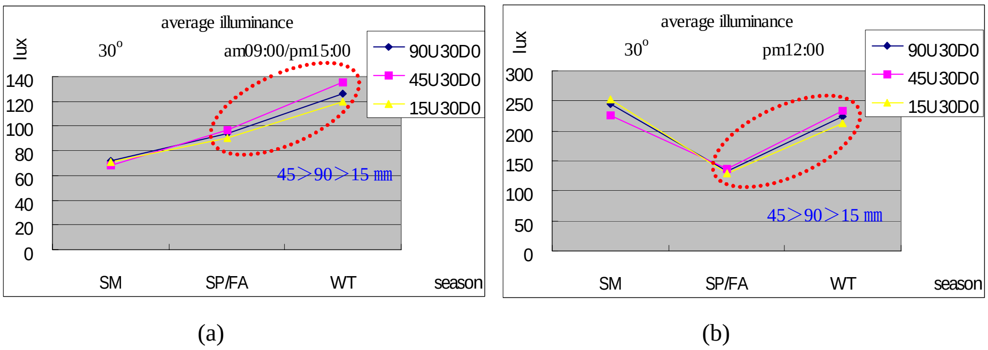


Figure 6 Impacts of various blade depths with 30 degree tilt angle on average illuminance during (a) morning/afternoon; (b) noon time for four seasons

Daylight factor assessment

This paragraph explores the optimum blade depth for tilt angles of 0 and 30 degrees to achieve the highest daylight factor under overcast weather condition for different seasons. Figure 7 illustrates the impacts of various blade depths with 0 degree tilt angle on the average daylight factor during different times of a day for four seasons. It has been found that both 45mm and 15mm blade depths achieve higher average daylight factor values for all four seasons. Figure 8 illustrates the impacts of various blade depths with 30 degree tilt angle on the average daylight factor during different times of a day for four seasons. It has been found that both 45mm and 15mm blade depths achieve higher average daylight factor values for all four seasons.

Uniformity of illuminance assessment

This paragraph examines the optimum blade depth for tilt angles of 0 and 30 degrees to achieve the highest uniformity of illuminance under overcast weather condition for different seasons. Figure 9 illustrates the impacts of various blade depths with 0 degree tilt angle on the average uniformity of illuminance during different times of a day for four seasons. It has been found that 45mm blade depth with 0 degree tilt angle achieves the best performance by obtaining the lowest uniformity of illuminance value for all four seasons. Figure 10 illustrates the impacts of various blade depths with 30 degree tilt angle on the average uniformity of illuminance during different times of a day for four seasons. It has been found that 15mm blade depth with 30 degree tilt angle achieves the lowest uniformity of illuminance value for all four seasons.

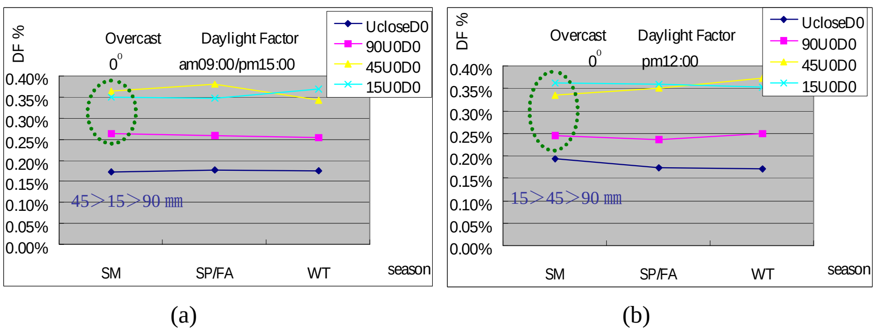
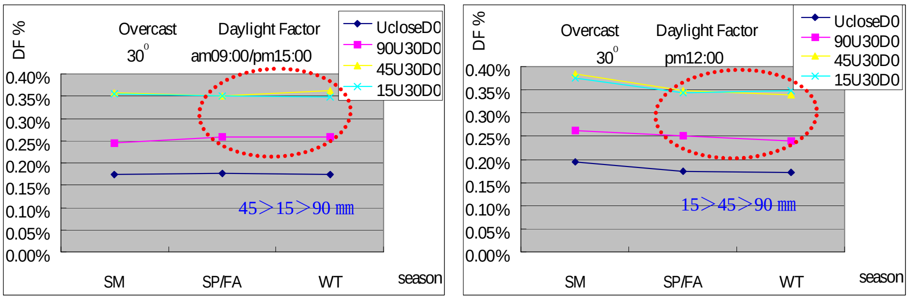
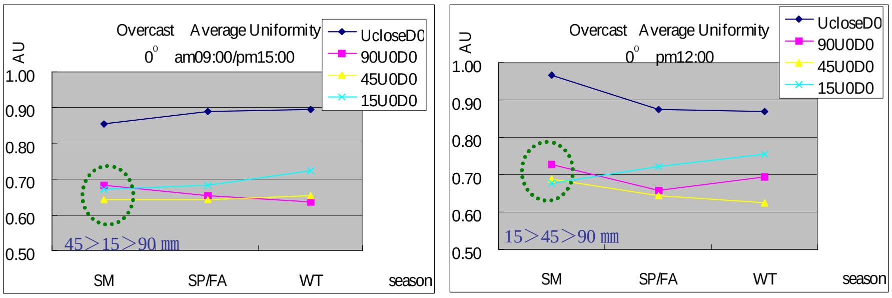


Figure 7 Impacts of various blade depths with 0 degree tilt angle on average daylight factor during (a) morning/afternoon; (b) noon time for four seasons under overcast condition



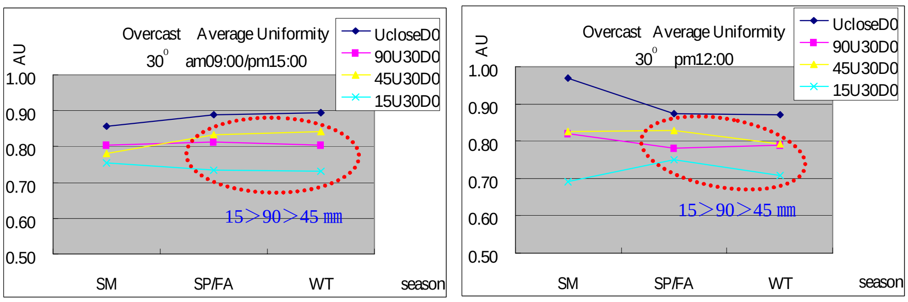
(a) (b)

Figure 8 Impacts of various blade depths with 30 degree tilt angle on average daylight factor during (a) morning/afternoon; (b) noon time for four seasons under overcast condition



(a) (b)

Figure 9 Impacts of various blade depths with 0 degree tilt angle on average uniformity during (a) morning/afternoon; (b) noon time for four seasons under overcast condition



(a) (b)

Figure 10. Impacts of various blade depths with 30 degree tilt angle on average uniformity during (a) morning/afternoon; (b) noon time for four seasons under overcast condition

CONCLUSION

This study is part of a series of research works on the development of a new window type, which integrates the functions of light re-direction, shading, anti-glare, and ventilation. The study seeks to maximize the usage of daylight through the light-reflecting function of louvers. The focus is to examine the optimum tilt angle and the depth of the blades in the upper part of a louver. Through RADIANCE simulations, this study evaluates the impacts from different tilt angles and depths of louver blades on the average illuminance, daylight factor, and uniformity of illuminance for four seasons.

This study takes the illuminance index as the first priority to be investigated. The point is that daylight is expected to penetrate deeper into a space as possible. It has been found that 0 degree tilt angle achieves the highest average illuminance during summer and 30 degree has the best performance for the other seasons. For either 0 or 30 degree tilt angle, both of the 90mm and 45mm blade depths achieve higher average illuminance values for all four seasons. For the daylight factor, both 45mm and 15mm blade depths obtain higher values for all four seasons for either 0 or 30 degree tilt angle. For the uniformity of illuminance, it has been found that 45mm blade depth with 0 degree tilt angle achieves the highest uniformity of illuminance and 15mm blade depth together with 30 degree tilt angle acquires the highest uniformity. To summarize the performance, the 45mm blade depth is selected for better total performance on illuminance, daylight factor, and uniformity of illuminance.

ACKNOWLEDGEMENTS

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亚热带地区百叶帘采光效果优化设计研究

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在台湾，总体电能消耗的 31%是由建筑运行引起的，其中近 1/3 是人工照明用电。因此，节能的有效途径之一就是对自然光的优化利用，这可以减少 50%的照明耗电量。为此我们对一种新型的窗户开展了系列的设计研究工作，这种窗户综合考虑了导光、遮阳、防眩光及通风等诸多因素，本文汇报的正是该项研究工作的一部分。研究的重点在于窗户上部百叶帘的设计；目标是发现能够最优化自然采光效果的叶片方向和倾角。

通过日照模拟软件 RADIANCE 的分析对比，我们研究了百叶帘叶片不同的方向和倾角对室内平均照度，采光系数及其季节一致性所产生的影响。百叶帘的叶片宽度分别假定为 90 mm, 45 mm, 及 15 mm，并选择春分(3/21)、夏至(6/21)、秋分(9/23)、冬至(12/22)作为春、夏、秋、冬四个季节的典型日，模拟计算时间分别为 9:00，12:00 和 15:00。

研究发现，百叶帘的叶片宽度为 45 mm 时能获得更高的平均照度、采光系数和季节一致性；30 度倾角在春、秋分可以获得更好的导光效果；而夏至日选择 0 度的倾角遮阳效果更好。

Desktop radiance 在上海生态办公样板房采光设计中的应用

齐志宇 （上海市建筑科学研究院）

摘 要 本文介绍了 Desktop radiance 模拟软件（以下简称 DeskRad）在上海生态办公样板房中的应用，展示了一个光环境模拟软件用于优化建筑采光设计的实例。在项目建筑设计中，设计师希望确定合理的天窗面积。通过模拟不同天气条件下、开不同面积天窗的大厅的照度分布，确定了天窗的大小。

关键词 Desktop radiance；模拟；天窗；采光设计

Application of Desktop radiance in lighting design of Shanghai Eco office building project

Abstract As a case of lighting simulation software for lighting design optimization, this paper applies the Desktop Radiance (DeskRad) in Shanghai Eco office building project. During design phase, the architect needs to set a right louver size to optimize the project. In order to fulfill the task, comparative study of the illumination distribution in ground floor lobby with different louver window sizes in CIE overcast sky and CIE clear sky was performed, and the answer is achieved.

Keyword Desktop radiance, Simulation, Louver, Lighting design

从 1991 年起,各国正在开展绿色照明,它旨在提倡使用高效节能照明产品,鼓励采用节能照明设计和技术,提高照明质量,保护环境。人们在天然光条件下,不但视觉功效比人工光高,而且还会使人们感到舒适和有益于身心健康,同时能起到节约电能、保护环境、有利于人类社会健康发展的作用,所以如何进行合理地天然采光是绿色照明的一项重要内容。[1]

1 项目介绍

2003 年启动的上海生态办公样板房项目为上海市科委立项课题，旨在利用多种生态技术，建造全新的生态理念办公楼。作为生态环境主要评价指标之一的光环境，也受到相当程度的关注。设计师最初提出的方案中在办公楼东面屋顶开了多个天窗，如图 1 所示平面图和剖面图，但不清楚天窗具体可以给照明带来多少益处，以及多大面积的天窗可满足照明要求，同时兼顾节能要求。模拟软件提供了一种解决问题的方法。

2 软件介绍

随着计算机图形学和光环境模拟软件的不断发展，光环境模拟软件的模拟精度逐步提高，因此实用性也在不断提高。现存多种模拟软件，由美国 LBNL 开发的 Radiance 基于 Radiosity 物理模型，在模拟准确性上是其中的佼佼者，但 Radiance 运行于 Unix 或者 Linux 系统。我们所采用的 DeskRad 是 Radiance 的 Windows 版本，算法原理和 Radiance 一致，但界面建立在 AutoCAD R14 或者 2000 上，建模更为方便。[2]

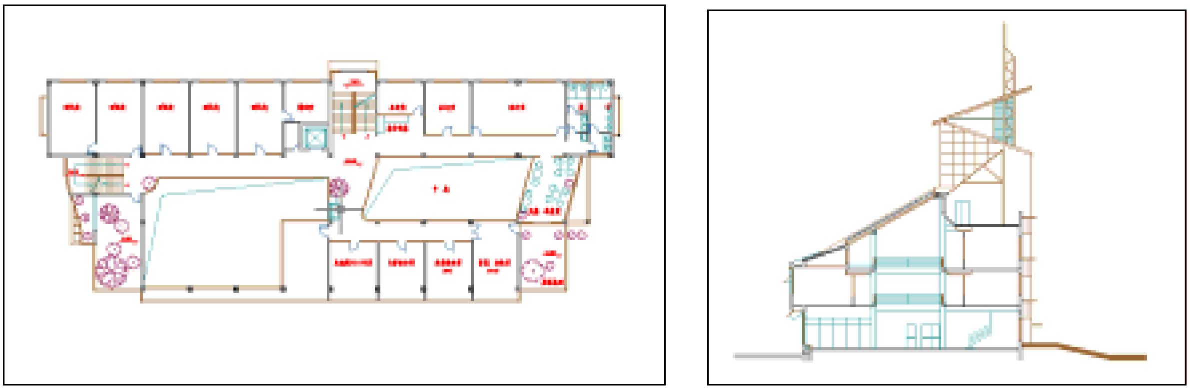


图 1　生态办公楼的平面图和剖面图

DeskRad 的准确性见于报导，对于一般多层建筑的实测和模拟对比显示，DeskRad 模拟软件的误差在 30%以内，部分情况下优于 15%。[34]

3　模拟流程

首先按照设计方提供的工程图纸，在 AutoCAD 中建立三维模型。灵活运用图层可以提高建模效率。也可以采用其他软件建模，完成之后导入 DeskRad 进行模拟。对于基本不影响结果的部分，可在建模中忽略。本文采用了 SketchUp 3.1 软件进行辅助建模，并在模型中忽略了对整个办公楼内照明影响比较小的屋顶部分。

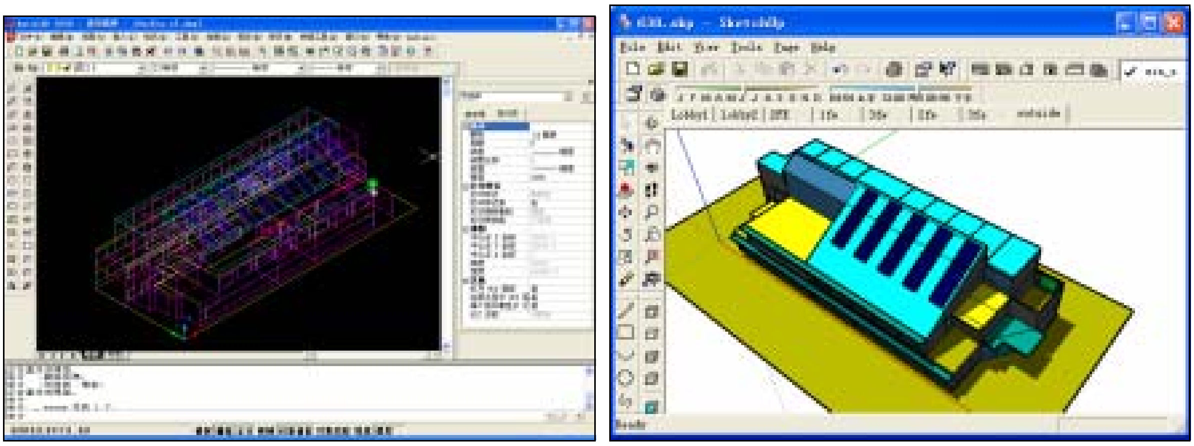


图 2　Desktop Radiance 的主界面和辅助建模软件 SketchUp

输入数据的准确性对于模拟计算结果的准确性有决定意义，因此我们认真选择各种平面对应的材料物理特性和窗户玻璃物理特性。使用到的材料和玻璃的物理特性见表 1。

表 1　模拟计算的材料物理特性列表

	反射率	透过率	颜色	镜面度(%)	粗糙度(%)
内墙	0.66	—	白	2.6	4
地板	0.42	—	淡黄	1.5	5
遮阳百叶	0.88	—	白	60	2
天花板	0.7	—	白	3	2
地面	0.2	—	黄	0.5	15
天窗玻璃	0.18	0.6	透明	—	—
南向窗玻璃	0.11	0.7	透明	—	—
北向窗玻璃	0.08	0.8	透明	—	—

为考察天窗对大厅采光效果的影响，我们建了 a）不开天窗、b）天窗面积为 2800*7000、c）天窗面积为 3500×7000mm 三种模型，分别考察了全阴天和夏至日 14 点大厅内距离地面 1m 高平面的光照情况。大厅平面图见图 3。

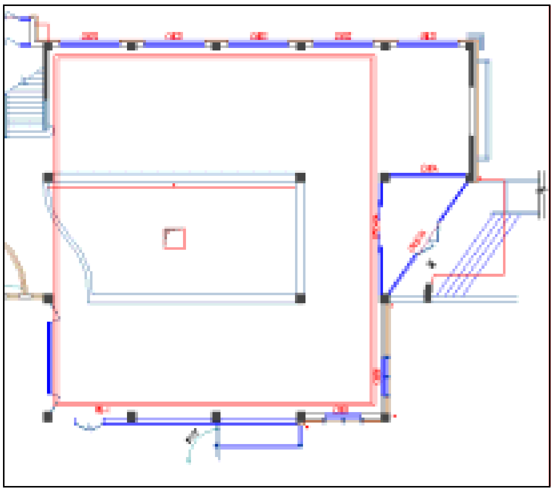


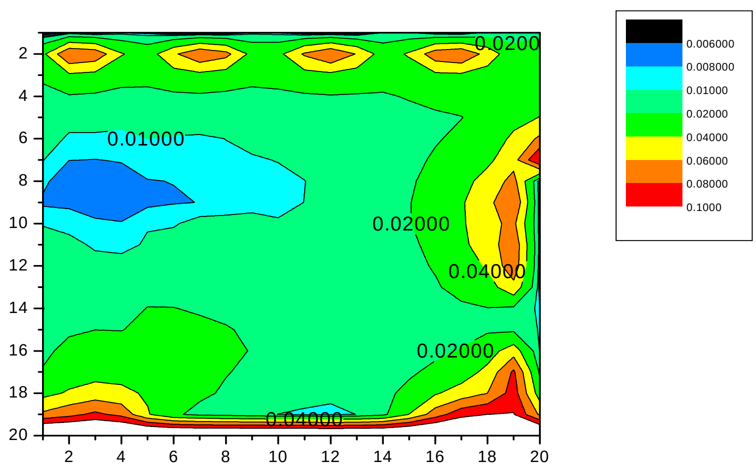
图 3 一楼大厅平面图，红色矩形为模拟范围

4 模拟结果分析

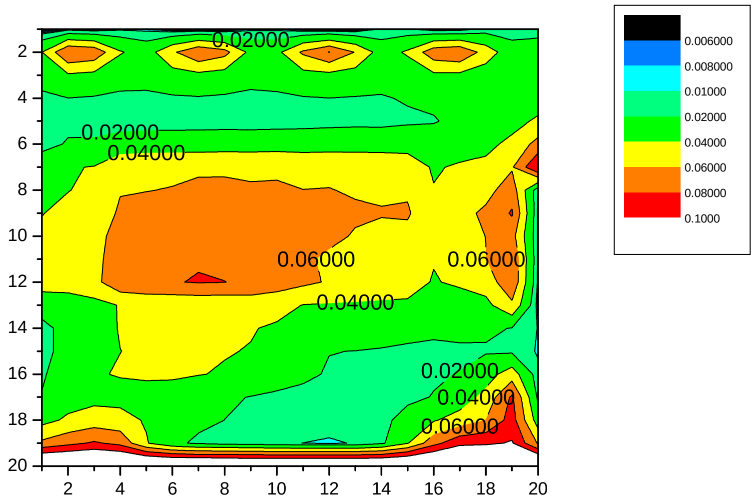
CIE 全阴天情况下，时间为 12 月 21 日 12 点，1 楼东侧大厅，平均采光系数数据见下表，分布见图 4。有天窗 b、c 相对于无天窗 a，平均采光系数高 1 倍多；但天窗面积增加为 3500×7000mm（c）与天窗稍小的 b 相比，采光系数和均匀度都差别不大。从采光系数分布图上也可以看到这一点。

表 2 全阴天情况下大厅内采光系数模拟结果

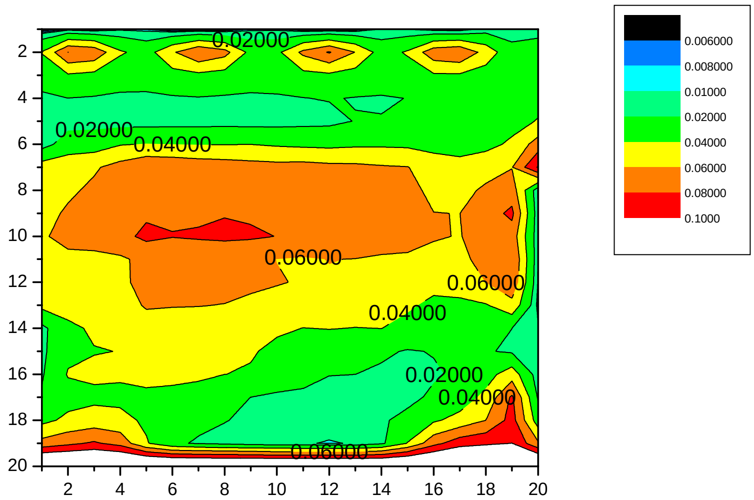
	a	b	c
平均采光系数(%)	1.9	5.1	5.6
平均值/最大值	0.22	0.15	0.16



a，全阴天



b，全阴天



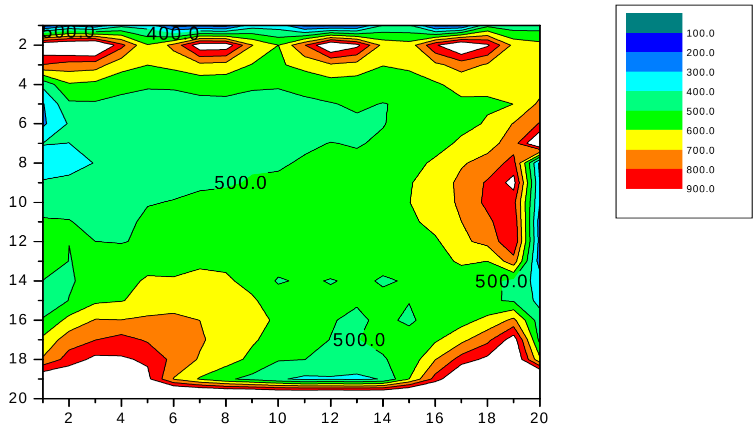
c，全阴天

图 4　12 月 21 日全阴天，1 楼大厅采光系数分布图

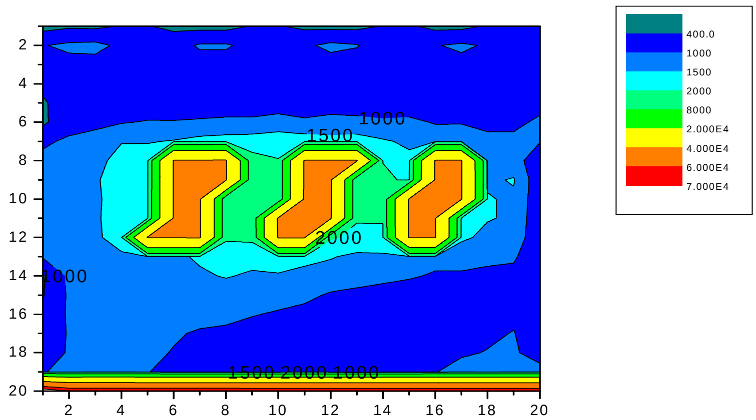
CIE 晴天情况，时间为 6 月 21 日 14 点。大厅内照度的模拟结果见表 3，分布图见图 5。不采用天窗（a）的照度分布最为均匀，而且也达到了办公工作的视觉要求[5]；开天窗时（b、c）的照度水平偏高，而且天窗投影区最高，易于形成眩光源，因此必须加以外遮阳处理。

表 3　夏至日晴天，大厅内照度模拟结果

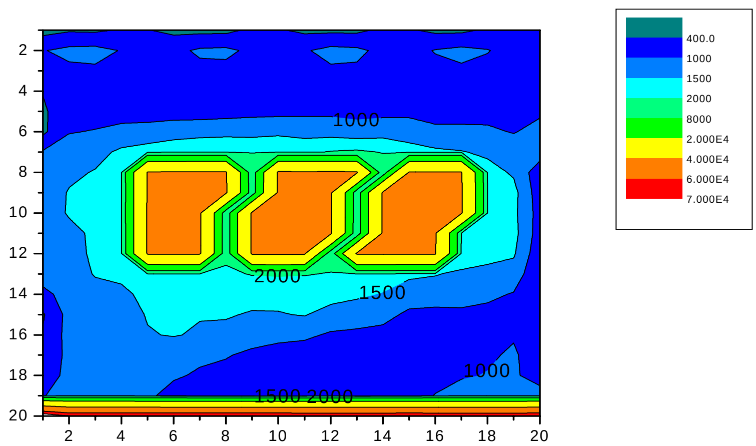
	a	b	c
平均照度(lx)	576	4821	6739
平均值/最大值	0.48	0.15	0.18



a，晴天



b，晴天



c，晴天

图 5　6 月 21 日晴天天，1 楼大厅照度分布图

5 小结

根据 1 楼大厅的照明模拟计算结果，天窗可有效增加办公楼内的照度水平，但天窗面积不宜过大，以免带来眩光和能耗方面的问题，从建筑物整体能耗估算结果也得到了验证。在本例中以 5 组 2800×7000mm 为宜，并在天窗上安装自动卷帘外遮阳系统，提供更为均匀的自然光照。

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香港大屿山: 1 绿色青年营, 2 种可再生能源, 3 方伙伴, “4E”原则

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（1.2.3.建筑师事务所；4.5.风力能-太阳能制冷-氢气）

摘　要　香港基督教女青年会营舍项目位于大屿山南岸之散石湾，重建工程在扩展营舍的同时，亦保持其原有两层楼高建筑的乡郊特色。基于教育、环保及整体效益之考虑，设计融合两种可再生能源系统。由于该地块朝南，建筑造型又拥有大面积屋顶平面，可充分利用“太阳能制冷”，以及“地源热泵”辅助制冷系统与提供生活用热水。该复合系统将节省大量用电，降低营舍之运作成本。该设计运用多种可持续发展策略，其中建筑师“因地制宜”，采用像坡地梯田般的“绿荫屋顶”将各营舍连接起来。绿荫屋顶同时起到增大绿化与活动空间，改善微观气候，提高屋顶隔热功能，储存雨水及提供人流连接（无须另设电梯以节省运作开资及能源）等作用。该环保设计之实现，与业主、建筑师/顾问、可再生能源专家三方通力合作密不可分。他们所达成的共识源于“4E 原则”，即教育(Education)、生态(Ecology)、经济(Economy)及建筑便于运用(Ease of use)四方面之协调。

1 Green Yo uth Centre, 2 Renewable Energies, 3 Partners, 4E Principles on Lantau Island, HK

Anthony Cheung and K S Wong, Architects, Ronald Lu & Partners (HK) Ltd.Eric Walker, President, Wind Future (Wind Energy, Solar Cooling & Hydrogen)

Abstract　The Hong Kong YWCA is re-developing a hostel facility at San Shek Wan on the south coast of Lantau Island to expand the area of conference and other amenities, while maintaining a 2-floor design similar to the original building in a rural setting. Based upon educational, environmental and cost-benefit considerations, an integration of two renewable energy systems is explored. Since the site has excellent sun exposure and the building configuration has a large ratio of roof area to floor area, “solar assisted air-conditioning” using an adsorption chiller is viable. A “ground source heat pump” further provides the necessary back-up for the solar cooling and supplies domestic hot water. This renewable energy combination would save a substantial amount of electricity, benefiting the new facility with lower operating costs and a quieter environment.

Among other sustainable design strategies, the architecture features a “down-to-earth” approach; with a sloping green terraced roof weaving various parts of the youth centre together. The green roof helps maximize the landscaped space, improve the micro climate, offer thermal insulation, retain storm water, and provide ramped connection between floor levels, thereby avoiding the elevator requirement and saving costs and operating energy. The green designs are critically dependent on the cooperation among the three key partners: the client, the architect/consultants, and the renewable energy specialist. They collectively share a vision based on the “4E Principle”, which embraces a balanced consideration of Education, Ecology, Economy, and Ease of use from a life-cycle perspective.

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生态住宅设计初探

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摘 要 面对全球性的生态环境恶化，缓解人类发展与自然界之间的矛盾成为当务之急，也是摆在建筑师面前的一个重要任务，建筑活动消耗大量的资源与能源，是人类重要的生产活动之一。

在我国，目前及今后一个时期内的建筑活动，规模巨大。住宅产业也在蓬勃发展，占建筑行业的半壁江山，住宅建设对生态环境造成的压力不言而喻。选择怎样的发展模式不但关系到人们的切身利益，也影响着我们的子孙后代。

在住宅建设中以生态思想为指导，采用生态技术，走生态发展之路，为我国住宅产业的发展提供一个新的研究角度及思考模式。

本文结合作者所做生态住宅方案案例的分析，力图从住宅的生态使用技术及实现这些技术所需的支持条件两方面进行探讨，试图探索如何将生态技术落到实处，应用于住宅建设。

关键词 生态技术；住宅建设；政策及手段

Abstract In view of the deteriorations of our ecologic environment, it is urgent to find a way that can ease the tension between urban development and natural protection. This imposes a tough task on Architects, because as one of the major activity of human beings, construction consumes a great part of our resources and energy.

As in our country, large-scale construction is taking place in the full swing at present and will continue to last for a long period. In particular, the construction of residential buildings will play a major role. Therefore, the pressure on ecological environment is immense. The strategy of development we choose will not only affect the living of ourselves but also our offspring.

In this paper, by analyzing the author’s own project plan, the author tends to apply his study into the real practice of residential construction.

Key words Ecological techniques, Construction of residential buildings, Policy and measure

二十世纪六十年代温室效应学说的提出，促使人们重新考虑能源的利用方式，引起人们对环境问题的关心，七十年代的能源危机，更是引发了人们对能源问题的广泛关注。近年来，随着发展中国家的崛起以及高消耗生活方式的扩展。环境、资源、能源问题进一步突出。许多国家已开始在各方面采取行动。

在我国，随着经济的迅速发展，发展与环境之间的矛盾凸现，近年来频繁出现的水荒、电荒、污染严重阻碍了社会的发展，威胁着人们的健康。国家也在从各方面采取应对措施。参照发达国家的发展历程，建筑业将成为我国国民经济发展的支柱产业之一， 它同时也消耗着大量自然资源和能源，产生大量的废弃物。据统计，建筑活动消耗了能源总量的近 40%，目前，我国建筑垃圾的数量已占到城市垃圾总量的 30%～40%。而全球建筑活动产生的温室气体占温室气体总量的 50%。[①]现阶段，以住宅建设为主导的中国建筑业仍是一个高能耗高污染的产业。对我国生态环境的破坏负有

[①] 窦以德 等编译，《诺曼·福斯特》，中国建筑工业出版社

很大责任。

针对以上问题，在建筑界，对生态住居建筑的探讨和研究，吸引了越来越多的建筑师参与其中。力图做到在当前及将来，以技术手段缓解环境与住居建设之间的矛盾，实现可持续发展。人创造了建筑，建筑也反过来塑造了人，影响着我们的生活方式与观念。生态住宅的建设，对于改变我们的生活观、自然观和价值观，自觉关爱自然生态，具有长远的文化和思想意义。从实际的物质意义来讲，可为我们创造自然健康的住居环境。地球不只属于我们这一代人，它同样是我们的子孙后代赖以栖身之所，我们有义务与责任减少能源与资源的浪费。

下面将结合作者所做一个生态住宅方案的介绍，从各方面对生态住宅的技术进行探讨。由于仅仅是一个方案，许多想法还比较粗糙，具体的实现手段还需要进一步完善。只是希望借此方案能有一个操作层面上的探索，而不仅限于理论上的研究。也希望起到抛砖引玉的作用。

1、 方案介绍：

1）场地：方案所在龙潭生态住宅开发区为山地，面临龙潭水库，属于生态保护区，植被秀美。

2）气候：该地地处北京郊区，属温带大陆性气候。夏季炎热，主导风向为东南风；冬季寒冷干燥，主导风向为西北风，全年风速较低，日照时间较长。

2、方案目标：

1）采用合理、生态的建材。

2）节约能源，最大限度使用可再生能源，例如太阳能。

3）节约水资源，加强水的重复使用。

4）节约土地，尽可能实现零占地。

5）保护环境，建造及使用过程中减少对植被的破坏。

6）文脉延续，延续特色住居方式，避免建筑形式的单一。

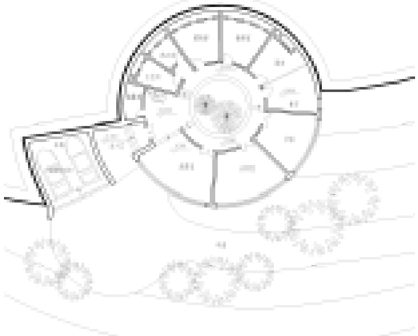


图 1 平面图

3、设计构思分析：

方案借鉴窑洞及土楼等传统居住形态，延用围合内院的概念，利用太阳能材料及技术，采取掩土建筑方式以达成既定目标。

4、实现手段与技术措施：

1）建材：采用混凝土及建筑场地开挖所得石料，使用当地材料，可以节省材料运输耗能。玻璃顶棚采用钢骨架，钢材可以循环使用，力学性能优良，可以以相对少的材料耗费达到承载要求，符合建材的 3R 原则。

2）节能：封闭的玻璃顶棚可以起到太阳房和拔风的效果，改善采光和通风状况并有效利用太阳能。结合通风井安装太阳能电池板，作为日常电力部分来源，部分存于蓄电池，供阴雨天使用。

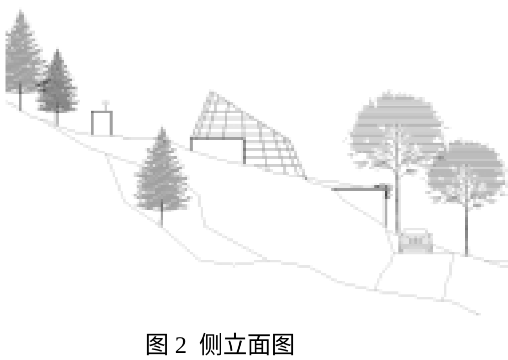


图 2 侧立面图

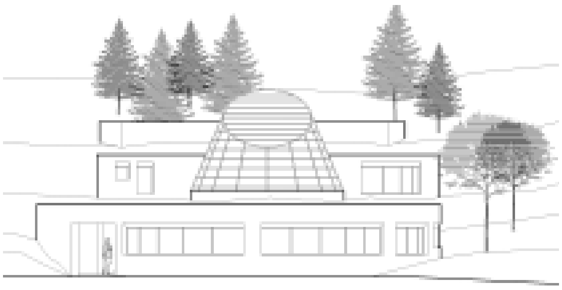


图 3 南立面图　　　　图 4 剖面图

玻璃顶棚的设计，旨在促进空气自然流通，达到自然空调的目的，以节约空调运行能源。玻璃顶棚为双层构造（图 5），双层玻璃中间为可调节式百叶，单面涂覆高反射型材料，如铝箔。

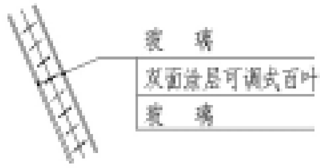


图 5 双层玻璃结构示意

在夏季白天（图 6，图 12），百叶的反射面朝向室外，反射阳光。玻璃顶棚下方为单向流通式吊顶百叶（图 7），气流只可以由下方往上方流动，不能由上方向下方流动。玻璃顶棚上方的空气被加热上升，由顶棚上方排出，形成负压。促进室内空气流通。

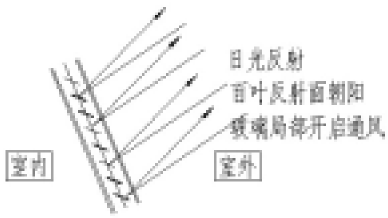


图 6 夏季白天百叶工作示意

新风由多向引风道（图 10）导入，多向引风道可以保证捕捉到各方向的风，导入的新风经过引风道内雾化水喷头的加湿降温，且在负压的吸引下下沉，经由处于房间下方的进气口流入室内，这样，室内下方空气温度较低，经人体散热和室内热量加温后，上升由顶棚排出，保证环境温度的舒适与空气清新。

夏季夜晚，（图 13）顶棚开启，由于该地位于山区，下有大面积水体（水库），在夜间和日间会有山地风形成，夜晚，山风将由山顶吹向山底。一方面山地风穿过顶棚上方，会在室内形成负压，促进室内空气流通。另一方面，山风可由引风道进入室内。形成适宜的室内温度。

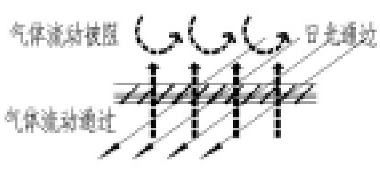


图 7 单向流通式吊顶百叶

冬季白天（图 8，图 14），通过百叶角度的调节，可将阳光引入中庭，将室内加热，同时，带有夹层的双层玻璃结构，可以有效防止热量散失，形成太阳温室，不用额外采暖。同时，顶棚的热空气由空气泵导入地下室，加热卵石床，将热量储存起来，以备阴雨天气和夜间使用。

冬季夜晚（图 9，图 15），百叶关闭，覆有反射涂层的一面朝向室内，防止室内热量散失。地下室卵石储热床在白天储存的热量散出，加热空气，热空气由风扇通过管道送至各房间。

部分顶棚处安装太阳能电池板，发出的电可以用来照明以及提供循环风扇的使用。

3）水利用：设雨水收集系统，厨房及卫生间灰水收集后进行简单生物处理，可供卫生间冲洗、绿化灌溉、洗车、洒扫等用途。

4）节地：建筑大部分嵌入山体中，基本实现零占地。

5）环境：屋顶可覆土绿化以恢复原有植被，减少了对室外环境的破坏。室内空气环境的优化由排风管完成。风向标式排风管（图 11）自动指向下风向，并由风扇形成负压，吸引室内污浊空气排出。排风管室外部分涂黑色吸热涂层，利用日光加热管口空气，有利于形成负压，促进空气流动。

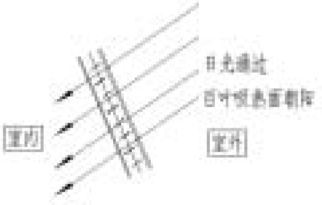


图 8 冬季白天百叶工作示意

6）绿化：在住宅北侧及西侧种植常绿树，可在冬季有效的抵御寒冷的西北风。在南侧种植落叶树，夏季的枝叶形成绿荫，遮挡阳光，防止室内过热；冬季落叶之后可以减少对阳光的阻挡，有利于阳光射入室内，提高室内温度。

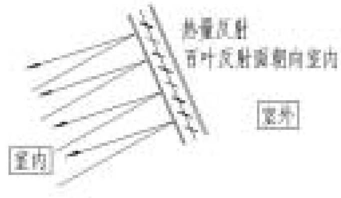


图 9 冬季夜晚百叶工作示意

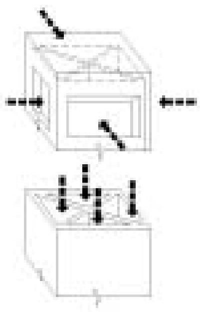


图 10 多向引风道工作示意

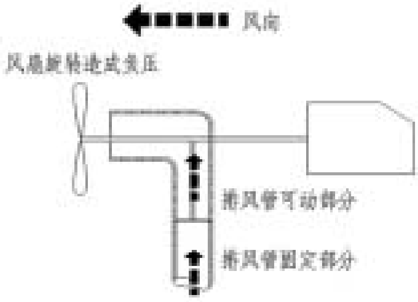
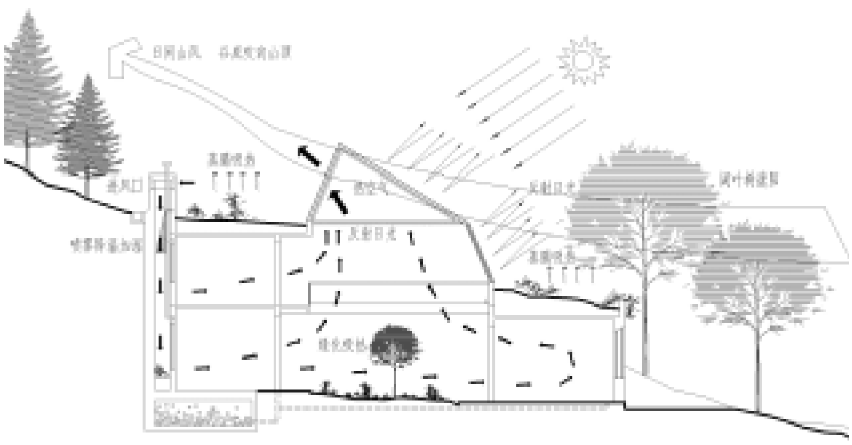


图 11 风向标式排风管



夏季白天

图 12 夏季白天工作示意图

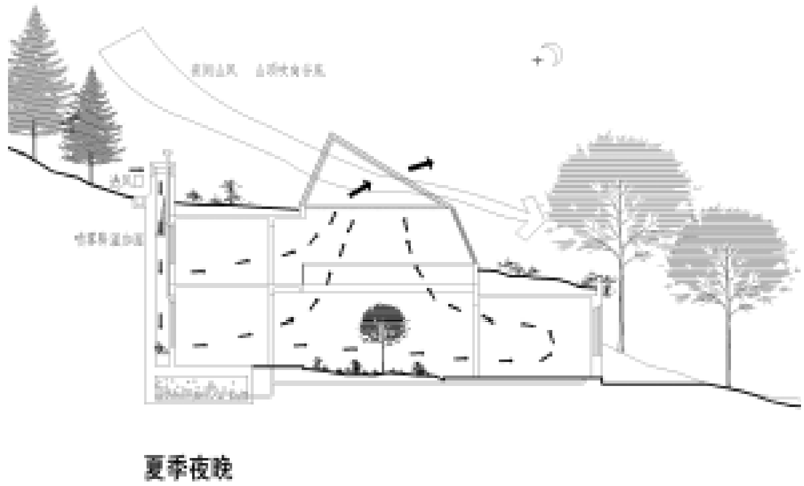


图 13　夏季夜晚工作示意图

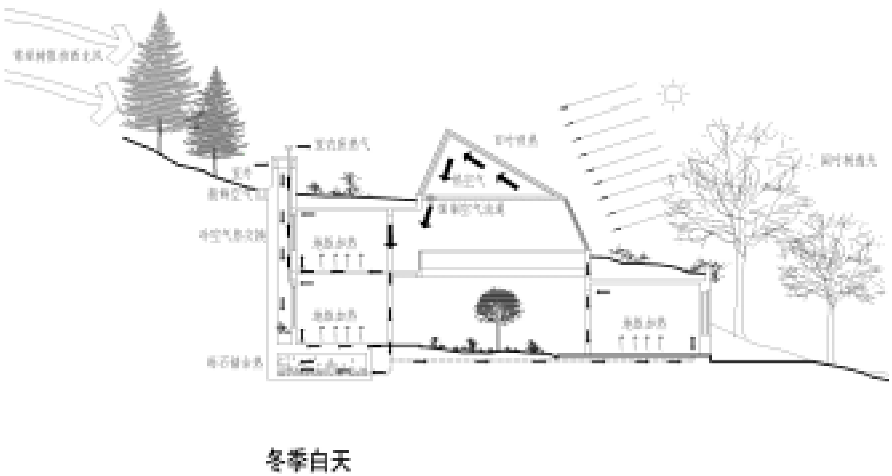


图 14　冬季白天工作示意图

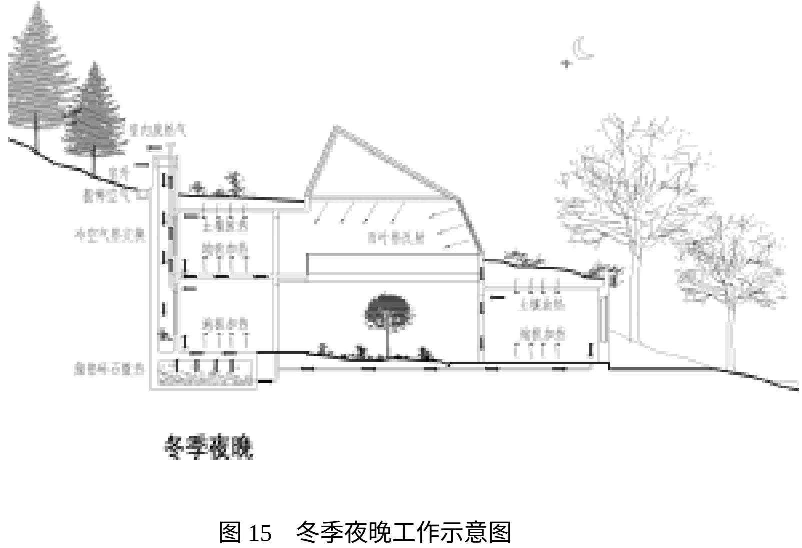


图 15　冬季夜晚工作示意图
资料来源：图 1 至图 15 均为作者自绘

设计的过程中自然考虑到方案的可实现问题，通过这个方案的设计，认识到在实现过程中可能遇到的一些问题：

首先，生态设计在建筑设计之外，最多涉及的问题是技术和材料问题，它们对于生态目标的实现具有至关重要的意义。

在建材方面，我们应该根据实际情况，选择适合国情的绿色材料，比如木材，本来是优质可持续发展的生态建材，它是自然光合作用的产物，力学性能良好，易于加工，在废弃后可以自然腐烂分解，不会对生态环境造成破坏。国外也有成熟的木建材产品和木结构住宅体系。并已有大量建成建筑。但我国森林资源几十年来遭到恶性破坏，不得不限制木材的使用。而竹材在我国极为丰富，我们也有利用竹材的传统，大到竹楼，小到竹筷，在日常生活中竹制产品随处可见。竹子是一种速生植物，力学性能也比较好，是一种比较理想的生态材料。我们是否应该对竹材加以研究开发，充分发挥它的长处。使之能够形成体系，广泛应用。

随着科技的发展，新型材料的出现也为生态目的的实现提供了更多的选择。比如在节能方面，新材料不断涌现。

其中，TIM 材料（Transparent Insulated Material 简称 TIM），由 K ·泰瑞 ·霍兰德博士（Dr. K. Terry Holland）领导研制，90 年代付诸实际应用，是一种透明的绝热塑料。目前也用于建筑，使用 TIM 的建筑据统计每年可节约能耗的 200 千瓦·小时／米 2（kw·h/m2），已能完全或部分地取消常规采暖。

门窗是建筑保温的薄弱环节，玻璃材料的保温技术是生态建筑节能的关键之一。随着现代化科技的不断发展，这一领域陆续出现了吸热玻璃、热反射玻璃、低辐射玻璃、电敏感玻璃、调光玻璃、电磁波屏蔽玻璃等各种新型玻璃材料。设计人可将它们组合成复合的构造形式，来达到生态建筑的保温和采光要求。

在建筑中利用太阳能为建筑提供能源，既无污染，又无噪音，并可替代常规能源。太阳能光热和光电材料在国外的建筑中也有一定的应用。但由于价格的效率的制约，在建筑中一直不能得到推广，尤其是太阳能发电，目前仅在一些试验性的生态建筑中使用。要改变这种状况，就需要要改进技术，大幅度降低成本。建筑中，当今最先进的太阳能技术就是创造透明的太阳能光电池，用以取代窗户和天窗上的玻璃。世界各国的试验室中正在加紧研制和开发这类产品。日本的一些商用建筑中，已试验采用半透明的太阳能电池将窗户变成微型发电站，将保温--隔热技术融入太阳能光电玻璃，预计 10 年后将取代普通玻璃成为未来生态建筑主流。

智能控制和计算机模拟技术也是实现建筑生态所需的技术条件。通过计算机模拟技术我们可以预先以数学模型模拟建筑在建成后的气流状况和室内温度、湿度和采光等情况，并反馈于建筑设计当中，对设计提出优化和改良。智能控制则可以根据室内外的环境状况对通风采光进行自动模糊控制，使能源的利用和室内环境达到最优化。

除了技术和材料问题之外，生态住宅所触及的不仅是建筑本身，还有一系列其他社会问题。

思想方面，尽管当前大家对环保和生态的意识已有所加强，然而，当真正涉及到个人利益时，

还是不惜以牺牲环境为代价的。这一方面是经济因素，一方面是人的素质问题，问题的解决需要假以时日，当前，可以以强制手段作为过渡措施。

目前，许多房地产开发商所感兴趣的是生态住宅或生态住区这块招牌，而对于提高住宅的具体性能，如加强保温、改善通风、采用更加高效的能源系统等方面并不肯投入。这除了观念上的问题外，很大程度上还在于错误地认为生态住宅就意味要采用大量昂贵的新技术、新材料。这在相当程度上阻碍了生态住宅的发展。

经济方面，生态住宅由与在舒适度和环境保护方面的要求较高，在造价上一般要高于普通住宅。它的效益多体现在社会效益方面，经济效益方面则一般要在使用过程的较长期才能得以实现。在目前以追求经济效益为前提的市场经济条件下，显然处于劣势。此外，许多生态技术还不完善，在目前以开发商为龙头的房地产开发模式中，多数开发商们都不会冒风险采用不成熟的技术，甘愿走老路。有的生态技术手段较成熟，性能也可靠，但国产化水平低，价格让人却步。

政策方面。生态住宅所触及的范围较广，需要各方面协调配合，由于我国的管理制度，条块分割的现象依然严重。电力、燃气、采暖、城建各部门互不协调，许多技术措施难以实施。由于生态住宅效益多体现在社会效益方面，经济效益也体现在使用过程中，投入者得不到当前的回报，国家应制定相关政策，鼓励生态技术的采用，给予经济上的支持。

落后的管理体制也对生态技术的运用造成阻碍，例如在我国，通过改善墙体、门窗的性能，建筑师可以很容易地设计出比原有节能标准节能的住宅。但实际的运作情况是“节能住宅”并不节能。其原因是居住小区的冬季供暖方式、收费标准并没有随之改变，用户对供暖量无法调节，采暖量的多少与其经济利益也毫无关系。在供暖量不变的情况下，良好的保温材料使得居室温度偏高，用户只好通过开窗通风来降低室温。“节约”下来的能量就这样又散失到室外，而小区采暖燃料的供应量则依旧居高不下。

生态住宅涵盖社会的各个层面，需要许多相关产业和实际技术作为支撑，同时也可带动许多相关产业的发展，在生态住宅发展的初期，需要国家以一定的政策刺激这些相关产业发展，将住宅发展和相关产业的发展纳入良性循环，然后借助市场的推动力，以经济杠杆为主，推动生态住宅产业的发展。国家应加大科研投入，发展生态技术。在增强国内生态高技术的研究和开发力度的同时，选择性地引进国外一些先进的生态高技术。由于生态住宅回报的长期性和社会性 ，国家可以投资做示范建筑单体或小区建设，引导生态住宅的良性发展。

可以预见，经过了理论介绍的热潮和社会的炒作之后，人们对生态住宅的认识将更加轻清楚、务实。随着国家政策的不断完善和相关法规的健全，贯彻生态原则的住宅将不断涌现。在此期间，政策的引导将起到重要作用，这需要在政策制定方面，具有前瞻性，并能够在当前的市场经济条件下，平衡各方面的利益。

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Shanghai Ecological Building Exhibition 2006

Prof. Joachim Malecki (Construction Ministry Hamburg, Director of the Department for Urban Planning)
Dr. Roland Winkler (SINOBAU e.V., chairman)

Abstract As a Chinese-German cooperation project the sister cities Shanghai and Hamburg will together prepare and carry out the Ecological Building Exhibition Shanghai to be opened to the public at the end of the year 2006. This project is based on the positive experience of the Solar Building Exhibition Hamburg 2005, which is part of an European cooperation project, where 12 partner cities in 5 EU-countries participate in the European Solar Building Exhibition (see also: www.eu-exhibition.org). This exhibition is centrally coordinated by ZEBAU (Center for Energy, Building, Architecture and Environment), a public-private institution of the city of Hamburg. ZEBAU itself is founding member of SINOBAU e.V., a non profit association aiming at promoting energy efficient building in China.

Through a demonstration of the possibilities of energy efficient building and the usage of renewable energy sources the Ecological Building Exhibition Shanghai 2006 will contribute to a sustainable urban development of Shanghai. It is planned to jointly develop an exhibition concept, to select appropriate projects and to accompany and supervise every stage from planning to construction until the exhibition is held in 2006. Furthermore it is envisaged to construct a Chinese-German Centre for Energy and Resource Management (CERM) which shall promote energy efficient building techniques and renewable energy technology during and after the exhibition.

The lecture will introduce the main ideas behind this cooperation project and give a summary with examples of the Solar Building Exhibition in Hamburg as well as the European Solar Building Exhibition.

1.Introduction

The People's Republic of China is by far the world's largest consumer of carbon. Over 70% of Chinese electricity is produced by coal power stations, mostly working with outdated environmental technologies, if at all. The unfiltered exhaust fumes of cars and the small carbon stoves in private households add to this as well. The air is dirty, towns lie under a haze, breathing falls heavily. The air must get purer.

If the Chinese economy is to continue to grow at the present speed, China will soon overtake the USA as the world's largest carbon dioxide issuer, with disastrous consequences for the global climate. Therefore, the rest of the world should have a vital interest in any measures that could help to stop this trend. The important question is: how to achieve this most effectively? The answer lies in building energy efficiency.

Why? As hardly anyone notices, the ratio of energy consumption for buildings compared to the overall energy consumption in China has risen dramatically in the last 25 years. This has to do with the unprecedented construction boom in the same time span. In China right now the incredible amount of 1.6 – 1.9 billion m^2 of new building space is under construction every year (the current overall floor area of all buildings amounts to about 38 billion m^2). In other words, during the last years and during the next decade to come, the floor space under construction in China in every single year equals about half (!) of Germany's existing overall residential floor area.

This has serious implications because new buildings lack even the most basic measures to improve energy efficiency (Chinese buildings consume between two to three times more energy per square meter than comparable buildings in Germany). Unlike technical appliances buildings have life spans of at least 50 years and can't be substituted easily to adapt to new standards. As a consequence year by year a huge amount of floor area in China is "locked" in a state of energy inefficiency for many generations to come.

The Chinese government has realized the gravity of this development and has not only begun to implement building energy efficiency standards but is also preparing to adopt a quota system to promote the use of energy from renewable sources.

The time is ripe to engage in building energy efficiency in China. This is a not only a key factor in reducing greenhouse gases on a global scale but also an area where this goal can be achieved far more easily and quickly than in other domains like renewable energies. The main obstacles are a lack of public awareness and local know how. To change this, building exhibitions have proved to be very effective.

2.Short Description

A building exhibition is an ideal means to promote energy efficient construction in China because it incorporates all aspects of energy efficient construction: ecological urban planning, green architectural design, innovative techniques for heating and cooling and the possibility for the large public and investors to get convinced through concrete experience.

In the frame of the first “Ecological Building Exhibition” in China it is planned to build up a new area of several hectares not only with energy efficient and ecological buildings for housing and business but also with an intelligent and sustainable infrastructure concerning amongst others traffic, energy, water and waste management.

The buildings will be developed by German and Chinese planners in close cooperation and built by construction companies and craftsmen from Germany and China.

After their completion at the end of 2006 more than 50 different house types can be inspected in about 10 weeks during the "Shanghai Ecological Building Exhibition". After the end of the exhibition, the houses will be occupied by their owners and users.

The energy supply of the new area should be covered by Renewable Energy Sources to a great extent – this will be an area of Shanghai with almost zero emission of CO_2.

As a core of the building exhibition it is planned to create a “Centre for Energy and Resource Management” (CERM) on the grounds of the exhibition, which shall promote energy efficient building techiniologies and renewable energy technology during and after the exhibition. Among the users of the Energy Innovation Centre will be

- architects and planners
- energy experts
- building suppliers

- construction companies
- research institutes
- politicians and authorities

The centre shall be used to hold seminars, to conduct workshops, to provide information about every aspect of energy efficient construction in China as well as in other countries, to exhibit energy efficient building materials, to establish contacts etc. In other words, it should become an indispensable information and competence centre for everybody interested in energy efficient construction in China.

3.Location

Why choose Shanghai as location for the first Ecological Building Exhibition in China?

· Although Shanghai does not belong to the heating area of China, the index of energy consumption for residential buildings is among the highest. This is due to the excessive and widespread use of air conditioning and at the same time almost complete lack of insulation.

· The energy consumption of 2000 has reached 54 million tons, among which coal represents 68% of the total primary energy used in Shanghai. The high proportion of coal consumption has brought serious adverse environmental impacts in Shanghai. Therefore local energy policymakers have launched regulations and made new policies to adjust the energy structure.

· In Shanghai solar energy is now mainly used for water heating. More than 65000 solar collectors are installed in shanghai (equivalent to about 130.000 m^2). But there is no example of integrated solar application technology in buildings (lighting, heating, cooling etc).

· Shanghai wants to become a global city of the future and to stay the technologically most advanced city in China (always being challenged by cities like Beijing, Tianjin or Shenzhen)

· The building energy efficiency standard for Shanghai and the Yangzi-region (JGJ-134-2001) has been put into effect and shall be enforced more rigorously than in other regions. Beginning with 2005 every new building has to adhere to the existing standards which implies theoretically at least an insulation of the building envelope. For 2003 it is estimated that about 3 Mio. sqm. of new building space will be insulated (about 5% of the total construction activity in Shanghai).

· The World Exhibition 2010 will be held in Shanghai and is already casting its shadows. The responsible authorities are completely aware that they have to start now if they want Shanghai to serve as an example of a sustainable mega-city of the future.

· Shanghai is certainly the richest and most international city in China and therefore an ideal starting point and multiplier for innovative concepts.

4.Targets of the Solar Building Exhibition

· Promote energy efficient construction in China in order to significantly reduce the emission of greenhouse gases through

- ncreasing public awareness
- technology transfer in the field of sustainable building and urban planning in China
- “best practise” examples for planners and administrations
- offering Chinese developers, construction companies and craftsmen an easier access to new

technologies and expertise

· Providing architects, planners and technology suppliers from Europe with an efficient means to enter the Chinese market for energy efficient construction

· Opening future perspectives for all participants, like for example follow-up-sales - Chinese citizens will have the possibility to buy the same type of houses they saw at the exhibition and have them built later at their own plots somewhere else

5.Benefits

The benefits of the Building Exhibition are manifold, ranging from the raising of public awareness for ecological problems to know-how transfer, business development and – last but not least – a significant improvement of the local and global environment.

5.1 Public awareness

· Concrete experience: Although more and more Chinese know of the advantages of energy efficient building they often can't believe it really works or is indeed a feasible option for China. At a building exhibition they get the "feel" of energy efficient construction, they can see it works and – very important – they see that it even goes along with nice architecture and a better room climate.

·Economical arguments: With the help of intelligent simulations it can be demonstrated how much energy and consequently money energy efficient buildings are able to save compared to conventional buildings.

· Large variety: A building exhibition can offer a wide variety of different low-energy and solar buildings so that for every taste and need there should be a suitable building.

· Innovative technology: Chinese are especially fascinated by innovative technology. In a building exhibtion all new techniques for energy-optimised cooling and heating, innovative building material and good urban planning concepts as well as Renewable Energies (RE) can be demonstrated effectively.

· Education: The planned Energy-Innovation-Centre of the Building Exhibition offers excellent opportunities for professional education of Chinese planners and craftsmen.

5.2 Contribution to energy-related policies and knowledge transfer

· The experiences of the Building Exhibition can contribute to create a genuine Chinese way of energy efficient building.

· The Building Exhibition can serve to evaluate current Chinese standards, regulations and policies on building energy efficiency as well as help with the formulation of new and more advanced standards.

· Other Chinese municipalities will inspect the “Shanghai Solar Building Exhibition” and be motivated to copy that concept in their own town or province.

5.3 Business development and cooperation

· The multinational project of the Building Exhibition contributes to cross-border development and the implementation of innovative concepts and offers many different opportunities for multinational cooperation. This also refers to building technologies that make sustainable planning and construction measures easier.

· Hundreds of regional SME´s will erect the buildings - supported by universities and experts

· European producers and construction companies get direct access to the Chinese market – they are supported by the project partners and the Shanghai administration.

· The exhibition offers excellent possibilities for trade – for example producers of building materials have the opportunity to sell their products to Chinese construction companies.

· The exhibition offers new marketing concepts for RES companies, producers of innovative building materials, planners etc. They can present their products or works at the “RES Fair”.

· Investors will be informed about the building projects and the investment opportunities. Each exhibitor, key actor or participant can present his investment offers on the exhibition web page.

· Chinese city planners, architects, engineers and craftsmen will be invited to workshops and events.

· An internet-based information system will present each stage of the development and provide further information on Chinese regulations and the Chinese market.

· Chinese planners, architects, craftsmen, construction companies and manufacturers will be motivated to join that innovative expanding market.

5.4 Improvement of the environment

· The Building Exhibition will contribute to a healthier urban environment in Shanghai.

· At the same time it will contribute to the reduction of green house gases and therefore to the protection of the global climate

· The exhibition will serve to demonstrate and promote innovative solutions for every aspect of urban infrastructure from innovative solutions for traffic systems (car-sharing-stations, solar bikes, public traffic) to waste and water management systems.

6.Target Groups and key actors

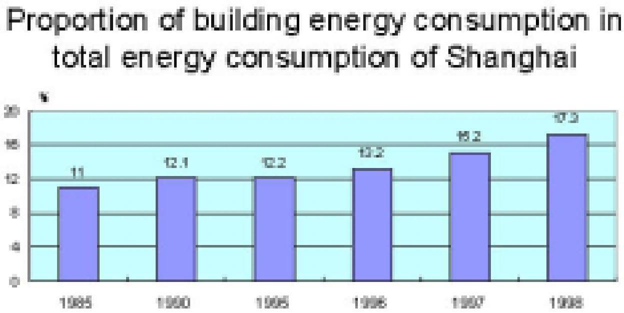
a) Target groups:

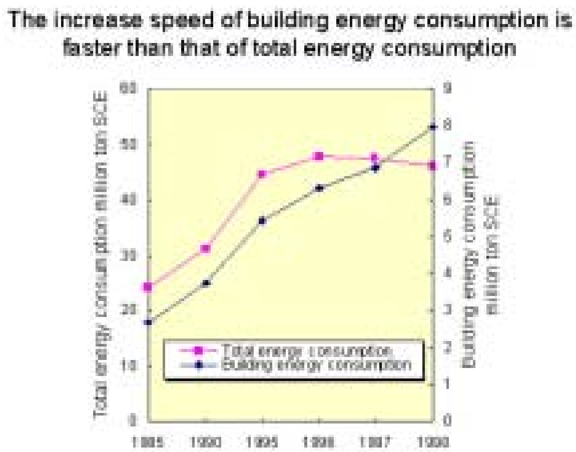
- politicians, civil servants
- city planners, architects, engineers
- building industry and the craft
- energy industry
- investors
- families/citizen and residents
- press, TV, broadcasting

b) Key actors:

- government
- municipal authority, politicians
- city planners, architects, engineers
- universities
- building industry and the craft
- energy supply industry
- relevant chambers (commerce, architects, engineers, crafts)
- investors

7.Facts





上海 2006 生态建筑展览

——致力可持续城市发展

作为中德合作项目之一，定于 2006 年底向公众开放的上海生态建筑展览会由上海和它的友好城市汉堡共同筹备。该项目将立足于 2005 汉堡太阳与建筑展览的成功经验。2005 汉堡太阳与建筑展览是一个欧洲合作项目的分项，该项目有 5 个欧盟国家的 12 个城市共同参与欧洲太阳与建筑展览（参见：www.eu-exhibition.org）。2006 上海生态展现主要由汉堡的一家半公立机构 ZEBAU（德国能源、建筑、设计和环境中心）进行协调，它也是在中国推广高能效建筑的非盈利性组织德中建筑节能技术合作协会（SINOBAU）的创建成员之一。

通过演示高能效建筑的多种形式和可再生能源的利用，上海 2006 生态建筑展览将推动上海地区的可持续城市发展，并计划在 2006 年展览召开之前，建立一种新的展览概念，并选择一些合适的项目，进行从规划到建造的全程跟进和监督。此外，中德双方期望在展览期间和展览结束后建立一个中德能量和资源管理中心（CERM），该中心将促进两国高能效建筑技术和可再生能源科技的应用和交流。

本演讲将介绍这个合作项目背后的主要观念，并举例总结汉堡太阳建筑展览和欧洲太阳建筑展览。

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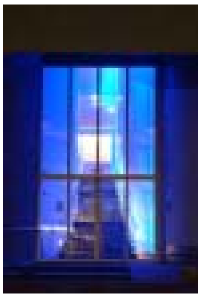
Roland Winkler 博士，德中建筑节能技术合作协会（SINOBAU）主席

Living Tomorrow Shanghai
A window to the world

The Living Tomorrow vision

Living Tomorrow is a neutral, international platform, open to all, offering a fascinating glimpse into the future and answers the question: *How will we live and work tomorrow?* It unites governments, trendsetting organizations and companies each of which demonstrates in its own specialist field how social, economical and technological developments will have distinct consequences for tomorrow's home and work environment.



The mission of the project is twofold: first of all it is a *permanent, dynamic and multidisciplinary forum* for all developers of innovative technology. Secondly, it *sensitizes and informs* the general public, professionals and media, giving them a reflection by means of demonstrations, on future economic, technological and social trends.

At the same time Living Tomorrow aims to offer its participants a maximum ROI by synergies in the realisation of mutual goals in *R&D, vision, social commitment, trend watching, image, PR and consumer research*.

Living Tomorrow has the ambition to create a network of 'Houses and Offices of the Future', with at least one project *on every continent*. Two highly successful projects were opened in Belgium and a third project is inaugurated in the Netherlands December last year. Shanghai will be the location for our Asian project.

The Living Tomorrow exposure

Living Tomorrow cooperates with *leading edge companies* throughout the world. The company labs of these firms act in close conjunction for innovations within the framework that Living Tomorrow offers and afterwards present them to their relations and the general public.

Living Tomorrow invites *Chinese and foreign universities* to cooperate with other labs that are currently taking part in Living Tomorrow, among which the MIT-Media Lab (Boston), Microsoft Labs (Redmond, USA), Philips Labs (Eindhoven), Visa International (London) and Unilever Research (Holland & UK).

Living Tomorrow has a strong impact on its *professional visitors as well as general public* by letting them expecience the practical implications of the major social, economical and technological trends in the world. It helps them to broaden their vision and assess the impact of these trends on their future business and life in general.

Students can visit Living Tomorrow at reduced rates. They can use the project as a basis for their studies, supported by the study material supplied by Living Tomorrow.

Many *Captains of Industry and Science* visited Living Tomorrow in the past: Bill Gates (Microsoft), Nicolas Negroponte (MIT Media Lab), Jacques Santer (former President of the European Commission) and many other COO's, Cots and researchers from the international business world. Therefore Living

Tomorrow invites government delegations and top managers to enter into debate, often generating large media interest.

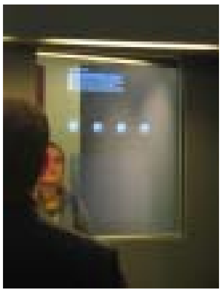
Living Tomorrow concept details

Organisations in general perceive the cooperation with Living Tomorrow as very interesting and this for several reasons. The main reasons for cooperation are *its social influence* and its *extensive experience as an innovation platform*.

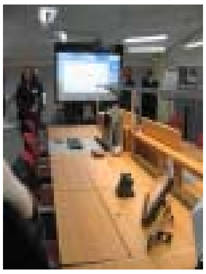
Through its *unique exposure capability,* we sensitise and inform people on the economic, cultural and scientific trends that will affect their future live and work. Ideas and concepts on future living and working are integrated in a real-life environment such as a kitchen, a home, an office and a workspace. Using innovative methods on exhibition arrangement the visitor can experience todays and tomorrows' trends and evolutions in lifestyle, picking up ideas and creating new ideas for their own houses and workplaces.

Living Tomorrow is not only a knowledge institute which enables knowledge transfer, but also a reputed R&D and innovation platform. Innovative content is what makes the concept a success. We expect to cooperate with many Chinese and foreign companies and researchers each in its own specialist field. Each of the following 10 themes receives ample treatment; *media and education, information and communication technology, energy, home and office automation, environment, safety, mobility, design, construction, and entertainment and health*.

By way of example, the following trends and evolutions have already been translated into usefull applications for every-day-life solutions; e.g. a smart washing machine connected to the internet will recognise a pair of red socks in a drum of 'white' washing. In that case the display asks you to remove the offending socks. The machine reads the tags on the clothing items, and sets the right mix of washing powder and softener.



Another example is the magic mirror. Most people begin their day in the bathroom, in front of the mirror. While washing and dressing, we think about all the things we have to do, and plan our activities of the day. On the mirror, we have all the relevant information in front of us. The smart mirror acts as a portal site with all the desired information: traffic report, wheater forecast, appointments diary and news headlines. It can even advise you in your clothing or skin cream. You can review your blood pressure, heart rate, temperature and body mass index, track the changes over time and send the results to your personal trainer.



Living Tomorrow will also pay attention to environmentally-friendly applications. These include the recycling of rainwater, semitransparent solar panels and solar collectors, a kitchen PC with tag reader for selective waste disposal and the use of recycled materials.

Some of the new possibilities that are being offered for the 'Office of the Future' are advanced video-conferencing, virtual archiving and multimedia libraries, and a photocopier that summarised and translates documents. At present in Europe you can not only see applications such as interactive television, but also portal sites with agent and speech technology, a virtual desk and advanced WAP & unified messaging. In Shanghai, we will continue our research and development in this direction. Various new Internet applications will also be displayed.

Governmental Policy Officials are major fans of Living Tomorrow because it offers them a *tool that supports their policy measures* and at the same time offers them a tangible, neutral platform in which the roads of the future are visualized. In the former projects, Living Tomorrow was regularly used by the government to present its long term strategies (state of the union) or to *welcome foreign delegations*. Living Tomorrow takes up the position of a reliable partner based on long term agreements with the government.

Many audiovisual productions are recorded in Living Tomorrow, mostly in cooperation with the government, which uses Living Tomorrow to boost its image or to support its policy. Furthermore, *thematic expositions and exhibitions* are accommodated, aimed at a specific target public in view of knowledge transfer on innovations and visionary applications, while also providing a platform for *PR activities* and for organising *events* like conferences, debates and product launches. This is why Living Tomorrow is also considered as an event platform.

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哈尔滨市第三步节能指标的确定

方修睦　　高鹏　哈尔滨工业大学

摘　要　建筑节能应该包括围护结构节能和系统节能两大领域。建筑物是用热的终端设备，建筑物能耗的高低，直接影响到整个小区的燃料消耗。现在执行的《民用建筑节能设计标准（采暖居住建筑部分）》JGJ26-95 是在第一部节能标准的基础上确定的。 第三步节能指标的确定，受建筑构造、保温技术、经济基础以及供热系统的节能潜力制约。本研究，在分析哈尔滨市第一阶段和第二阶段节能指标构成的基础上，分析了第三步节能时，供热系统的节能潜力以及建筑物和供热系统各自应承担的节能比例。提出了第三步节能时，哈尔滨的各种节能指标，并利用实例证明所确定指标的合理性。

关键词　建筑节能；节能 65%；节能指标；分析

建筑节能应该包括围护结构节能和系统节能两大领域。建筑物是用热的终端设备，建筑物能耗的高低，直接影响到整个小区的燃料消耗。在《民用建筑节能设计标准（采暖居住建筑部分）》中对建筑设计和采暖设计分别规定了具体的节能指标 [1]，这两个指标分别为建筑物耗热量指标 q_H（w/m^2）和采暖耗煤量指标 q_C (kg/㎡标准煤)，两指标的关系见图 1。

$$q_H = q_{H\bullet T} + q_{INF} - q_{I\bullet H} \qquad (1)$$

式中　$q_{H\bullet T}$ —单位建筑面积通过围护结构的传热耗热量，w/m^2；

q_{INF} —单位建筑面积的空气渗透耗热量，w/m^2；

$q_{I\bullet H}$ —单位建筑面积的建筑物内部得热，w/m^2。

$$q_C = 24Z\frac{q_H}{H_C \bullet \eta_1 \bullet \eta_2} \qquad (2)$$

式中　Z ——采暖天数，d；

q_H ——建筑物耗热量指标，W/㎡；

H_C ——标准煤热值，8.14×10^{3}Wh/ kg；

η_1 ——室外管网输送效率，%；

η_2 ——锅炉运行效率，%。

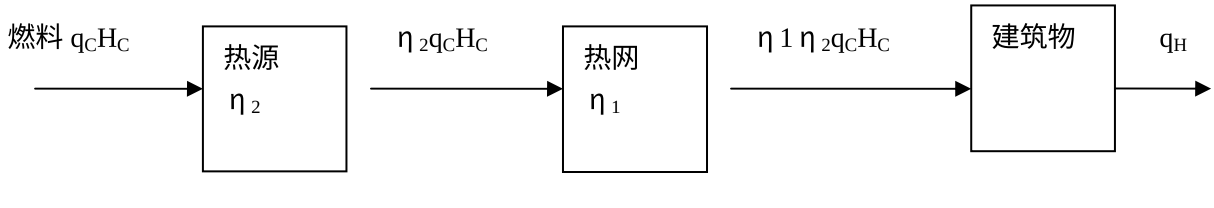

图 1　　建筑物耗热量指标与采暖耗煤量指标的关系

1　节能指标的计算方法及节能指标的分配

现在执行的民用建筑节能设计标准[1]是在第一部节能标准的基础上确定的。在节能标准中将80~81年通用住宅设计的建筑物耗热量指标q_{C80}作为节能的计算起点。

- 第一阶段节能的目标是在80~81年通用住宅设计的建筑物耗热量指标的基础上节能30%，即q_C／q_{C80}＝70%；
- 第二阶段节能的目标是在第一阶段节能的基础上节约30%，即q_C／q_{C80}＝50%；
- 第三阶段节能的目标是在第二阶段节能的基础上再节约30%，即q_C／q_{C80}＝35%。

如果用上角标"，"表示节能改造后的参数，则采取节能措施后，系统的实际节能率应大于或等于要求的节能率ε，即

$$\frac{q_H^{'}}{q_H}\frac{\eta_1\eta_2}{\eta_1^{'}\eta_2^{'}} \le 1-\varepsilon \qquad (3)$$

建筑物节能率　$$\varepsilon_H = 1-\frac{q_H^{'}}{q_H} \qquad (4)$$

热网节能率　$$\varepsilon_1 = 1-\frac{\eta_1}{\eta_1^{'}} \qquad (5)$$

锅炉节能率　$$\varepsilon_2 = 1-\frac{\eta_2}{\eta_2^{'}} \qquad (6)$$

供热系统节能率　$$\varepsilon_3 = 1-\frac{\eta_1\eta_2}{\eta_1^{'}\eta_2^{'}} \qquad (7)$$

总的综合节能率　$$\varepsilon = 1-\frac{q_H^{'}\eta_1\eta_2}{q_H\eta_1^{'}\eta_2^{'}} \qquad (8)$$

能源利用率　$$\varepsilon_c = \eta_1\eta_2 \qquad (9)$$

能源利用率提高　$$\Delta\varepsilon_c = \eta_1^{'}\eta_2^{'} - \eta_1\eta_2 \qquad (10)$$

节能标准规定，80～81年，η_1＝0.85；η_2 ＝0.55；第一阶段采取节能措施后，$\eta_1^{'}$ ＝0.9；$\eta_2^{'}$＝0.6；ε＝0.3。 由此求得第一阶段和第二阶段各项节能指标（见表1）。由表1 可知：

表 1　各个阶段节能指标分解

项目	计算公式	不节能	第一阶段节能	第二阶段节能	第三阶段节能
q_H　W/㎡		33.7	27	21.9	17.1
q_c　kg/㎡		37.2	26	18.6	13.1
η_1		0.85	0.9	0.9	0.93
η_2		0.55	0.6	0.68	0.73
ε_H	$\varepsilon_H = 1 - \frac{q_H^{'}}{q_H}$		0.2	0.35	0.493
ε_1	$\varepsilon_1 = 1 - \frac{\eta_1}{\eta_1^{'}}$		0.056	0.056	0.086
ε_2	$\varepsilon_2 = 1 - \frac{\eta_2}{\eta_2^{'}}$		0.083	0.191	0.247
ε_3	$\varepsilon_3 = 1 - \frac{\eta_1\eta_2}{\eta_1^{'}\eta_2^{'}}$		0.134	0.236	0.311
ε_C	$\varepsilon_c = \eta_1\eta_2$	0.4675	0.54	0.612	0.6789
$\Delta\varepsilon_c$	$\Delta\varepsilon_c = \eta_1^{'}\eta_2^{'} - \eta_1\eta_2$		0.0725	0.1445	0.2114
ε	$\varepsilon = 1 - \frac{q_H^{'}\eta_1\eta_2}{q_H\eta_1^{'}\eta_2^{'}}$	0	0.3	0.5	0.65

（1）第一阶段节能标准，总节能率为 30%，其中建筑物节能率为 20%，供热系统节能率为 10%；

（2）第二阶段节能标准，总节能率为 50%。其中建筑物共节能 35%，供热系统共节能 23.6%。

3　第三阶段节能指标探讨

建筑物耗热量指标也可以表示为：

$$q_{Hn} = q_{H80}\left(1 - \sum_{i=1}^{n}\varepsilon_{Hi}\right) \tag{11}$$

式中　q_{Hn} —n 阶段建筑物耗热量指标，W/㎡；

q_{H80} —　1980-1981 年通用住宅设计建筑物耗热量指标，W/㎡；

ε_{Hi} —某一阶段建筑物节能率。

第二阶段是在第一阶段能耗指标基础上，总节能率为 30%，建筑物约承担 20%，则可求得建筑物节能率为：

（1－20%）×20%＝16% ≈ 15%（JGJ26-95 标准取值）

则依据［1］中规定的建筑物耗热量指标相关参数和所采用的计算方法， 如果第三阶段节能指标在第二阶段能耗指标基础上，总节能率为 30%，其中建筑物亦按承担 20%计算，则建筑物节能率为：

（1－20%－15%）×20% ＝13%

根据式（11）可得哈尔滨地区第三阶段建筑物耗热量指标为：

q_{H3}＝33.7 W/㎡ ×（1－20%－15%－13%）＝ 17.52 W/㎡

这表明，哈尔滨地区第三阶段建筑节能 65%时，预计建筑物耗热量指标为 17.52 W/㎡。由此可以推算出要实现第三阶段节能 65%的目标，能源利用率 ε_C 应为 0.6944，这远大于第二阶段 ε_C ＝0.612。

随着技术的进步，第二阶段规定的 η_1 及 η_2 均可以提高。但理论分析表明，供热系统的节能潜力是有限的，在现有的技术条件下，，η_1，η_2 只能分别提高为 0.93 和 0.73（将另文详细分析）。此时能源利用率为：$\varepsilon_c = \eta_1\eta_2 = 0.93\times 0.73 = 0.6789$， 仍然小于所要求的 0.6944。

这表明，如果使 q_{H3} 控制在 17.52 W/㎡，系统总的节能率是达不到 60%的。如果将在第三阶段能源利用率定为 0.6789，则可以求出 q_{H3} ＝17.1 W/㎡。

这表明，在第三阶段，建筑物要节能 49.3%，供热系统要节能 31.1%（表 1）。也就是说，在第二阶段节能的基础上，建筑物的节能率为：

$$x = 1-[0.2+0.15+(1-\varepsilon_H)] = 1-[0.2+0.15+(1-0.493)] = 0.143$$

在第二阶段节能的基础上，建筑物承担的比例为：

$$y = \frac{0.143}{1-0.2-0.15} = 0.22$$

由此确定围护结构传热系数的限值为：墙体传热系数限值［K_q］＝0.41 W/(m2· K)；屋面传热系数限值［K_w］=0.30W/ m2 ·℃；窗户热系数限值［K_C］＝2.0 W/(m2· K)

3 实例分析

为了验证所确定的上述指标的合理性，以哈尔滨市 13 栋住宅楼为对象，对不同用途（一层为车库商服、普通住宅）和不同户型（复式住宅、普通单层住宅）的住宅建筑的建筑物耗热量指标进行了分析。所分析的建筑物层高为 2.8m，其基本情况见表 2。在表 2 中，(1）为底层是车库或者商服，上部 6 层为住宅；(2）为 1～6 层全部为复式住宅；(3）为 1～7 层为普通住宅。

表 2 建筑实例基本参数

	建筑面积(m^2)			体形系数		
	(1)	(2)	(3)	(1) *	(2)	(3)
北 A	8612.16	8612.16	10047.52	0.216307	0.216307	0.207405
北 B	8612.16	8612.16	10047.52	0.216307	0.216307	0.207405
北 C	3471.36	3471.36	4049.92	0.250342	0.250342	0.241839
北 E	5186.28		6050.66	0.208532		0.200029
北 F	4000.92		4667.74	0.235583		0.227080
北 H	5036.64		5876.08	0.241073		0.232570
北 J	5207.7		6075.65	0.240410		0.231906
北 K	4861.92		5672.24	0.244142		0.235639
北 L	5097.12		5946.64	0.229502		0.220999
嵩 D			4151.91			0.1948
嵩 B			4157.507			0.277503
嵩 C			6288.624			0.249712
嵩 E			3383.279			0.291769

* 表示建筑物的体形系数不包括一层。

分析结果表明：

（1）K_C=1.8 W/ m^2 ·°C时，除北鸿 A 栋和北鸿 C 栋一层为车库商服时，建筑物耗热量指标大于 17.1w/m^2 外，其余均未超过预定的限值。

（2）K_C=2.0 W/ m^2 ·°C时，除北鸿 A 栋和北鸿 C 栋一层为车库商服时及一层为住宅时，建筑物耗热量指标大于 17.1w/m^2 外，其余均未超过预定的限值。

这表明，所确定的哈尔滨市第三阶段的节能指标是合适的。

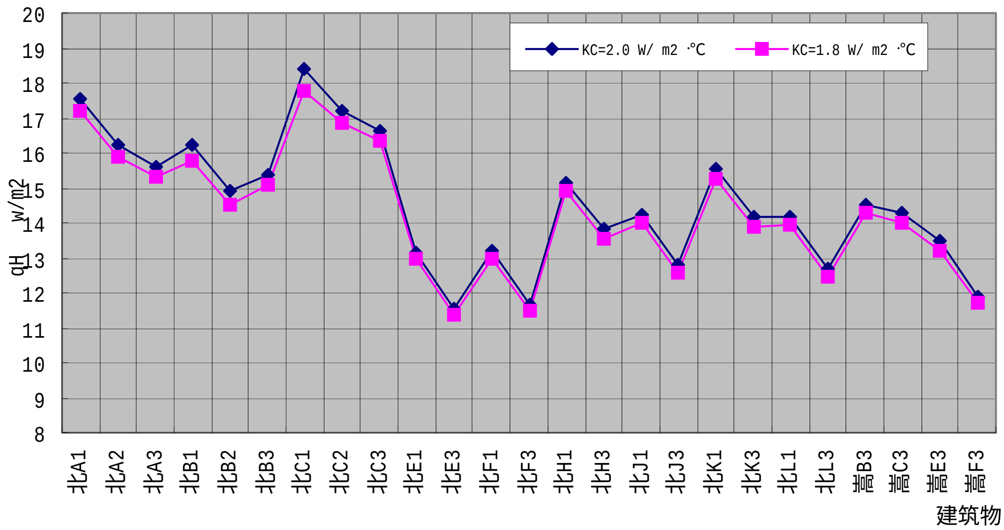

表 2　典型住宅的建筑物耗热量指标

注:建筑物角标 1、2、3 分别对应表 2 所示的（1）、（2）、（3）

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CONTAMW 模拟技术
在生态建筑办公楼自然通风设计中的应用

叶剑军　袁静　李景广

摘　要　本文利用 CONTAMW 通风及污染物模拟软件，在上海建筑科学研究院生态办公楼设计阶段，对生态楼设计方案的室内通风及污染物浓度进行模拟。模拟结果表明，门窗的开关对室内自然通风的影响很大；局部的污染不会对周边房间产生影响；室内外温差不小于 3℃的情况下，室内自然通风的换气次数大于 3，满足人体对通风的需求。
关键词　生态建筑；自然通风；室内空气质量；CONTAMW；多区域模型；预测模拟

THE APPLICATION OF CONTAMW TO ASSESS AN ECO-BUILDING DESIGN ON NATURAL VENTILATION

Ye Jianjun　Yuan Jing　Li Jingguang

Abstract　CONTAMW, a software tool for simulating indoor ventilation and pollutants, is applied to predict and assess the IAQ of the SRIBS eco-building during its designing period. It is showed that the states of the windows and doors affect dramatically the natural ventilation, while local potential pollutants do little impact to other surrounding zones. It is also recognized that the limit value of the temperature difference to satisfy the ventilation demands of human is 3℃
Keyword　Eco-building, natural ventilation, IAQ, CONTAMW,　multi-zone model, simulation

1　问题背景

自然通风是生态建筑设计过程中，一直受到关注的问题。良好的自然通风设计，可以既达到节能的目的，又有助于改善室内的空气品质。目前由上海市建筑科学研究院承担的上海市科委重大项目“生态建筑关键技术体系集成”，其主体工程是在莘庄实验基地建造生态建筑样板办公楼。如何对建筑师提出的建筑设计方案中自然通风和室内污染状况进行预测和评价，不仅可以保证建成后，样板楼室内良好的空气质量，同时也为推广该技术提供本地化的工程样板案例。

CFD（Computational Fluid Dynamics 计算流体力学）是一种预测和评价建筑设计阶段，室内通风与污染状态的方法和手段。但是由于往往建筑内房间数量众多，且形式错综复杂，CFD 需要计算量巨大，计算时间长，或者说对于目前计算机运算速度的水平下，几乎很难实现，况且 CFD 的细致描述室内各参数的特点，对于设计阶段的建筑室内空气质量的预测和评价，显然是没有必要的[1][2]。

近年来，多区域模型在预测分析和评价 IAQ 和室内通风方面得到了应用，它与 CFD 技术相比具有计算时间短，描述信息简单明确的特点。目前较著名的基于多区域模型的应用软件有 CONTAMW[3]（美国国家标准与技术研究院 NIST 研制开发）和 COMIS[4]（美国加州大学劳伦兹.伯克利国家实验室开发 LBNL）两种，这两个软件都可以帮助确定：

(a)气流：由于机械通风、作用于建筑外立面的风压以及室内外温差引起的热压效应，建筑系统内存在的渗入、渗出以及房间之间的气流；

(b)污染物浓度：依靠气流传播的污染物散发问题。

这些软件可以有各种应用。它计算房间气流的能力可以评价建筑内通风的好坏，可以确定建筑内通风随时间的变化和空间分布，还可以预测建筑围护结构密封措施对新风渗入量的影响。

CONTAMW 与 COMIS 相比，有它自己的优点：

1） 操作输入界面友好，计算结果及后处理直观，易于理解；

2） NIST 又开发了与 CONTAMW 相对应的一系列软件，这些软件可以对 CONTAMW 的功能作进一步的完善和补充；

3） CONTAMW 的软件版本不断升级，并正在与目前测试和研究建筑材料最为著名的 NRC（加拿大国家研究院）合作，计划将材料污染物释放作为数据库嵌入 CONTAMW 中。

基于上述优点，本文决定采用 CONTAMW 对生态建筑室内自然通风和污染物浓度的预测分析与评价，指导优化生态建筑的自然通风设计：

1) 分析评价门窗开关对自然通风的影响；

2) 分析评价局部污染在自然通风状态下对整个建筑的影响；

3) 分析评价室内外温差对自然通风的影响

2 模型的建立

根据建筑初步设计的几何尺寸和朝向，在 CONTAMW 中建立三层建筑框架，定义各区域的名称，面积体积，指定围护结构的漏风特性。在定义建筑及房间参数时，作如下假定：

1) 将建筑内空间分为多个计算区域，各区域内部计算参数相同

2) 室内温度恒定且为 28℃*

3) 室外温度恒定为 20℃，室外风速为零（只考虑热压引起的自然通风）

4) 计算条件为稳定工况

*注：由于影响自然通风效果只与室内外温差有关系，因此设置的室内温度和室外温度的绝对值与计算结果无关。本文将室内温度设为 28℃，室外温度设为 20℃是在模拟室内存在热负荷的情况下设置的，这些热负荷包括人员、设备仪器、以及日照等，其中 28℃是自然通风下人体的热舒适温度，为了形成室内外的温差，室外设为 20℃。

图 1、图 2、图 3 分别显示了软件中建筑平面图，其中红色标记的房间或区域是需要考察通风量的区域（1 楼：仪器自校室、生态建筑展示厅；2 楼：第三测量室；3 楼：仪器分析室）。

图 1 生态建筑 1 楼平面图

图 2 生态建筑 2 楼平面图

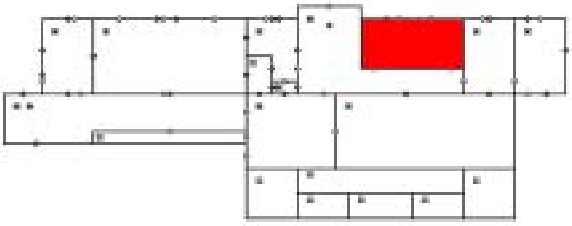

图 3 生态建筑 3 楼平面图

表 1 给出了建筑内各房间区域的面积和体积设置值，其中面积是按建筑设计平面图纸的标注尺寸计算得到，体积是软件根据各层的层高确定的。另外左右中厅贯穿三个楼层，在软件计算中各层的体积会自动相加。门窗等的漏风参数选用的是软件内置的 ASHRAE 关于漏风参数的数据库中推荐的最佳估计值。

表 1　区域面积与体积设置表

名称	面积（m2）	体积（m3）
一楼		
销光室	27.72	110.88
光学模拟实验室	17.89	71.56
控制室	9.83	39.32
声学室	27.72	110.88
仪器自校室	27.72	110.88
空调设备性能室	27.72	110.88
男厕	8.14	32.56
女厕	5.96	23.84
电梯	4.82	19.28
配电室	2.76	11.04
厕所前室	3.59	14.36
大型实验设备	84.6	338.4
左中厅	126	504
准备室	12	48
总控制室	12.32	49.28
演示厅	50.4	201.6
北部入口区	42.5	170
生态建筑展示厅	273.5	1094
右中厅	87	348
电梯前室	9.03	36.12
二楼		
测试室 1	27.72	97.02
测试室 2	27.72	97.02
测试室 3	27.72	97.02
测试室 4	27.72	97.02
测试室 5	27.72	97.02
男厕	8.14	32.56
女厕	5.96	23.84
大空间办公室	80.64	282.24
办公室	27.72	97.02
北部楼梯区	83.16	291.06
西部楼梯区	49.35	172.725
电梯前室	39	136.5
南部办公室走廊	21.42	74.97
三楼	面积（m2）	体积（m3）
小 CHAMBER	27.72	108.108
模拟 CHAMBER	83.16	324.324
设备控制室	19.89	77.571
电梯	4.82	18.798
配电室	1.38	5.382
北部楼梯区	42.84	167.076
仪器分析室	40.32	157.248
微生物分析室 1	27.72	108.108
微生物分析室 2	27.72	108.108
西部楼梯区	33.74	131.586

3　模拟结果分析

3.1　自然通风的模拟结果

图 4~7 是生态建筑样板楼利用 CONTAMW 模拟自然通风的计算结果，图中给出了通过各门窗的空气流动的方向和大小。从图中可知，通过生态样板楼 1、2、3 层外围护结构的门窗的空气流动方向都朝里，而顶部开口的空气流动向外。也就是说，由于热压作用，室外的空气从下层开口进入，从顶部开口排出，这一结果和建筑师提出利用顶部开口提高自然通风的设想是一致的。

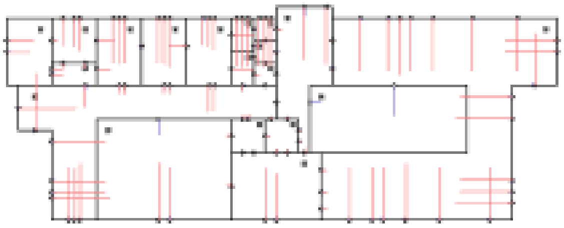

图 4　生态建筑样板楼 1 层通风状况

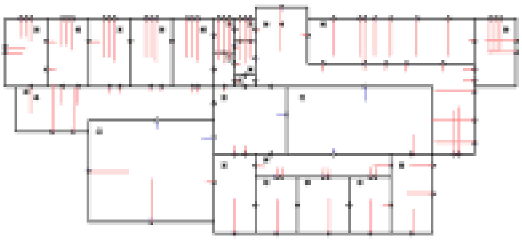

图 5　生态建筑样板楼 2 层通风状况

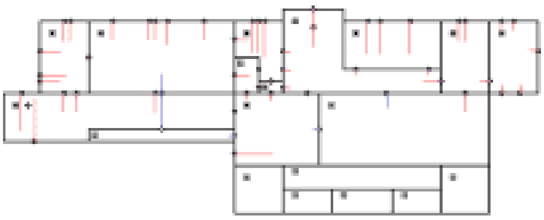

图 6　生态建筑样板楼 3 层通风状况

3.1　门窗开关对自然通风的影响

笔者分别对生态建筑模型门窗作开关两种状态的设置，分别对这两种状态进行模拟。为了说明问题取建筑物内 4 处典型区域进行分析，表 2 分别列出了这四处典型区域在不同门窗状态下，室内通风量和换气次数的大小。从数据上明显可以看出，门窗开关对通风的这两个指标参数影响很大，因此打开门窗可以显著提高室内的自然通风条件，从而有利于改善室内空气质量。

表 2　生态建筑样板楼各层典型区域通风指标在不同门窗状态下的模拟结果

门窗状态	1 楼				2 楼		3 楼	
	仪器自校室		生态建筑展示厅		第三测量室		仪器分析室	
	kg/s	ACH	kg/s	ACH	kg/s	ACH	kg/s	ACH
开	1.374	37.05	30.63	83.72	0.161	4.97	2.415	45.91
关	0.003	0.084	0.069	0.189	0.003	0.0787	0.004	0.083

3.2　局部污染在自然通风状态下对整个建筑的影响

为了了解和评价局部由于工作原因产生的污染物对其他区域的影响程度，同时考虑到将来办公楼各功能房间的实际情况，将 1 楼仪器自校室、2 楼第三测量室和仪器分析室共 3 个区域的 VOC 浓度设定为 1000ppb（2.33mg/m^3），分别模拟门窗开关两种状态下，各房间污染物浓度的水平。表 3 分别列出了除浓度设定区域以外，其他区域的浓度水平，并由高到低排列。由表中数据可以

得到，当某些功能房间由于工作的需要可能产生污染物的时候，它对其它房间的影响是相当小的，当 VOC 浓度在设定房间内为 1000ppm（2.33mg/m^3）时，无论是门窗开关，受影响的区域最大浓度只有 0.35 mg/m^3，而标准为 0.6 mg/m^3，可见该生态建筑样板楼的设计及房间功能布置较为合理。图 8、图 9、图 10 分别用颜色表示了室内各房间浓度水平。

表 3　生态建筑样板楼部分区域污染影响模拟结果

门窗状态	高→低			
开	2 楼西部楼梯区	1 楼大型实验设备区	1 楼左中厅	3 楼电梯前室
	0.339mg/m^3	0.334 mg/m^3	0.156 mg/m^3	0.025 mg/m^3
关	2 楼西部楼梯区	3 楼北部楼梯区	1 楼大型实验设备区	1 楼左中厅
	0.349 mg/m^3	0.337 mg/m^3	0.206 mg/m^3	0.131 mg/m^3

图 8 生态建筑 1 楼污染物浓度水平（门窗状态开）

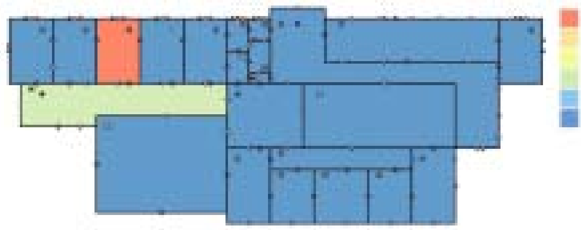

图 9 生态建筑 2 楼污染物浓度水平（门窗状态开）

图 10 生态建筑 3 楼污染物浓度水平（门窗状态开）

3.3　室内外温差对自然通风的影响

为了评价室内外温差对自然通风效果的影响，笔者分别设置室外温度为 20℃和 25℃（室内为 28℃）及室内外温差分别为 8℃和 3℃的情况下进行模拟，考察在不同情况下，典型区域室内通风量和换气次数的影响。表 4 给出了不同工况下典型房间通风参数的模拟结果值。由表 4 中数据可以判断，随着室内外温差的降低，通风量和换气次数都减少。观察自然通风最小的 2 楼区域可以判断，如果将 3 次换气次数作为通风基本要求的话，室外 25℃及室内外温差为 3℃将是一个极限，也就是说当室内外温差大于等于 3℃时，可以满足自然通风的要求。

表 4　生态建筑样板楼各层典型区域通风指标在不同温差情况下的模拟结果

室外温度	1 楼				2 楼		3 楼	
	仪器自校室		生态建筑展示厅		第三测量室		仪器分析室	
	kg/s	ACH	kg/s	ACH	kg/s	ACH	kg/s	ACH
20℃	1.374	37.05	30.63	83.72	0.161	4.97	2.415	45.91
25℃	0.829	22.36	18.45	50.43	0.099	3.041	1.473	28.00

4 结论

- 关闭门窗会极大的影响自然通风的效果（换气次数接近于 0）
- 无论门窗全部关闭还是全部打开，在热压驱动的自然通风状态下生态建筑样板楼中可能产生污染的地点，即使浓度相当高，对周边区域的影响都相当小
- 室内外温差对自然通风有相当影响，温差越大，换气次数越高。当门窗全开情况下，生态建筑的中性面在 2 楼附近，取 2 楼房间为考察对象，如果自然通风的最小允许换气次数为 3，那么热压驱动的自然通风的最小温差不能小于 3℃，这一结论可以用于自然通风和机械通风的自动切换控制。

5 展望

CONTAMW 的计算结果可以用来评价建筑设计方案中自然通风的优劣。因此，利用该软件可以为建筑师在建筑设计阶段对自然通风设计方案的选取提供技术参考。

CONTAMW 是基于多区域模型预测和评价建筑室内空气质量和通风的应用软件，它的计算结果的有效性得到了一些实例的验证[5][6]，但是由于它在计算中所采用的气候、建筑性能等参数数据库都是建立在符合西方国家特点的、或是在西方国家适用的条件下的，而在我国，特别是上海地区，这些数据库因此并不可靠，至少是不全面的。因此有必要针对中国特点建立一系列符合我国国情和气候特点的本地化数据库。此外，该软件计算结果也需要本地化有效性的验证，这也是在生态建筑样板楼建成之后，需要进一步开展的研究工作。

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Sustainability: Building the future today

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C.A.M. Stap, Managing Director Energy in the Built Environment, Ecofys BV

1. Introduction

There is little need to explain that there is a worldwide necessity for sustainable buildings. From a technological point of view we are already capable of building houses and offices with a very high-energy performance (in terms of energy efficiency, generation and usage of sustainable energy). However, current building practice shows that often we do not produce the quality we are capable of (and economical issues are not always to blame).

There are many relations between the building construction and its energy supply. In this paper we will make clear that an optimal building can hardly be realized when considering the building installations as 'add ons' instead of integral elements of the whole. To make the energy supply an holistic element of the building design requires a vision on various aspects.

In this paper we discuss many ideas that may contribute to the realization of high quality sustainable buildings. Firstly we focus on the role of the authorities, who define, with their policy, the boundary conditions for sustainable building. Next we look at the stakeholders in the building process. With some examples of building projects in The Netherlands we will illustrate that the future can be built today.

2. Policy

The most important goal concerning energy in the built environment is to increase the energy performance whilst complying with health and safety aspects. A high-energy performance is defined by a low usage of fossil fuels, or low CO2-emissions per unit of volume.

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[1] Ecofys has a clear mission: a sustainable energy supply for everyone. This is the goal that everyone in our company believes in and strives for. In a company that is a leader in renewable energy and energy efficiency, knowledge and innovation are key elements in turning the ideas of today into the viable solutions of tomorrow.
An experienced market leader
Established in 1984, Ecofys specialises in energy saving and renewable energy solutions. As part of the Econcern group (www.e-concern.com), we offer research and consultancy services as well as product development. Besides Ecofys, the companies Ecostream, Evelop and Ecoventures also belong to the Econcern holding.
Over the years we have conducted extensive research and completed projects for many energy companies, housing associations, building companies, (inter)national and local authorities, and energy consumers around the world. With more than 150 employees in six countries, we are one of the largest consultancies in sustainable energy and climate policy.
Broad expertise
Ecofys offers a wide range of high quality services, based on our extensive knowledge of renewable energy and energy saving solutions. Areas of expertise include solar energy, wind energy, biomass, hydrogen technology, energy supply and climate policies. Our experts are organised around different markets. Technical, financial, legal and planning disciplines are combined to develop balanced and cost-effective solutions.
Innovative and forward thinking
Ecofys is always at the forefront of climate and energy market developments. Because of our activities in strategic research and our contributions to international and local policy development we lead the way in applying these advancements in our projects. We also continue to develop new products of our own, or in partnership with other organisations.

Authorities should stimulate the market to develop buildings with a high-energy performance. Hence, policy makers have to be focused on the objectives instead of the means (we are in favour of regulation aimed at a certain energy performance without enforcing specific options).

Figure 1

The Netherlands has chosen to implement a system based on a standard for the energy performance of buildings. This system gives both the policy makers and the building industry a significant amount of flexibility. The market forces determine what kind of measures will be developed to meet the regulation.

The Energy Performance value (EPC) is a measure for the expected building related energy use of a house (space heating, ventilation, cooling and hot water supply), subject to standardized occupant behaviour. An EPC value of 1 corresponds to an annual energy demand for a typical Dutch terraced house of approximately 1000 m3 of natural gas @35 GJ. A lower EP-value indicates an expected smaller energy use. The graph shows the development of the Energy Performance Standard (in Dutch: EPN) for houses in The Netherlands.

The EPN was introduced in 1995, but it is possible to calculate the EPC for the previous years (see also figure 1). The two oil crises in 1973 and 1979 were the reason for the Dutch government to start regulating the insulation of buildings. The thickness of insulation was increased, step by step, from 0 to 8 cm's and later, in 1990, requirements for double-glazing were also introduced. A second important improvement was the introduction of condensing boilers for space heating. At the introduction of the EPN in 1995, the design had to comply with an EPC of 1.4 maximum. In two stages the required EPC has now been lowered to 1.0 in 2004.

Figure 2

Figure 2 shows that the developments were above the expectation of renowned energy research institutes. Not too many years ago the progressive decrease of the EPC was believed to be unrealistic because of economic barriers. On the other hand, demonstration projects were carried out to show that from a technological point of view low EPCs could already be realized in an early stage. Currently the majority of both the Dutch politicians and those in the building industry believe the unexpected fall of prices of sustainable technologies is due to the strict energy performance legislation. Therefore, a new EPC level of 0.8 has been announced for 2006. Even an EPC of zero is being predicted. Various energy concepts making use of heat pumps and solar energy etc. are possible, reducing the net use of fossil fuels over the years to zero (figure 3).

PANDA Houses

WWF have worked with several large project developers to build very energy efficient houses in 5 locations in the Netherlands (Nieuwegein, Tilburg, Nijkerk, Almere en Apeldoorn). The project was very successful and has been continued in 2002 with 'solar houses'. The most important features of the project are that the houses are realised without any subsidies and that they have only made use of proven techniques and measures. These houses are therefore built within the existing commercial construction and financing methods.

Figure 3

3. Vision

As for all things that humans create, a vision is necessary to design an optimal building. Certainly, the principal and the architect should develop this vision in the earliest stage of the development process, thus allowing synergy between the energy supply and the building. Apart from being an element in an urban environment and determining the structure and atmosphere of a district or a city, a building is foremost the containment of a number of user functions, facilitating its occupants and contributing to their well-being. Therefore, the energy supply needs to be an integral component of the building and will be of influence on investment costs as well as exploitation costs of the building.

For this reason the architect of a building must be aware of the implications of the building design on the energy demand and the indoor climate. An optimal energy supply system can only be achieved when taking the energy aspects into account in the earliest stage of development of a building.

With regard to buildings we distinguish various aspects that make up a vision:

- The time-dimension and life cycle approach
- The Trias Energetica
- Client orientation and stakeholder analysis
- The learning curve

3.1 The time dimension

Time dimension

All construction activities of today will be part of tomorrow's future. Looking at very old maps of city centers we will often recognize the street plan that still exists and even some of the buildings that are still in use. This shows that the choices we make during design of towns, buildings or infrastructure will influence the possibilities for a sustainable energy future.

How can we design a sustainable energy infrastructure in new areas that will be prepared for the future? This is a complex question because the whole energy chain consists of different components influencing each other. Also new clean and sustainable technologies are being developed and will be commercially available in the near future.

In the table below the different levels of the built environment are given together with the expected lifetime and aspects that need to be taken care of.

Level	lifetime in years	Influence on lifetime energy consumption	Aspects affecting the energy use
Urban plan	150-200	+	Solar design Space for new infrastructure Density
Building design	50-80	++	Low energy demand for indoor climate (e.g. insulation, air tightness etc) Possibilities for integrated sustainable energy (e.g. PV, Solar hot water)
Energy infrastructure	30-50	++	Affects the choice for in-house conversion (e.g. natural gas, heat distribution). Affects the choice for future introduction of renewable energy (e.g. biogas, H2)
Distributed energy production	15-25	+	Source (e.g. natural gas, oil, earth heat). Efficiency (e.g. cogeneration)
Building installations	10-15	+	Efficiency, capacity Synergy with building envelope
Equipment	1-10	++	Choice affects highly the electricity usage

Normally, buildings will have a lifetime of at least 50 years. It is likely that within the life cycle the installations will be exchanged or retrofitted. The design should facilitate changes to energy supply system.

Infrastructure

In order to create a truly sustainable energy supply system clean energy carriers should be used, to eliminate many small sources of CO2-emissions. The most common CO2-free energy carriers for the built environment are electricity and heat (hot and cold water). In the near future hydrogen has the potential to become a viable option.

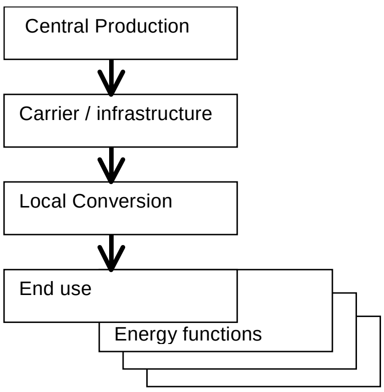
Electricity is a versatile energy carrier with many possibilities. Especially looking at the decreasing need for heat for space heating, due to the improved insulation, heat recovery from ventilation air etc., the idea of an all-electric energy supply system for houses and offices is a realistic alternative for the near future. On the other hand it is also a relatively expensive form of energy.

The production of electricity always results in the simultaneous generation of heat. We can make use of this phenomenon by cogeneration of heat and power (CHP). Cogeneration can be realized on the level of:

- A district (large scale district heating and/or cooling by combined cycle units)
- One large building (large office buildings, flats or a series of terraced houses)
- One house(micro CHP)

Energy chain

The energy supply for the built environment consists of four elements: central sources/production; energy carriers; local sources and conversion; and end use. The demand for electricity and heat can be met by a number of energy carriers. Currently these are restricted to natural gas, district heat and electricity. In a sustainable future other carriers could play an important role, e.g. biofuels, synthetic (natural) gas or hydrogen.



Several possibilities are available for the central or local production of energy. The CO2-emission in the energy chain is largely dependant of the fuel source for production. Electricity from coal will emit more than twice the amount of CO2/kWh compared to a natural gas electricity plant. Renewable sources such as PV, wind or hydro will reduce the CO2 emission to zero.

Mainly there are two ways to reduce CO2 emissions in the chain: 1) reducing the energy demand and 2) lowering the CO2 content of the energy carriers.

Important programs to reduce the energy demand in the built environment are based on a passive design and making use of insulation, heat recovery, efficient boilers etc. Mainly this is meant for lowering the heat demand in houses and offices. More and more we see electricity having a growing part of the total energy demand. Cooling and lighting are the main applications responsible for this. Therefore programs in Europe more and more focus on energy efficiency improvement in these areas.

Lowering the CO2 content of the energy carriers in the energy chain will of course help to lower the CO2 emission in the whole chain. For the long term it is expected that new carriers as mentioned above will play an important role. Another possibility is the CO2 capture and storing. Some experimental projects are currently delivering the first results and it is expected that CO2 mitigation could play an important role in the middle term future.

When using heat inside buildings we want to work with low temperatures. This enables us to use all kind of generation methods (solar heat, heat pumps etc.) with relatively high efficiencies.

Heating and cooling can be done with centralized as well as with decentralized systems. District heating and district cooling can be very interesting options depending on the energy supply chain, the type of buildings (building density) etc. Networks can also serve as collective sources for decentralized heat pumps.

At the moment there is a trend towards decentralized energy supply systems, also called distributed power generation. This trend is based on various developments:

- Liberalization of energy markets
  Liberalization makes the network accessible for small producers
- Increasing need for autarkic systems
  The fear for terrorism and the fear of failure of the function of the market (black outs) feed the need to become self-supporting
- Technological developments
  The introduction of low cost photovoltaic systems, micro CHP-units etc. make decentralized power generation more attractive.

3.2 Life cycle approach

With respect to energy we need to realize that the building design influences the energy consumption during the entire lifetime of a building and that this energy consumption can be quite significant. For a house, the building related energy demand (depending on the climate zone) is in the range of 40 GJ/year. With a lifetime of 50 years this results in an energy use of 2000 GJ or some 350 barrels of oil. Still, feasible energy saving measures are often not implemented because of economical constraints. Normally, the beneficiary party will be the occupant and not the initially investing project developer or housing association. New ways of organizing the energy supply could offer a solution for this problem. Actually, the occupants of a building are not interested in electricity or hot water, they want light, a nice indoor climate etc. Energy service companies (ESCO's) can provide services that fulfil the needs of the end-users in a more direct way. Outsourcing of the energy supply to ESCO's can result in optimization of the life cycle costs. We see a trend where installers get involved in the early stages of the building process to guarantee performances for a fixed price for comfort, safety, ICT and energy management in a building. We also notice a trend of building companies leasing buildings to the occupants. This is also a formula that stimulates the market to use a life cycle approach.

3.3 Trias Energetic**a**

Any amount of energy that can be reduced will not have to be produced. So, the first priority should be to avoid waste of energy. Orientation of the building, positioning of the rooms with specific functions, insulation, etc. are good examples of measures that are very economical and can save a great deal of energy. The remaining energy demand should be met by renewable energy as much as possible. Only if necessary the remainder of the energy demand should be supplied by efficient use of fossil fuels.

1 reduce the energy demand by rational use of energy

2 use renewable energy

3 utilize fossil fuels with maximum efficiency

3.4 Client orientation

There are many stakeholders in the building process (NB: in many cases the occupants who have in fact the largest interests are not present during the actual building process!). The interests of the various stakeholders depend on the specific situation (ownership, organization of the energy supply, etc.). The parties involved in the building process should be aware of the interests of all others involved.

Stakeholder	Interests
Principal/ Project developer	Profit
Architect	Name and Fame
Authorities/Municipality	Compliance with regulation
Consultant	Innovation
Construction firm	Turn over / Profit
Owner/Occupant	Comfort
Energy company	Client relations
Supplier	Turn over
Occupant	Comfort

3.5 Learning curve

New legislation is one of the driving forces for a continuous development of new sustainable technologies all over the world. Before these technologies become commercially available, they will follow a learning curve through stages such as prototype, experiment, demonstration and best practice. Putting the new technologies into practice will improve reliability, create markets and lower prices.

Figure 4: first zero energy street

Large scale introduction of new technologies will not take place if reliability and price are not fully optimised. Therefore, ambitious new developments could make use of a ‘dynamic’ development scheme: experimental and demonstration technologies will have a limited role in the first phase of a development, for example only 2% respectively 18% of the total building volume. Hence, these technologies will be improved, lessons will be learned and prices will go down. This will smoothen the path for large-scale application of this technology in the next phase of the development. This is shown in the following picture.

Figure 5: learning by doing

The integrative approach: a recipe for sustainable building

Can we afford sustainable building? We think the question should be: ‘Can we afford not to make our buildings sustainable?’ Already we experience the negative effects of the human energy use. Together with the oil prices we may expect that in general energy prices will rise steeply within the next years. It is obvious that not all available options for energy conservation and for renewable energy are feasible yet. However, by using an integrated approach many costs can be reduced or avoided.

One example is the integration of photovoltaic solar panels in the envelope of buildings, replacing other construction materials.

Figure 6: Integration of PV

From the societal point of view we should optimize the life cycle costs and not just focus on the investment costs. Especially in a large market like China, the scale-effects will have a large impact on the price of new technology and materials.

To summarize the above mentioned ideas, a number of essential steps should be taken to create an integrative approach to sustainable building:

Figure 7 : vision: a necessity for integrated approach

DESIGN PHASE

1. Create a vision on the integration of energy supply in the building design; always consider the energy supply system as an integrated element of the building(design).
2. Make sure all disciplines are represented in the design team and use methods that allow/facilitate co-operation between the disciplines.
3. Make sure to get a clear picture of the required user functions of the building (for this a stakeholder analyses can be quite useful).
4. Analyse the relation between the building and its environment;
building orientation, available infra structure, organization of the energy supply are important elements.
5. Keep future options open where possible.
6. Use the Trias Energetica as a leading guideline for your design.
7. Translate your vision into a concrete terms of requirements.
8. Use a life cycle approach to evaluate the feasibility of investments (make sure to involve the exploitation costs in the analyses).

PROCUREMENT AND CONSTRUCTION PHASE

1. Ensure continuity in the building process;
results from the design phase should be used in the procurement and construction phases.
2. Use clearly defined procedures to assure the quality during the construction phase.

EXPLOITATION PHASE

1. Make guidelines for the users of the building and for service and maintenance companies to ensure that the installations are used correctly.

Literature

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Environmental assessment of buildings – development and trends

Introduction

Sustainable construction as quality issue in building projects has developed over the last 10 years in a number of European countries, including The Netherlands. But also outside Europe, e.g. USA, Canada, Japan. Background is sustainable development as defined for the first time in the United Nations Brundtland report. Sustainable construction is the contribution to sustainable development of decisions about the built environment.

The scope of building quality issues has widened from the building itself (indoor climate, building physics) to the impact of buildings upon resources (upstream data) up to the whole life of buildings including re-use of existing buildings and demolition strategies. Issues like adaptability and flexibility become part of the equation.

Sustainable construction combines a focus on quality for the users with the condition of such use of resources that the environment as a whole does not get overloaded or over-exploited.

Sustainable construction introduces life cycle thinking on all aspects of a building: architecture, construction methods and structural engineering, mechanical and electro technical installations. The use-value and cultural identity are essential.

Adaptability and flexibility are key aspects to achieve sustainable buildings.

Sustainable construction involves all participants in the building sector. Developers and investors develop buildings, designed by architects and consultants. This process is closely related to the governmental requirements and the user demands.

This article focuses on the development of tools aiming at a sustainable built environment in the Netherlands. The building sector in the Netherlands was first identified, in 1990, as an ‘environmental’ sector in the National Environmental Policy Plan, the so-called Sustainability Agenda and its Annex on Sustainable Building. The Netherlands’ history in reducing energy use in the building sector goes back to 1973. Also other basic environmental concerns have been addressed in legislation for many years, e.g. through zoning taking into consideration noise, contaminated land, water and air pollution and minimum requirements as to indoor climate.

The Sustainability Agenda of 1990 added new environmental issues such as lifecycle impacts of energy use, consumption of materials, water and land and improved indoor conditions and so-called ecological zoning, e.g. defining nature zones and areas between cities as ecological areas. The Dutch government regards Lifecycle Assessment as a suitable method for formulating rules and regulations governing the use of materials and products.

The Dutch Environmental Council for the Construction Industry has put together various indicators for determining the environmental performance of a product, namely exhaustion of resources, emissions (to air, water and soil), energy, waste and nuisance.

Also present and foreseeable building rules and regulations prompt the building industry to reflect on environmental aspects.

Initiatives from different actors in the market moved the issues forward. The building sector as a whole agreed on information documents describing sustainable building measures for urban planning, infrastructure and buildings.

Construction products manufacturers agreed on an environmental declaration scheme through which the environmental impact of materials can be specified as technical specifications.

An environmental assessment method for buildings was established by the building industry, using the environmental declaration scheme as input for developing databases.

The government sets performance targets for energy consumption of buildings in use and is developing a so-called Environmental Material Performance Standard.

Cities and municipalities develop projects meeting requirements based on the above schemes and approaches.

Energy Performance Standard

In 1996, the government set performance targets for energy used by buildings as part of the national Building Code. When submitting a building plan to a local authority, the party requesting planning permission must present a calculation of the building's Energy Performance expressed by a so-called EP-coefficient (EPC). This is calculated by dividing the characteristic use of energy of the building by an admissible characteristic energy performance. The characteristic use of energy of a building corresponds to the energy required for heating, ventilation, lighting and hot water. The lower the EP-coefficient, the better the energy efficiency.

Establishment of an Environmental Construction Product Declaration Scheme

In 1999, manufacturers of construction products agreed on an environmental declaration scheme through which the environmental impact of their products can be specified. Buyers and sellers of construction products as well as others active in the building sector have increasingly been requesting information on the environmental aspects of materials used. To meet this demand, lists of environmental preferences were drawn up and published in the Handbook on Sustainable Building (Anink et al. 1996), of which the first version appeared in 1991. However, according to the building industry, the information given appeared at times to be based on inaccurate data, and the industry therefore decided to provide this information on its own following an Environmental Product Declaration Scheme, MRPI, i.e. Environmentally Relevant Product Information. The Dutch Federation of Suppliers to the Construction Industry defines MRPI as follows:

Verified information on the environmental aspects of a building material, construction product or building module generated at the initiative of a manufacturer (or its representative) by means of an environmental lifecycle assessment (LCA) study which can be used for communicating with specific target groups.

To create an MRPI page, a manufacturer needs a Lifecycle Assessment (LCA) performed by a certified research institute according to the MRPI-procedure. After verification, the data are summarised on an

MRPI page. This MRPI page thus contains verified environmental information on the material or product. DHV develops MRPI pages for clients.

Introduction of a Building LCA Tool: Eco-Quantum

Until recently, only construction products were subjected to LCA. But a building is more than an assembly of components, so establishing an LCA of completed works is important. In order to provide architects and developers with an instrument to measure the environmental performance of buildings the Steering Committee for Experiments in Public Housing, the Dutch Building Research Foundation and the Association of Dutch Architects and the government supported the development of Eco-Quantum.

Eco-Quantum is a computer program based on LCA. It calculates and quantifies the environmental effects during the construction and life of a building, from the moment the raw materials are extracted and transported, via production, erection and use to demolition or dismantling. This includes consumption of energy and water, maintenance during use, differences in durability and maintenance requirements and the need for re-building. Eco-Quantum also takes into account the possibility for selective demolition and renovation.

Both architects and local communities welcomed Eco-Quantum as an easy-to-use tool enabling them to improve the environmental quality of projects in an expedient manner. Their only negative comment was that some material alternatives were not yet integrated. Work is and will remain ongoing to improve that part of Eco-Quantum by adding alternatives. This will be facilitated by the above mentioned Environmental Product Declaration Scheme (MRPI) whereby industry provides certified data that can be entered into Eco-Quantum.

DHV assists SBR in marketing Eco-Quantum and by evaluating large numbers of projects against it, and publish results. Also DHV develops applications of Eco-Quantum in cooperation with municipalities who want to develop sustainable building policies.

National packages concerning sustainable building

The Action Plans on Sustainable Building mention 'harmonisation' as one of the four directions for spearhead action. In 1995 and 1997, two such Plans were published. An outcome of this was the development of National Packages for Sustainable Building to harmonise the various requirements prescribed by local authorities in the field of sustainable building. A National Package is a collection of measures and recommendations. It can function as an instrument for local authorities because they can select measures appropriate to their policy on sustainable building. If a local government decides to enlarge its policy on sustainable building, the measures can also be enlarged, or a larger selection of recommendations can be made. Up to 2004, such National Packages have been published for new and existing housing, commercial buildings, urban planning and infrastructure.

Broad consensus within the construction industry and among product manufacturers, developers and government has been achieved on the definition of sustainable measures. The National Packages are now used to define criteria for new project developments, to create agreement within project consortiums and to define eligibility for ‘green’ financing schemes.

In the late nineties, about a hundred building projects were selected as demonstration projects for sustainable and energy-efficient building. The Netherlands Organisation for Energy and Environment and the Steering Committee for Experiments in Public Housing jointly run a programme to financially support and disseminate information about these projects. The National Packages have been used to identify the eligibility of such demonstration projects.

DHV has developed five of the National Packages Sustainable Building in The Netherlands.

Observations

Globally, nationally, regionally, and locally relevant environmental targets must be addressed to economical sectors, including the construction sector. These should be short, medium and long-term environmental targets. Ideally these targets are agreed between major parties in a sector.

There is a need to integrate principles of sustainability into the practice of design, construction maintenance and management of buildings. The parameters that matter most must be identified in a language that is consistent with the issues typically addressed in the construction sector.

A clear link between environmental issues and the impact caused by a building must be established, and communicated. There is a need for building environmental assessment methods, which respond to environmental issues, and define sustainable levels in existing language and parameters.

Many of the current building environmental assessment methods apply for each method unique credit systems and weighting methods, and result into unique single units. There is the risk that communication about such single units or a certain rating becomes a target in itself without the possibility to make reference to the relevant environmental issues.

Even though the issues raised in the methods do overlap, each country launching a method develops indicators for their own market. Building environmental assessment tools have been most successful in countries, where government, industry, developers, architects and Life Cycle specialists develop common language and indicators.

There is a trend to address environmental issues in relation to decision-making steps. Most current environmental assessment tools have started from completed design assessments. Latest developments demonstrate that other relevant stages are now also addressed to mention: early design and building management and operation of existing buildings.

Most tools combine self-assessment, with a type of external assessment, which if often related to a certification procedure of the results. Such procedure guarantees the quality, while the involved parties can also work with the method directly.

The certification route seems to be most successful, and consistent with working method of building managers. On the other hand some opposition from architects and designers is reported, since the procedural route does not always challenge designers.

Sustainable construction is often implemented through approaches primarily based on checklist of measures. Most tools are based on application of such measures and good practice approaches. This limits the assessment to known solutions. Sustainable construction however should be implemented through integrated approaches, and optimised solutions within the domain of each player in the construction sector.

The trend towards performance-based assessment may help to overcome this drawback and challenge designers and building managers to freely invent innovative solutions.

Conclusions

Inclusion of sustainability and energy requirements in the Building Codes is the most important in order to achieve a good baseline quality. The implementation of the energy performance standard has been extremely successful.

Practical design information and reference material play an important role for building designers and design institutes. The National Packages Sustainable Building have proven to offer a good platform for dissemination and communication.

Excellent quality should be rewarded by the introduction of a building certification scheme. This must be based on scientifically justified environmental assessment methods, supported by industry driven environmental databases.

Good practice demonstration projects supported with information dissemination activities have proven to be most convincing to the construction sector.

Innovation in energy concepts for heating and cooling

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Summary

This paper concerns the application of sustainable energy for heating and cooling of buildings. It will be shown that winter cold and summer warmth are well applicable for this purpose. Various innovative energy concepts will be presented, which are suitable for China and are widely used in The Netherlands. Experiences with the market introduction of these new technologies will be briefly discussed because they may be useful for Chinese architects, designers and governmental organisations.

Introduction

Cooling and heating of buildings is required to achieve a nice living climate and a comfortable working place. For office workers a good indoor climate improves the productivity by 2 – 10 percent. Figure 1 shows investment results for the West European situation. The loss of productivity increases when the ventilation rate is lowered and especially when no cooling is provided. Fifty lost hours a year means about 3% productivity drop corresponding to €1600 per employee a year. Investing in a good working environment appears to be very profitable.

On the other hand cooling and heating with conventional equipment, chillers and gas or oil fired boilers, take a lot of energy. Fossil fuel reserves are not inexhaustible and nowadays we are going to experience that the production of cheap oil can not limitless be forced up. As soon as the oil demand exceeds the supply, the price will go up. From the economic point of view it makes sense to pursue high energy efficiency in heat and cold supply for buildings. This can very well be achieved by applying sustainable energy sources as will be discussed in this paper.

Choose right energy source

Applying natural energy sources, like winter cold and summer warmth, avoids the spilling of fossil fuels (coal, oil, gas) for 'low-grade applications'. Keeping a building at a temperature of 22 °C is clearly a 'low-grade application' as it requires temperature levels of only 10 – 50 °C. Fossil fuels should be reserved for high-grade applications like high temperature industrial processes, power generation or input for the chemical industry.

From the environmental point of view it is necessary to control the growth of the energy consumption to reduce the CO_2-emission and to avoid global warming, of which the occurrence has already been noticed (figure 2).

Peak shaving

In climate zones where cooling is required in summer, the electrical peak load in cities may increase enormously due to all the air conditioning equipment turning into operation simultaneously. The required capacity of power plants and the electrical infrastructure is strongly determined by the cooling power peaks. Storage of free winter cold for cooling in summer saves a lot of money and contributes to peak shaving over the year.

DEC: cooling with solar heat

Air can be cooled by dehumidification, heat exchange and humidification. This type of air conditioning is known as Desiccant Evaporative Cooling (DEC). It is an energy efficient process, enabling the application of solar heat for cooling purposes.

The working principle of DEC is shown in the figures 3 and 4. The sorption wheel (A) plays a key role in the system. It is a heat recovery wheel with a coating of sorptive material (e.g. silicagel or lithiumchloride). With this sorption wheel the air can be strongly dehumidified.

Winter

In winter both the sorption wheel (A) and the second heat exchanger (B) are used for heat recovery from exhaust ventilation air. Up to 85% of this heat can be recovered for heating the ventilation supply air. Additional heating may be unnecessary with this system. Thanks to the sorption wheel 80% of the moisture in the exhaust air can be recovered for humidification of the supply air.

Summer

In summer the ventilation supply air has be cooled. Firstly this will be done by humidification and adiabatic cooling of the exhaust air in humidification section (C). The process is shown in figure 5. If more cooling is needed, a two stage process is used (figure 6). The incoming outdoor air is being conditioned in 3 steps:

1. drying in the sorption wheel (A); step 1-2 in figure 6;
2. cooling in heat exchanger (B); step 2-3;
3. humidification of air (C) and adiabatic cooling; step 3-5.

The sorption wheel has to be regenerated, which means that the moisture is expelled from the sorption material by heating up the air (step 8-9 in figure 3). The maximum required temperature for the regeneration heater (E) is about 70 °C. With this temperature the outdoor air of 28 °C, 60% r.h. can be cooled down to 15 °C. Solar collectors can produce the heat for regeneration. The efficiency (Primary Energy Ratio) of the 2-stage cooling process is 0,6 which is comparable with absorption chillers. It means that that the regeneration heat must be solar heat or free waste heat. Regeneration heat from a gas fired boiler is energy inefficient compared to electrical chillers.

An example of an installation with DEC and solar collectors is shown in figure 7. The solar heat is stored in a buffer tank. In case of a heat shortage from solar the boiler will additionally deliver warmth. Figure 8 shows the measured results during a warm day. The outdoor air is cooled down to about 18,5 °C.

Energy efficiency

Both in winter and summer the energy consumption of a DEC system with solar collectors is lower than a traditional installation (boiler + chiller). In The Netherlands the overall saving of energy for heating and cooling amounts to 45% (table 1).

Table 1 Energy consumption and saving with DEC

	Eenheid	Conventional	DEC system with solar
Summer / cooling	[m³ a.e.]	3700	3600
Winter / heating	[m³ a.e.]	12500	5300
Total	[m³ a.e.]	16200	8900
Saving with DEC system	[m³ a.e.] [%]	-	7300 45

Profitability

The most expensive part of a DEC system is the sorption wheel. Also the solar collectors may still be rather expensive. The investment costs of an air handling unit of 20.000 m^3/h and up with DEC is comparable with a traditional unit in combination with electrical chillers. Smaller systems with DEC are relatively more expensive. For a good investment comparison of DEC with a conventional cooling system one has also to take into account the costs of the electrical power connection, the extra technical room for cooling equipment, cooling towers etc.

Moreover DEC systems need much less maintenance than mechanical chillers, they do not need refrigerants and they consume less energy. This means that the annual running costs are lower and an extra investment will be paid back.

Is DEC applicable for China?

The best performances of DEC will be achieved in regions with little humidity, much solar radiation and high air temperatures. In Shanghai the average relative humidity is high (figure 9) and DEC will require much energy for dehumidification. It is expected that DEC will be most suitable in inland towns like Xi’ang and Zhengzhou.

Seasonal energy storage in the soil

There are various different ways to meet the need for heating and cooling in built-up areas (offices, university buildings, hospitals, shopping centres etc.). Apart from generating cooling through chillers (mechanical cooling), absorption cooling or DEC there is the possibility of storing winter cold in the soil to meet the cooling demand in summer.

Seasonal energy storage in water bearing sandlayers (aquifers) can offer a viable alternative to conventional methods of cooling. Economic aspects are an important factor in choosing the required cooling system. Reducing energy costs and environmental aspects are of growing importance.

Aquifer seasonal cold storage could be cost effective in offices larger than 4.000 m^2, hospitals with 300 plus beds and other buildings with a cooling load of 400 kW and up. Cooling is often the main purpose of energy storage. However both cold and low-temperature heat can be stored and utilized. Seasonal storage cuts the annual energy consumption and energy costs for cooling by 40 – 80%. In The Netherlands aquifer storage is proven technology. Over 250 large aquifer storage projects have been realised in the past 15 years. It is a profitable alternative to chillers.

Aquifer storage technology

The working principle of aquifer storage is simple (figure 10). The energy is stored in a water bearing sandlayer, a so called aquifer. The groundwater is pumped up and injected with two wells (a doublet).

In the winter season groundwater is pumped up from the warm well. The groundwater is cooled down with cold air or with the aid of a heatpump. The groundwater is stored in the cold well at a temperature level of about 8 °C.

In summer the process runs in the opposite way. If cooling is needed the groundwater is pumped up from the cold well and used for cooling the building. The groundwater is warmed up till about 18 °C and injected into the warm well.

Only the groundwater pump needs electricity. Compared to a mechanical chiller the power peak reduces by 90%.

Heatexchanger

The groundwater circuit has to be separated from the building circuit to avoid corrosion or air leakage into the groundwater flow. This is done with a plate heat exchanger which has to be placed at ground level or below. Too much height would also cause a high pumping pressure and energy consumption as the groundwater is not a closed loop circuit.

Aquifer storage in China?

The availability of free cold in winter is a necessary condition for seasonal cold storage. In figure 11 the average monthly temperatures of Beijng and De Bilt (Netherlands) are shown.

Cooling in buildings is required at temperature of ±17 °C and up. The cold demand corresponds to the area between the maximum temperature curve (upper dotted blue curve) and the line of 17 °C. Cold storage starts at temperatures of ±9 °C and lower. The availability of usable cold can be estimated with the area between the line of 9 °C and the minimum temperature curve (lower dotted blue curve).

Compared to De Bilt the temperatures in Beijng are higher in summer and lower in winter. However it shows from figure 11 that enough winter cold should be available in Beijng to apply seasonal storage.

In figure 12 the average temperature curves of other Chines cities are shown for various degrees of latitude. Macao appears to be much to warm for seasonal cold storage. Sheyang and Liyang are at the boundary. The less hours are available in winter for cold storage, the bigger the equipment has te be in order to get enough cold.

As a rough guideline one could say that Chinese regions northern of ±30° northern latitude have enough free cold in winter to meet the summer cooling demand in office buildings.

The availability of aquifers is a second criterion to apply seasonal energy storage. Generally speaking aquifers are present in delta areas. The Netherlands is a delta area and over 80% of the soil contains aquifers. In China the region as indicated in figure 12 may contain aquifers as it looks like a delta area. This is in accordance with Chines publications from 1980 an dearlier on groundwater use and storage for cotton mills.

Cooling capacity and costs

A groundwater flow of 1 m^3/h gives 8 to 12 kW cooling capacity. One doublet configuration can approximately produce 100 to 120 m^3/h groundwater. This gives a cooling capacity of 800 to 1,400 kW at maximum for one doublet. A higher cooling capacity requires more cold and warm wells.

The costs of the whole storage installation (wells, pumps, piping, engineering, permission) are strongly related to the well capacity. The indicative investment costs ranges from € 2500 to 3500 for 1 m^3/h groundwater flow in a doublet configuration. It makes sense to apply a temperature range of 8 – 10 K between extraction and injection temperature in order to reduce the costs per kW cooling capacity.

Profitability of aquifer storage

In order to know the profitability of aquifer storage a technical and economic feasibility study has to be done. The technical feasibility mainly depends on the availability of a suitable aquifer and the proper design of the cooling system in the building. Especially the chosen temperature levels and sizinf of heatexchangers should meet the specific characteristics of an aquifer storage concept.

The economic feasibility firstly depends on the energy tariffs that implies the savings of energy costs and secondly the investment costs for making the wells for the storage system compared to the investment for a conventional chiller.

To give an impression of the economic feasibility a number of Dutch projects have been shown in table 2.

Table 2 Key figures of some storage projects in The Netherlands

Project description	**N**ew building **E**xtension **R**etrofit	Cooling capacity of storage [kW]	Cold demand to storage [MWh/yr]	Storing cold with	Pay back period [year]	Investment costs system with storage x 1000 €	Years in operation [year]
'Groene Hart' Hospital	E	600	310	air handling units	4,6	430	11
Hospital 'Zuiderziekenhuis'	R	500	300	air handling units	-	636	9
Head quarters Schiphol Airport	N	2000	1130	dry cooler and air handling units	lower investment	1070	8
Rijksmuseum	R	1000	770	drycooler	-	681	7
Maria Hospital	E	1000	920	air handling units + dry cooler	3,5	680	7
Office building Anova	N + R	1550	580	heatpumps + drycooler	1,8	772	8
Office building Zwitserleven	N	1300	875	heatpumps + airhandling units	5,5	636	7
Philips Compentence Centre	R	2000	900	drycooler	lower investment	1163	7
Ministry of Foreign Affairs	R	500	440	cooling tower	1	350	6
Office Queens Towers	R	1650	824	heatpumps + air handling units	-		4
City Centre Alphen	N	1700	765	heatpumps	4		3
Cisco Building	N	3000	8370	heatpump + cooling towers	4,1		3
Town quarter 'Oostelijke Handelskade'	N	8300	4980	heatpumps + surface water	6		5
Town quarter 'Paleiskwartier'	N	7000	3850	heatpumps + pond	5		3

For most of the projects the pay-back period is less than 6 years and in some cases the investments of the storage system are even lower than for a conventional option.

Integration of heating and cooling

If the cold and heat demand of a building are more or less in balance, it may be attractive to apply a heat pump for space heating. The cold storage serves as a heat source for the heat pump, as is shown in figure 13.

In winter the heat pump runs for heating the building and additionally produces cold to load the storage. In summer mode the storage delivers the cold for cooling. Optionally the heat pump can also be applied in summer for additional cooling during peak loads.

In The Netherlands the office building of Anova Insurances in Amersfoort (floor area 26,000 m^2) was the first project with this system concept (table 3).

Energy efficiency was one of the key issues when the retrofit and extension of the original building started. Many energy saving measurements were taken to reduce the need for energy, such as: low energy glazing (U-value < 1.8 W/m^2K), automatic lighting control, speed controlled pumps and heat recovery from ventilation air. However not only a high energy efficiency but also a perfect indoor climate was required. Therefore climatic ceilings were applied for both heating and cooling. Each room has individual temperature control. Climatic ceilings are very well suited for a system with heat pumps and storage thanks to the moderate temperature levels.

Table 3 Main data of the energy system for Anova office building

Energy storage:		Heatpumps:	
- number of wells	2	- number of units	2
- depth of the wells	240 m	- compressor type	Screw
- average temperature		- refrigerant	R-407C
• cold well	8 °C		
• warm well	17 °C		
- cooling power	2000 kW	- heating power	2 x 462 kW
- groundwater flow	10 – 120 m3/h	- design temperatures	50/44 – 11/6 °C
- stored energy	1000 MWh/y	- average COP	4.1

The integration of heating and cooling saves 40 to 50% fossil fuels compared to traditional chillers and gas fired boilers.

The installation was taken into operation in 1996. A monitoring program was carried out, showing that the heatpumps function properly.

Nowadays tens of similar projects have been realised. In some of them the solution with heat pumps and aquifer storage appeared to be very cost effective compared to the traditional alternative.

Examples of innovative concepts with storage, heatpumps and solar

Seasonal thermal energy storage is a very useful concept to apply sustainable energy in individual buildings or town zones. Seasonal storage tides over the time gap between supply and demand of energy. Winter cold, solar heat from summer become useful in this way.

When collectively applied in a town zone with a variety of buildings, seasonal storage also functions as an exchange of cold and heat between different types of buildings. Dwellings need only warmth for space heating and domestic hot water, whereas office building need much more cooling. Seasonal storage combined with heatpumps enables the exchange of the both. The result is an overall saving of over 50% of fossil fuels.

In the following chapters 4 examples from The Netherlands will be presented to illustrate this:

1. Aquifer coupled heatpumps for newly built houses
2. Solar energy and storage for a retrofit housing project

3. Solar energy, storage and heatpumps for a newly built city zone with commercial buildings, houses, shops etc.

4. Smart integration of storage and heatpumps in a small commercial office building

1. Aquifer coupled heatpumps for newly built houses

In domestic houses various heatpump projects have been realised. Traditionally the Dutch houses are equipped with high efficiency gas fired boilers, connected to the fine-meshed gas grid in the Netherlands. Electrical heatpumps are more a more expensive solution. The main reasons for applying aquifer coupled heatpumps are:

- Energy savings; 25 – 50% less fossil fuels compared to boilers. Local governments often stimulate energy efficiency. Part of the deal with project developers may be a higher energy efficiency than the national Energy Performance Code stipulates.
- Although cooling in dwellings is not yet common, it becomes more and more popular. With an aquifer system the cooling can be delivered by the groundwater, whereas the storage is (partly) regenerated with the waste cooling warmth.

In one-family houses individual heatpumps are applied. The heat source is a collective low-temperature network which is fed by a central aquifer storage system. For apartment buildings a central heatpump is more usual, often combined with a peak power boiler. The heat demand in an average new dwelling is: 15 GJ/yr for space heating and 7.3 GJ/yr for hot water. In the Netherlands it is usual to build 30 – 50 houses per hectare.

Regeneration of the aquifer is easy to do in the summer season. Solar energy for regeneration is collected with surface water (Broekpolder project) or with road collectors (project in Heeteren, see figure 15). Cooling will improve the inner climate of the dwelling and will also contribute to aquifer regeneration (about 30%).

2-MW project; the most energy efficient heating system in a retrofit housing project

In March 2003 a unique energy system was set into operation. Nine blocks with 382 apartments are to be heated with solar energy. Seasonal aquifer storage and heat pumps are applied for optimal utilization of the solar energy. The apartments are going to save 70% energy compared to the original situation. Initiators of the project were three housing corporations and a utility company. This project is expected to be the first in a series of similar projects in existing housing districts.

Large-scale retrofit

The 40-year-old apartments have been upgraded by an extensive retrofit. New toilets, bathrooms and kitchens were installed. The thermal quality of the envelope has been improved by additional insulation of the walls and floors and new windows with low-emissive glazing. As a result the existing radiator heating system is oversized and can operate at lower temperatures. This makes them more suitable for sustainable ‘lower-grade’ energy sources. In each dwelling a mechanical ventilation set was installed. With this package the apartments are expected to last for at least 15 more years.

Heating system

Originally tap water heating was done by individual gas fired heaters without a flue gas outlet. These heaters had to be replaced by another more convenient solution allowing a somewhat larger warm tap water flow. Space heating was provided per block by centrally placed boilers with a heat distribution network. The boilers had also to be replaced.

The housing corporations had originally planned to install individual gas-fired boilers per apartment for both space heating and hot tap water. However, such a solution would take up scarce living space, making it less attractive for the residents.

A centralized heating system based on sustainable energy therefore appeared to be a good alternative. Both the housing corporations and the local government strongly supported this solution and initiated a cooperative venture with a utility company. Table 4 shows the timeline for the project

Table 4 Project timeline

	1998	1999	2000	2001	2002	2003
Initiative						
Energy study, system concept						
Preliminary and final design, tendering						
Start realization						
Delivery						**X**

Overall system concept

The system (figure 17) consists of solar collectors (figure 15), short-term storage, seasonal storage, heat pumps and peak demand boilers.

In summer the energy for domestic hot water is supplied by solar collectors. A total of 2,850 m^2 glass covered solar collectors have been installed on the roofs of the nine housing blocks (7,6 m^2 per apartment). Each block of houses has its own technical service space with a storage tank, heat pumps and boilers. The surplus heat in summer is stored in a central aquifer storage at a temperature of 45 °C. In winter, the heat is extracted and used mainly for pre-heating and additionally as a heat source for the heat pumps.

Heatpumps

In this particular project, it made sense to use gas-fired heat pumps, as the natural gas infrastructure was already installed. The existing electricity network might have been insufficient for the installation of electrical heat pumps.

In each block of about 40 houses two absorption heat pump (figure 18) units were installed with 38 kW condensor capacity each. Gas-fired heat pumps in this power range are readily available. The heat pumps used were manufactured by Robur in Italy. They were originally designed for cooling and had air-cooled condensers, but were redesigned to serve as water/water heat pumps. According to the manufacturer, the COP will be in the range of 1.4 to 1.6. This is comparable to the COP of an electrical heat pump (at an average efficiency of electricity production in the Netherlands of 39%).

The water inlet temperature of the evaporator may increase until 30 °C, and the heat pump can easily provide 60 °C water. These parameters make the unit very suitable for retrofit housing projects. Another plus is the relatively small evaporator capacity of the absorption type heat pump, which is about half the capacity of an electrical type. The sizing of the groundwater circuit for the aquifer storage (wells, piping, and pumps) is based on the required evaporator power for all the heat pumps together. A smaller evaporator capacity is therefore favorable from the viewpoint of storage investment costs.

Heat storage

The seasonal storage for the 2 MW-project comprises 2 wells with a depth of 115 meter and a maximum capacity of 50 m^2 groundwater per hour. The storage temperature in the warm well is 45 °C. This temperature is the result of an optimization process involving the following parameters: storage efficiency, material selection, heat yield of the collectors and direct heating capacity of the storage.

Short term heat storage is done with steel tanks with a volume of 9.5 m^3. The thermal stratification in the storage tank is an important factor influencing proper operation. This stratification is shown in figure 19. During sunny winter days, solar heat can be stored at a rather high temperature, which makes the heat usable for space heating and pre-heating of domestic hot water.

Savings/ costs

Before the retrofit, annual gas consumption was 1,915 m^3 per apartment. This figure is expected to drop to 565 m^3 per year, a decrease of 70%!

The investment costs for the energy system amount to 5.3 million euro. The actual investment is lower due to subsidies. For the residents, the total heating bill will decrease somewhat.

1. Paleiskwartier Den Bosch; solar energy, storage and heatpumps for a newly built city zone

The building area at the west side of the railway in Den Bosch is reconstructed. Part of this project is the redevelopment of business park Wolfsdonken. In this area 135,000 m^2 commercial buildings and 1,200 domestic apartments are being realised. The total area consists of about 17 sub-areas.

One of the focus points for the new park is the efficient use of energy for cooling and heating. The thermal energy is supplied by a 4-pipe ring line, connected to 5 cold wells and 5 warm wells. In each sub-area heat pumps and peak boilers deliver the warmth for space heating and domestic hot water. The heat pumps are coupled with the ‘warm’ pipes of the groundwater circuit. The heatpump evaporators produce the cold energy for cooling.

Thanks to the 4-pipe concept cold and warmth can be delivered simultaneously without mutual interference. Depending on the balance between the cold supply and cold demand the storage system will operate in loading or unloading mode. The total heating capacity is 15 MW and the cooling capacity 7 MW.

A central pond in the district is used as a solar collector in order to store heat in summer and keep the aquifer in thermal balance.

The first stages of the system have been built and are already in operation. The total project will be finished in 2006.

2. De Thermo-Staete; integration of sustainable heating and cooling with the building design

High insulating glazing considerably improves the overall quality of the building envelope. It allows the designer to project the heat supply components in a room wherever he wants. This freedom of choice opens the way to get rid of radiators and convectors in the room. Utilizing the building construction for heating and cooling purposes is a promising approach. It saves space, improves the indoor climate and perfectly matches with sustainable heating and cooling concepts like aquifer coupled heatpumps. Practical experiences and monitoring results confirm the viability of thermally activated floors.

De Thermo-Staete (figure 22) is an office building (2000 m^2 gross floor area) which was built in 1999 with the motto “More with less”. More human friendly with less environmental load and an extremely low energy consumption. An extensive utilisation of daylight gives an ever changing experience in the building, whereas the electricity consumption for artificial lighting is reduced by 60 percent to an average 4 W per m^2 floor area.

A very well insulated building envelope and high efficiency heat recovery from ventilation air reduce the required heating power to only 54 kW. Three aquifer coupled heat pumps keep the building warm in winter time.

In summer the aquifer system supplies all the cooling. Simplicity and robustness were the design targets for the aquifer system in order to get a heating and cooling system which is also profitable for this kind of small scaled projects.

Integration of heating and cooling in the building structure

In The Netherlands various floor systems have been developed with the heating and cooling system incorporated in it. The first is the Wing$^+$ floor (figure 23). The precast concrete floor consists of a 30 cm hollow core slab with on each side a ‘wing’ 60 cm broad and 10 cm thick. The clear space above the wings reduces the weight by about 40 percent, enabling a bigger span up to 10 m (with 40 cm floor thickness even 14,5 m).

Plastic tubes are mounted onto the reinforcement rods and moulded. The distance between the bottom side of the floor and the tube centre line is about 6 cm. In the construction stage the tubes of the prefab floor elements are connected tot the main lines for cooling and heating water. All the technical installations - piping, cabling, ventilation supply air - are integrated in the Wing$^+$ floor. The total thickness is only 34 cm including a finishing layer and carpet.

Design aspects

Thermally activated floors do not allow a suspended ceiling because the energy transfer between the floor and the room would be unacceptably restricted. The acoustic damping of the ceiling panels have to be compensated. This has to be taken into account from the very beginning of the design process. As is shown in figure 22 (right) acoustic panels may be hanged up to the wall. Other solutions are baffles or acoustic ‘isles’ under the ceiling.

Secondly artificial lighting armatures should better not be mounted to the ceiling for aesthetic reasons and to avoid leakages in the tubes due to drilling.

The envelope of the building should meet the insulation specifications and should not contain any leakages because discomfort may be the result. We introduced infrared measurements in the contract documents as part of the quality control procedure. This appeared to be a useful tool to prevent failures and to discuss them if they still occur.

To prediction of comfort levels in rooms with high glass walls is very well possible with modern calculations tools like Computional Fluid Dynamics. Especially for the first projects with thermally activated floors it is important to get insight in the physical behaviour of the building and to find out the limits of application.

Temperature levels

Thermally activated floors have a large heat exchanging surface. This enables a lower surface temperature to get the same power transfer. In case of heating with the ceiling the heat transfer coefficient is about 4 W/m^{2}K. A building with a well insulated envelope (Rc = 3,5 m^{2}K/W) and 40% low-emissive glazing (overall U-value = 1,6 W/m^{2}K) requires about 12 Watt per m^2 floor surface in steady state conditions with an outdoor temperature of –10 °C. As is shown in figure 3 the ceiling temperature becomes not higher than 24 °C, corresponding to a water temperature in the tubes of only 27 à 28 °C at maximum.

This simple non-dynamic calculation appears to be a quite good estimation. In figure 4 the measured water temperatures are presented for an office building which is equipped with Wing$^+$ floors.

Self control

As the surface temperature of the ceiling is only a few degrees higher than room temperature, the heat transfer is strongly sensitive to a change in the room temperature. An increase of 1 degree in the room will drop the heat transfer by about 50%. This is a very useful effect to get an even temperature. On the other hand it is clear that additional radiators with heating fluids of 50 °C and up, would disrupt this self control effect.

Buffer capacity

As a consequence of the floors ‘thermal visibility’ an enormous buffer capacity is available. An 2,9 cm concrete layer in the ceiling has 17 times more buffering capacity than the full 2,9 m air column between floor and ceiling! All kind of peaks in the thermal load due to occupancy, solar radiance etcetera are smoothened over time. For the engineer it means another way of thinking. Instead of designing for a peak cooling load (in kW) the daily cold demand (in MJ) becomes leading. One may also decide to cool only during night time with a lower energy tariff. When 24 hours per day are utilized for cooling the installed cooling capacity needs to be only 60% of the traditional value. Especially for sustainable cooling systems this is an attractive aspect in order to reduce investment costs.

Experiences

In the above mentioned office building De Thermo-Staete the heating is done by 3 small heatpumps with a condensor capacity of 18 kW each. The available heating power of 27 Watt per m^2 suits the heat demand. The supply heating water temperature remain below 30 °C (figure 25).

In summer the required cooling power is only 32 Watt per m^2 to keep the indoor temperature in the range of 21 – 23 °C (figure 26). All occupants have been polled by an independent institute. They give an report-mark 8 for the thermal climate.

Advantages of an integral design approach

Thanks to the application of sustainable heating and cooling and an integral design of the building and technical installations an enormous reduction of energy consumption can be achieved. De Thermo-Staete is the most energy efficient office building in The Netherlands and has nevertheless a perfect indoor climate. The energy consumption is measured during 3 years and appears to be 60% lower than the energy performance code prescribes.

Apart from the annual electricity consumption the electrical peak power has also been strongly reduced. This can be shown with the electrical peak power for the cooling installation:

- traditional installation with chillers for 2000 m^2 building: 37 kWe (=100%)
- cooling with aquifer storage, traditional building: 4 kWe (=11%)
- aquifer storage and thermally activated floors: 2,4 kWe (=7%)

Market introduction of sustainable heating and cooling

In The Netherlands the market introduction of seasonal storage took about 10 years. At start in 1988 most attention was paid to technical development, market studies and demonstration projects. It is important to realise succesful projects in the beginning. The availability of design tools and know-how is an important success factor and should be supported by the government. The following target groups and actions can be distinguised:

Target groups	Actions / focus points
Principals	General information, energy efficiency of the technology, feasibility and reliability, PR-aspects
Consultants, mechanical engineers	Design course, workshops, assistance with feasibility studies
Installers	Design course, workshops, instruction on testing the groundwater system and control software
Project developers	General information, demonstrate feasibility, instruction on project management
Manager, maintenance engineer	reliability of the system, know-how transfer on maintenance of wells
Local governments	General information, planning

Conclusions

1. Sustainable heating and cooling systems can not be ignored in order to achieve not only a high energy efficiency, but also a perfect indoor climate and consequently a nice working place and low loss of productivity.

2. Solar heat or other waste heat sources can be used for the driving of two-stage Desiccant Evaporative Cooling systems (DEC). In China they are expected to be applicable in region with lower relative humidity (e.g. Xi'ang and Zhengzhou).

3. Seasonal energy storage in the soil (aquifers) is a very attractive and profitable technology to realise sustainable energy systems. In China the climate will be suitable in regions northern of 33° north latitude. The soil is expected to be most suited in the delta region around the Yellow Sea (Huanghai).

4. The experiences in The Netherlands with design, design tools and market introduction of sustainable heating and cooling could be of use for Chinese government, architects and engineers.

Sino-Dutch co-operation in sustainable building

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Introduction

The Dutch governement introduced a National Green Plan in 1990. Since than a lot has changed in the building industry in the Netherlands. Real estate developers, architects, engineers and building contractors became aware of the possibilities to make comfortable buildings with a higher quality and lower maintenance cost. In the first years the cost for the sustainable buildings was between 5 and 10 % higher. After a few years when a better energy performance became law, there was no significant difference anymore.

But there are many companies who do more than that. These companies show there clients that they are able to develop, to design and to build 'Green Buildings' that combine good comfort and living with low maintenance cost.

Some general rules for "Green Building" are:

1. Develop a site that adds more value to existing communities, culture, urban planning and the environment.
2. Investigate the possibilities of re-using existing buildings.
3. Investigate the site for the available potential (sun, wind, rain, soil).
4. Improve thermal comfort by energy-efficient design.
5. Reduce the environmental impact of energy use.
6. Develop flexible designs to enhance the use of buildings.
7. Minimize the use of water and materials.
8. Use environmental friendly materials.

"Sustainable building" – how to start

There is a growing demand for new and comfortable housing. The 'Western'-style of living means a high demand of energy. Energy that has at the same time disastrous impact on the environment and the daily living conditions. Instead of adding to environmental problems we will show how an increased standard of living can be obtained with a bioclimatic approach.

The thermal comfort in a building is influenced by many different factors like the day and night temperature, the amount of solar radiation, the orientation of window openings, the thermal insulation, the thermal mass of the building, the ventilation rate and the quality of the building materials. The P.R. China has many different climates that request a different approach. Every climate needs another combination of these factors. Some examples are:

- cold region : insulation, thermal mass, passive and active solar energy, heat recovery ventilation,
- hot summer, cold winter region : thermal mass, shading, passive and active solar energy, ventilation,
- hot summer, warm winter region : no thermal mass, shading, indirect daylight, excessive ventilation, etc.

In some cases the installations for heating and cooling can be avoided or the capacity can be decreased as a result of design strategies that addept to the local climate. This means a better thermal comfort, lower investments and lower maintenance cost for the client or owner of the building.

Figure 1: Climate regions in the P.R.China.

The Bioclimatic approach - what does it mean?

The main objective of bio-climatic design is to provide ‘comfortable’ living conditions with a minimum and meaningful input of artificial energy. This reduces investments and running cost (energy) as well as ecological damage.

First of all we have to write down the brief. The space we need, the comfort that we require, the budget that we have, and the energy that we will use.

The building site has a lot of usable potential like the surrounding landscape and the climate. Sun, wind, rain and earth can be helpful.

Traditional building tells a lot about the use of these potentials. By looking to traditional buildings we can learn about the site and the local climate. This however does not mean that we will copy or only design traditional houses and buildings.

Figure 2: Traditional buildings in a hot and humid region of China.

The site for a project can be very sensitive for new influences. In a village with mainly traditional houses, the design has to fit comfortably in the setting of traditional houses.

New build villages and cities are different : in new villages and cities the design will be modern and has to adapt to the city climate.

The steps that have to be made, are :

1.Requirements (brief) for each building
2.Information about the climate
3.Information about the local culture
4.Requirements on thermal comfort that is needed
5.Research on available energy sources
6.Conceptual design for each climate
7.Architectural design
8.Technical design.

Energy

The use of energy is a very important issue from the many aspects of “Green Design”. The need for energy has a large impact on the environment (air quality, pollution, etc) and also a large impact on the the economics. A high dependency on electrical power means power shortage in summer when all buildings need cooling. Decreasing the need for cooling will also decrease the need for electrical power.

Use of indirect daylight will decrease the use of artificial lights and decreasing the heat load of a building and the need for electrical power.

Figure 3: New inventions in solar hot water systems.

Figure 4: Daylight tube for indirect daylight without increasing the heatload.

As a tool for the designer, there is the “Energy strategy in 3 steps”. The steps are:

1. Energy saving by design

• insulated envelope (roof, walls, floors)

• controlled infiltration of air (draught)

• shading and passive cooling (if needed)

2. Sustainable energy

• use of solar energy

• use of wind

• use of rain water

3. Efficient installations

• high-efficient stove / bio mass

• biogas installation

• heat-pump (heating and cooling)

• efficient ventilation with heat-recovery

The first step, saving energy’ is the most important step. It does not make any sense to use sustainable energy as the building is not efficient.

In a few case the bioclimatic approach is shown.

Case 1: Zhongdian County, Northwest Yunnan

For the Shangri La Botanical Garden we designed an Energy Efficient office and several houses.

The approach is based on the climate and available resources. The climate charts show a sunny winter and a less sunny summer. The difference between day and night temperature is around 10°C. This means that the direct use of solar energy (passive solar energy) is the basis for the design. Because of the change in use and the possibility to heat a room at night (after sunset) this passive principle is extended with active solar systems.

A rule for the winter seasons is to maximize heat gain during the day and minimize heat loss. This means that buildings have to face south and southeast to receive solar energy through the windows, especially in the morning hours. Ventilation has to be controlled in the building and especially in the kitchen and the bathrooms. The entrance has to be protected against draught by an entrance porch.

For the summer seasons it is important to minimize heat gain during the day and enable heat loss at night. Although the average temperature is not very high it is possible that the strong sunrays heat up the buildings. Indoor temperatures above 22°C are less comfortable and with a good natural ventilation the heat load can be lowered. Thermal mass of the building is also suitable to store the heat by day in the construction and release the heat at night when the building is ventilated with cooler air.

Figure 5: Energy efficient office in traditional style in Shangri La.

Figure 6: Combination of passive and active thermal solar in the energy efficient office in Shangri La.

This approach is based on tradition and old Chinese knowledge and some new techniques can be an interesting addition to this. In general we will use the electricity from the grid, although in remote areas we can use photovoltaic modules to generate electricity. For hot water we have the roof integrated solar thermal panels. These are produced all over China.

The solar thermal systems will be connected for short-term storage. In this way the solar heat gained by day can be used in the evening and on cloudy days. There is no need to store solar energy for a long time.

For auxiliary heating in the Energy Efficient office we will need a high efficient biomass stove. The waste wood from the garden can be used however the house will not require this.

In houses with livestock (pigs) the possibility of bio-gas can take the function of the open (wood) fire, but cooking on bio-gas is not the same as sitting around the open fire place. So the main problem will be the fireplace which is a cultural issue and an environmental issue. A high efficiency water cooker and the use of bamboo charcoal instead of wood can take over the role of the traditional wood fire. Heating the space will be taken over by the solar energy system instead of heating with the fire. A light tube can be used in buildings to bring daylight deep into the centre of the building.

Points of attention for the design are:

1. Heating : high thermal insulation, protection against wind, use of direct passive solar energy, use of thermal solar energy with storage and auxiliary heating with best available sources
2. Ventilation : controlled ventilation and solar chimney
3. Hot water : solar thermal energy
4. Cooking : bio-gas or efficient wood-stove with bamboo charcoal
5. Day-light : direct daylight and light tubes.

Case 2: Modern house in warm climate in Kunming, Yunnan

Kunming has an altitude of around 1890 meters. The climate has a warm summer and a cool winter.

In December and January the average temperature is around 9° C and the average maximum temperature is around 14° C. Minimum temperature is around 2° C. In the summer the average maximum temperature will be around 24° C. during the night this will be about 7° C lower.

Bio climatic approach:

Heating - This will be mainly done with passive solar energy and by facing the windows of the house on east and south. So the sun can heat the house early in the morning.

Ventilation - Ventilation window openings and internal ventilation windows above the doors will give cross-ventilation through the house. The top floor has ventilation openings so that the hot air can rise and leave the house on top.

Shading - Different types of shadings are used. The living room on the ground floor has screens (steel/bamboo) that can be moved in front of the windows. The windows on the first floor are shaded by roof overhangs and by placing the windows in a loggia.

Cooling - Starting point is to prevent sun to enter the house in warm periods. Internal ventilation will take away warm air when there is enough wind. At night when the outside temperature is lower the house has to be ventilated by using the top floor openings. By day during warm weather with low wind speed the house should be kept close to prevent hot air to come into the house. To make the house more comfortable during the hot days there are 3 steps that can be made. Every step will need a higher budget.

Step 1: Ceiling fan in combination with energy efficient lights (less production of heat).

Step 2: Water circulation through the floors. This is done with a tube system in the floor that can be used to pump around cool water. This will cool down the construction and the indoor air (with closed windows). The tube system will be used in the cooler period for radiant heating with solar hot water.

Step 3: Water circulation with cooled water by a heat pump. The heatpump can also cool down the indoor air directly with the use of an air exchanger. In winter the heatpump can heat the water and circulate it through the floors.

Hot water - The south roof has space for solar hot water panels that will be integrated in the roof between the tiles.

Daylight - Every room has windows for daylight. The bamboo screens will take away the direct sun but leave some daylight to come through. In the dinning room we use daylight tubes to transport daylight from the outside into the dinning room.

Artificial light - Light bulbs produce a lot of heat and the use of energy-efficient lights will keep the temperature low as well.

Solar energy - The house has a roof solar thermal collectors. The hot water is stored in a tank and is used for radiant heating and hot water.

Plan layout - The different rooms are designed on an orientation that is most suitable for indoor climate and comfort. Living room and study are situated on the southeast corner of the house and will warm up in the morning during winter. These rooms can be shaded in summer with screens.

Kitchen and master bedroom are on the cooler north side of the building.

Other bedrooms are situated south and north. On the west side are only secondary spaces like the garage, storage and bathroom. The dinning room will be in the heart of the house and daylight is used with the daylight tube.

Figure 7: Day and night and average temperature each month in Kunming. The blue area are (day) temperatures above 25° C; the red area are temperatures below 15° C.

Figure 8: Bio-climatic designed house in Kunming.

Structure and materials

Main construction of the house will be concrete floors and columns in combination with brick walls. The walls will be thermal insulated with 50 mm of mineral wool. The outside of the house will be bricks, plaster, and bamboo panels.

The roof will be plywood (bamboo) with 50 mm of mineral wool insulation and an outside cover with tiles or bamboo sheeting. The sheeting can be used in 2 layers to keep the roof cooler. The air gap between the 2 layers has to be open on both sides for ventilation.

In the interior floors and walls will be covered with bamboo flooring and decorative panels.

Case 3: Modern house in cold climate in Beijing

The climate in Beijing can be hot and humid in summer and severe cold in winter. Average minimum temperature in January is – 10° C and average maximum temperature is about 1° C. In summer this will be between 20 and 30° C. But summer temperature can go up to 40° C as winter temperature can go down to – 25° C. The difference between day and night temperature is around 10°C. The humidity is between 45% in January and 78% in July.

The amount of sunshine hours is around 2780 hours a year. This high amount of sunhours (2748 hours) give large opportunities for energy-efficient housing.

The prototype house for Beijing has been built in The Netherlands. The average temperatures are more or less the same. Beijing is about 5° C warmer in summer and about 5° C colder in winter. Big difference is the amount of sunhours in the Netherlands compared to Beijing. The Netherlands has about 1470 sunhours a year and this is about 50% of the amount of sunhours in Beijing.

The idea behind this project is to design and built a comfortable and energy efficient house. The building is very well insulated and the main windows are facing south to use passive solar energy during the heating season. The windows have low emittance double glazing. The thermal insulation is about 200 mm thick. Mechanical ventilation with heat recovery will give fresh air all year round.

The internal temparature is very comfortable because of the high surface temperature of walls and windows and the use of low temperature radiant heating. The heating system is feeded by the heatpump in the house.

The advantage of the heatpump is the possibility to heat in winter and to cool in summer. So these houses have cooling without air-conditioning but a system that cools down the thermal mass of the buildings. In fact there is an exchange of heat energy between the house mass and the earth. The use of a heatpump is very energy efficient. Because of the very low electricity demand it is possible to produce the electricity with photovoltaic modules that are part of the building. In summer the houses produce 3three times more electricity than needed. This electricity is feed in the grid and in winter it will be used again.

Figure 9: prototype of the houses in the Netherlands.

Figure 10: Cross section of the houses.

For Beijing this prototype house is very interesting. Many houses in Beijing use local or central heating (sometimes coal) in winter. The use of coal gives a lot of air pollution that can be avoided with this new system. The advantage of this system for Beijing is the high amount of sunhours. The system can be much smaller than in the Dutch situation. Advantage for the grid connection is the production of electricity in summer when many houses ask for more energy.

The houses have the living and kitchen on the ground floor, three bedrooms and a bathroom on the first floor and a spare room with roof terrace on the second floor. The PV systems are designed like a pergola above the houses and are independent from the orientation of the houses itself. The energy use is 50% below the Building standard in 2000. The other 50% is produced by the 6.2 kWp PV solar system on top. This makes it a zero-emission house.

For the Chinese projects we worked together with:

World Wildlife Fund China, Beijing,

International Bamboo and Rattan Network INBAR, Beijing,

The Nature Conservancy TNC, Kunming,

Shangri La Botanical Garden, Shangri La,

The Urban & Rural Planning & Design Institute of Yunnan, Kunming.

Transforming Chinese Buildings[1]

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（节选）

I. Introduction: NRDC[3] and China

NRDC's Energy Program has over 25 years of experience in the development of building and equipment energy standards and in their implementation and enforcement. We have also developed significant expertise in a wide variety of energy efficiency incentive and market transformation programs.

Since 1997, NRDC has collaborated intensively with Chinese experts and officials on improving energy efficiency in buildings. NRDC has a comprehensive M.O.U with the Chinese Ministry of Construction's Research Institute for Standards and Norms to improve the energy efficiency and environmental performance of Chinese buildings. NRDC was an active participant in the development of residential energy efficiency codes for the "hot in summer/cold in winter"(transition zone) standard recently promulgated by the Ministry of Construction. NRDC is also working with other U.S. participants in assisting provinces within the transition zone in implementing the national code, and in developing residential and commercial building codes for other regions in China. NRDC is spearheading commercial green building demonstration projects in Beijing, Shanghai, Chongqing and Shenzhen.

II. Why Building Environmental Impacts are Important in China

On average, people spend 70-90% of their time indoors; therefore it is vital that interior conditions be maintained in a comfortable and healthy level, at a reasonable cost and with minimal impact on the natural environment.

Buildings represent 20-25% of China's total energy consumption. Industrial energy for the manufacture of building products, principally concrete and steel, represents another 15-20%. In terms of total energy consumption, this places China's building sector on a par with developed countries, where buildings consume approximately 40% with another 5% or so represented by the embodied energy of materials.

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[1] This work is supported by the Energy Foundation’s China Sustainable Energy Program.
[2] The authors, respectively, are Co-Director of NRDC’s Energy Program and Director of NRDC’s International Energy Project. The authors also wish to acknowledge the significant contributions of Eveyln Arevalo and Bryanna Millis.
[3] NRDC is a non-profit U.S.-based NGO dedicated to preserving the natural environment and protecting human health. NRDC employs a staff of approximately 200 environmental professionals with technical expertise in science or law. NRDC has seven major environmental program areas. NRDC is supported by over 500,000 individual members as well as by foundation grants, and, to a much smaller extent, government grants and professional fees. NRDC does not accept corporate contributions. For more information see <http://www.nrdc.org>.

The environmental impact of this energy consumption is severe. Direct combustion of coal for cooking and heating produces severe indoor and ambient environmental quality problems. Consumption of electricity for a variety of end-uses in the urban areas requires predominantly fossil fueled power plants to produce the electricity, with its attendant local air quality and global environmental impacts.

While a number of policies are suitable for limiting local air pollution and greenhouse gas emissions, one of the most effective, and certainly the most economically attractive is improving energy efficiency. Energy efficiency reduces emissions by reducing the need to burn fossil fuels in buildings or industrial sites or transportation vehicles, or by reducing electricity consumption, which cuts the usage of fossil fuels in electric power plants.

III. What is Market Transformation?

Market transformation encompasses the totality of programs and policies that fundamentally alter practices within an industry, in this case the buildings sector. We will describe below a broad array of policy and programmatic tools that will help improve the quality and comfort of Chinese buildings, while at the same time lower operating costs and reduce energy consumption.

Before we discuss the various tools of market transformation, it is useful to examine the market that is being transformed. In general, as shown in Figure 1, a typical market can be broken down into 5 segments: Innovators, Early Adopters, Early Majority, Late Majority and Laggards. We will use these terms below when discussing which market transformation tools are most effective at engaging each particular segment of the building market.

As Figure 1 shows, both mandatory standards and voluntary market-based activities are needed to transform the market. Standards are essential for setting performance benchmarks for voluntary policies and addressing the portions of the market that are not responsive to voluntary measures. Market based programs on the other hand push an industry to go beyond minimally acceptable performance and incentivize innovations that can eventually be incorporated into common practice.

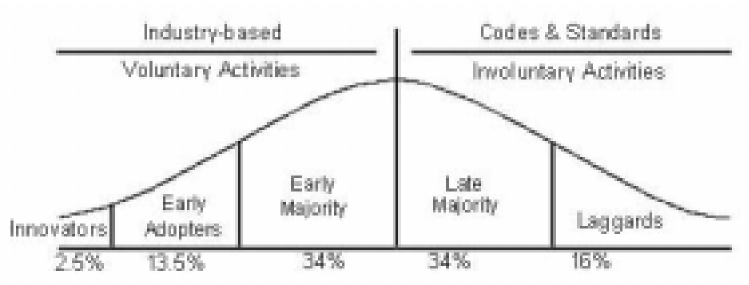

Figure 1 General Market Composition

The terms "Early adopters" and "Laggards" in Figure 1 suggest that there is an inevitable progression from less energy-efficient to more energy-efficient in the building sector. This is not necessarily the case without the stimulus of policy. In some cases, such as American water heaters and refrigerators between 1950 and 1972, American automobiles following 1986, and "torchiere" style lighting fixtures worldwide in recent years, efficiency has actually declined over time. In other cases, such as lighting systems globally from about 1950 to 1980, efficiencies were stagnant. Market transformation policies, including codes and standards, are essential to creating forward progress in markets affecting energy efficiency.

Figure 1 could also lead the viewer to the mistaken belief that it is problems or mistakes on the consumer side of the equation that are impeding the progress of energy efficiency. But the problems are more complex than that: they are consequence of market structures, rather than "mistaken" behaviors by any one sector of the market.

Table 1 shows the four basic markets[4] that market transformation policies would address in the building sector. Each of these markets is comprised of different decision makers from the policy and investment perspective. Within these decision makers there are Innovators, Early Adopters, Early Majority, Late Majority and Laggards who would be targeted by different policy and programmatic options.

Table 1 Market Segments for Buildings

New Commercial[5]	New Residential[6]
Existing Commercial	Existing Residential

IV. The Tools of Market Transformation

A number of mandatory and voluntary policies and programs aimed at the building industry have been implemented successfully in the United States. Table 2 provides a brief definition of the major categories of market transformation policy options. These elements will be described more fully below.

Table 2 Summary of Market Transformation Policies and Programs

Market Transformation Tool	Description
Mandatory	Has the force of law. Requirements must be fulfilled prior to building occupancy.
Building and Equipment Energy Codes	Minimal legally acceptable practice for building construction and equipment performance.
Building and Equipment Energy Standards	Generally provide structured recommendations for implementing minimally required or best practice.
Voluntary	Optional. Building may be occupied whether project participates or not.
Incentives	Provide something of value to a project. Can be monetary or non-monetary.
Labeling Programs	Buildings that meet certain criteria are given a performance label to distinguish them in the market.
Education/Training/Information (ETI)	Provide market with tools and skills to make the energy efficient and ecological choice.
Industry Collaboratives	Can pool intellectual and financial resources to achieve higher levels of performance.
Procurement Programs	Large users set internal energy efficiency goals for purchased items.

[4] These basic markets could also be subdivided a number of ways, but this is unlikely to add much to the discussion.
[5] These are called "public buildings" in China.
[6] From an energy perspective, high-rise multifamily dwellings tend to behave more like commercial buildings, so they are generally included in programs and policies directed at commercial buildings in the United States. For the purpose of this paper, we will address multifamily high-rise buildings in the residential sector because developers of multifamily high-rises are also the primary builders of low-rise housing, which has much different energy use and characteristics.

The four principal policy options to improve the energy efficiency of buildings are (1) Do nothing—"the market" will take care of it, (2) Pursue a purely command and control strategy that relies exclusively on mandatory codes, (3) Pursue a purely voluntary strategy where optional, market-based programs are the primary driver, (4) Adopt an integrated approach of mandatory measures coupled with voluntary programs benchmarked on required minimum performance levels. We believe Option 4 is the most effective path for policy makers.

IV. Building and Equipment Codes: The Foundation of Market Transformation

The impacts of energy efficiency standards in the United States have been significant, particularly for jurisdictions that have pursued a policy of continuous improvement.

In the United States, since the mid-1970's, most state and many local building codes[7] have imposed significant energy efficiency requirements on new homes and commercial buildings. However, despite considerable development efforts of standards by professional organizations, national building code organizations, and Federal agencies, a considerable gap remains between what is considered to be economically desirable building construction and actual practice.

The Energy Policy Act of 1992 (EPAct) requires States to ensure that new non-residential buildings meet or exceed the efficiency standards recommended by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE).[8] EPAct also requires States to consider requiring new homes to meet or exceed the Model Energy Code of Council of American Building Officials (CABO) now called the International Energy Conservation Code (IECC).[9]

A. The Economics of Energy Codes

Energy codes have been one of the most cost-effective ways of meeting regional and national energy needs. Discounted fuel-cost savings over the lifetime of a residential building are typically at least twice the cost of the projected cost of efficiency. That is, a code that adds $1,000 to the cost of a new house will produce $2,000 of present value in energy savings. For non-residential buildings, the results generally are even better: benefit-cost ratios of 3 or 4:1 are common.

Generally, estimates of economic benefits from energy codes are likely to be understated. The economics of energy efficiency are considered prospectively: the costs of complying with the code are estimated using the cost in the marketplace for the technologies predicted most likely to be used for compliance. But actual costs generally are lower for two separate reasons.

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[7] Construction requirements are set at the state and local level in the U.S. Energy efficiency standards for new buildings are employed at the state and local level in virtually all of the 50 states. Model standards developed by the federal government and by professional associations do exist, but first must be adopted into local or state regulations before becoming mandatory. The U.S. Department of Energy (DOE) assists states and local code jurisdictions in upgrading their building standards and improving their implementation and enforcement.

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2. The energy efficiency measures and strategies used by the construction industry to comply are often less expensive than the ones assumed by government officials in developing the codes. This is a nearly inevitable outcome of reliance on performance-based standards, and one of the primary arguments for relying on them, as we discuss below.

B. California's State Building Code: Perhaps The Most Effective Building Energy Code in the World

California first set its energy efficiency standards for buildings and appliances in the mid-1970s. Savings from buildings and appliance standards in California to date exceed 5,400 megawatts, more than 10% of total electricity demand for all purposes (which is about 45,000 megawatts). These savings are projected by the California Energy Commission to grow to 10,000 megawatts in the year 2010. As the volume of new construction increases over time these savings should grow.[10]

California had virtually no requirements for energy efficiency in new buildings before 1975 when a new agency, the California Energy Commission (CEC), was established by state law to plan comprehensively for energy supply and energy efficiency. The CEC was explicitly mandated to develop energy efficiency standards for buildings.[11]

In 1976-77, the CEC's new standards mandated significantly increased levels of energy efficiency, restricted the use of electric resistance heating, and also embodied several innovations. First, rather than requiring all houses to contain the same levels of conservation measures, a basic passive solar building with prescribed efficiency levels was used to define a baseline level of energy consumption.[12] Several additional prescriptive packages, or alternative combinations of conservation features, were provided explicitly in the building standard and certified as achieving equivalent energy consumption.

Second, the CEC developed a simple "point system" for

Mandatory Codes in Times of Supply Shortage

Energy efficiency codes can also be used to avert problems of shortage of either fuel or electricity. For example, in early 2001, California adopted modifications to its energy efficiency standards for buildings that were designed to aid in avoiding predicted electricity shortages and the likelihood of blackouts. These revisions are estimated by the California Energy Commission to save 200 megawatts of peak demand for every year they are in effect.

Several regions in Russia were also motivated by the prospect of fuel shortages in adopting residential energy efficiency standards. Over the past several years, these regions have had difficulty securing sufficient fuel supplies. Interior temperatures maintained by the municipal district heat system in residential buildings were failing to meet minimal comfort standards. Energy efficiency standards eased the situation by assuring that new buildings put less strain on fuel supplies.

[10] These estimates of energy savings from California's codes are conservative because they assume that the energy code remains fixed at the level most recently adopted. It is common practice for codes to be revised every three to five years to include higher levels of energy efficiency. Because the savings from these future revisions are hard to predict, they are not included in projections of energy savings.

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In 1987, the CEC established new prescriptive packages of conservation measures more energy efficient than the previous packages. For commercial buildings, it adopted stringent lighting power limits and restricted the common practice of providing heating and cooling simultaneously. More importantly, the CEC eliminated the "fixed budget" approach for commercial buildings as well as residential buildings, and defined carefully the rules for computer simulation to eliminate loopholes in the computer process, which had begun to undercut efficiency goals significantly. While the "custom budget" procedures appeared to be a way to appease and weaken the standard when they were first adopted, subsequent field experience showed that they created more fairness and did not compromise energy efficiency significantly.

Following these revised rules, reports from the field suggested improved builder acceptance of, and compliance with, the standards, as well as the decreased paperwork and simplified compliance. They also demonstrated a continued and even growing builder interest in using the performance-based approach. Many observers believe that the increased level of educational materials provided along with the standards and the effort to train building code officials can be credited with this result.[14]

California: Training = Compliance

To optimize compliance, CEC focuses on two primary methods. The first involves simplification and explanation of the standards, and the provision of easy-to-use forms and calculation methods. The second approach involves training of local building code officials, both to communicate the importance of enforcing the energy standards and to explain how the enforcement is to be carried out. CEC also supports regular forums for communication with building code officials, architects, energy calculation consultants, builders, and public interest organizations. Manuals are also provided to explain and supplement the standards, and to provide step-by-step calculations. Furthermore, a bi-monthly newsletter to architects and building code officials explains issues of interpretation. A toll-free telephone service is available to respond to specific questions concerning interpretation of the energy standards.

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[13] See section VI.C.1 and 2 on pp.15 and 16 for a discussion of prescriptive and performance-based energy standards.

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The code revision process was accelerated due to California's electric power crisis of 2000. In response to legislation intended to avert blackouts, the Energy Commission rapidly adopted improvements in both residential and commercial building codes, adding significant requirements for solar-reflective windows in non-residential buildings and requiring upgraded air conditioning systems and reflective roofs in the cooling climates, along with accelerating the date that leak-free ducts were required in the residential standards.

During the 1990s, several utility evaluation studies looked at the extent of compliance with the code, and with the extent to which buildings exceeded it as a result of utility-sponsored incentive programs. The studies show that code enforcement was generally quite good, with average energy performance of buildings consistent with that which would be predicted from the text of the code. One study showed that by 2000, over 90% of residential buildings were demonstrating compliance using the performance method.[15]

Developing a Code: What Not to Do

The development of the Building Energy Performance Standards (BEPS) is an example of an early miscue by the federal government. The Energy Conservation and Production Act of 1976 required the development of national mandatory standards for all new U.S. buildings. DOE first issued a draft of the building energy performance standards (BEPS) in 1979 for new commercial and residential buildings.

BEPS was a disaster both politically and technically.

Politically, it failed because the federal government tried to usurp the task of regulating construction, which traditionally had been the purview of the states. Many states had adopted their own standards and DOE received many comments that insisted on maintaining local control.

Technically, BEPS offered no guidance on how to comply with defined energy budgets under the performance path. Although the performance approach already was available in the prevailing building standards issued by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), builders rarely used it. This created two problems. First, BEPS mandated 100% reliance on this difficult-to-use provision that was hardly ever employed and with which designers and builders were uncomfortable. Second, the fixed budget approach in BEPS required much more intensive investments in energy efficiency measures for some building or building types than for others, in contrast to the ASHRAE standard, which required about the same efficiency measures regardless of the details of the buildings' site or its purpose.

These criticisms of BEPS caused Congress to restrict mandatory building energy standards to the Federal sectors and voluntary for all other sectors.

[15] "Residential New Construction Study." Prepared by Regional Economic Research, Inc. San Diego, CA, for Pacific Gas & Electric, 10 September 2001.

Transforming Chinese Buildings[1]

David B. Goldstein, Ph.D.
Robert K. Watson, M.S.
Natural Resources Defense Council[2]

I. Introduction: NRDC[3] and China

NRDC's Energy Program has over 25 years of experience in the development of building and equipment energy standards and in their implementation and enforcement. We have also developed significant expertise in a wide variety of energy efficiency incentive and market transformation programs.

Since 1997, NRDC has collaborated intensively with Chinese experts and officials on improving energy efficiency in buildings. NRDC has a comprehensive M.O.U with the Chinese Ministry of Construction's Research Institute for Standards and Norms to improve the energy efficiency and environmental performance of Chinese buildings. NRDC was an active participant in the development of residential energy efficiency codes for the "hot in summer/cold in winter"(transition zone) standard recently promulgated by the Ministry of Construction. NRDC is also working with other U.S. participants in assisting provinces within the transition zone in implementing the national code, and in developing residential and commercial building codes for other regions in China. NRDC is spearheading commercial green building demonstration projects in Beijing, Shanghai, Chongqing and Shenzhen.

II. Why Building Environmental Impacts are Important in China

On average, people spend 70-90% of their time indoors; therefore it is vital that interior conditions be maintained in a comfortable and healthy level, at a reasonable cost and with minimal impact on the natural environment.

Buildings represent 20-25% of China's total energy consumption. Industrial energy for the manufacture of building products, principally concrete and steel, represents another 15-20%. In terms of total energy consumption, this places China's building sector on a par with developed countries, where buildings consume approximately 40% with another 5% or so represented by the embodied energy of materials.

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[1] This work is supported by the Energy Foundation's China Sustainable Energy Program.
[2] The authors, respectively, are Co-Director of NRDC's Energy Program and Director of NRDC's International Energy Project. The authors also wish to acknowledge the significant contributions of Eveyln Arevalo and Bryanna Millis.
[3] NRDC is a non-profit U.S.-based NGO dedicated to preserving the natural environment and protecting human health. NRDC employs a staff of approximately 200 environmental professionals with technical expertise in science or law. NRDC has seven major environmental program areas. NRDC is supported by over 500,000 individual members as well as by foundation grants, and, to a much smaller extent, government grants and professional fees. NRDC does not accept corporate contributions. For more information see <http://www.nrdc.org>.

The environmental impact of this energy consumption is severe. Direct combustion of coal for cooking and heating produces severe indoor and ambient environmental quality problems. Consumption of electricity for a variety of end-uses in the urban areas requires predominantly fossil fueled power plants to produce the electricity, with its attendant local air quality and global environmental impacts.

While a number of policies are suitable for limiting local air pollution and greenhouse gas emissions, one of the most effective, and certainly the most economically attractive is improving energy efficiency. Energy efficiency reduces emissions by reducing the need to burn fossil fuels in buildings or industrial sites or transportation vehicles, or by reducing electricity consumption, which cuts the usage of fossil fuels in electric power plants.

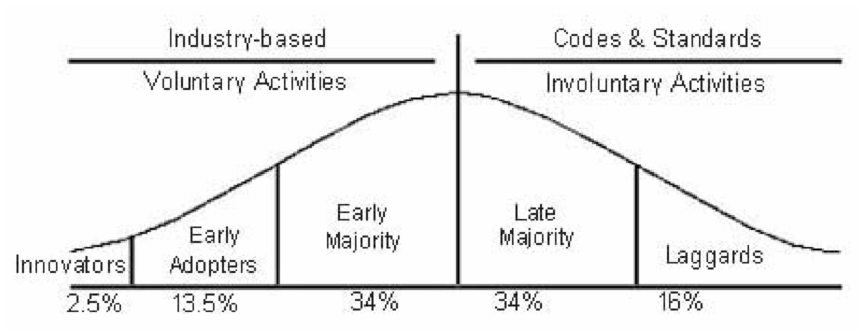
III. What is Market Transformation?

Market transformation encompasses the totality of programs and policies that fundamentally alter practices within an industry, in this case the buildings sector. We will describe below a broad array of policy and programmatic tools that will help improve the quality and comfort of Chinese buildings, while at the same time lower operating costs and reduce energy consumption.

Before we discuss the various tools of market transformation, it is useful to examine the market that is being transformed. In general, as shown in Figure 1, a typical market can be broken down into 5 segments: Innovators, Early Adopters, Early Majority, Late Majority and Laggards. We will use these terms below when discussing which market transformation tools are most effective at engaging each particular segment of the building market.

As Figure 1 shows, both mandatory standards and voluntary market-based activities are needed to transform the market. Standards are essential for setting performance benchmarks for voluntary policies and addressing the portions of the market that are not responsive to voluntary measures. Market based programs on the other hand push an industry to go beyond minimally acceptable performance and incentivize innovations that can eventually be incorporated into common practice.

Figure 1. General Market Composition



The terms "Early adopters" and "Laggards" in Figure 1 suggest that there is an inevitable progression from less energy-efficient to more energy-efficient in the building sector. This is not necessarily the case without the stimulus of policy. In some cases, such as American water heaters and refrigerators between 1950 and 1972, American automobiles following 1986, and "torchiere" style lighting fixtures worldwide in recent years, efficiency has actually declined over time. In other cases, such as lighting systems globally from about 1950 to 1980, efficiencies were stagnant. Market transformation policies, including codes and standards, are essential to creating forward progress in markets affecting energy efficiency.

Figure 1 could also lead the viewer to the mistaken belief that it is problems or mistakes on the consumer side of the equation that are impeding the progress of energy efficiency. But the problems are more complex than that: they are consequence of market structures, rather than "mistaken" behaviors by any one sector of the market.

Table 1 shows the four basic markets[4] that market transformation policies would address in the building sector. Each of these markets is comprised of different decision makers from the policy and investment perspective. Within these decision makers there are Innovators, Early Adopters, Early Majority, Late Majority and Laggards who would be targeted by different policy and programmatic options.

Table 1: Market Segments for Buildings

New Commercial[5]	New Residential[6]
Existing Commercial	Existing Residential

IV. The Tools of Market Transformation

A number of mandatory and voluntary policies and programs aimed at the building industry have been implemented successfully in the United States. Table 2 provides a brief definition of the major categories of market transformation policy options. These elements will be described more fully below.

[4] These basic markets could also be subdivided a number of ways, but this is unlikely to add much to the discussion.
[5] These are called "public buildings" in China.
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Table 2: Summary of Market Transformation Policies and Programs

Market Transformation Tool	**Description**
Mandatory	Has the force of law. Requirements must be fulfilled prior to building occupancy.
Building and Equipment Energy Codes	Minimal legally acceptable practice for building construction and equipment performance.
Building and Equipment Energy Standards	Generally provide structured recommendations for implementing minimally required or best practice.
Voluntary	Optional. Building may be occupied whether project participates or not.
Incentives	Provide something of value to a project. Can be monetary or non-monetary.
Labeling Programs	Buildings that meet certain criteria are given a performance label to distinguish them in the market.
Education/Training/Information (ETI)	Provide market with tools and skills to make the energy efficient and ecological choice.
Industry Collaboratives	Can pool intellectual and financial resources to achieve higher levels of performance.
Procurement Programs	Large users set internal energy efficiency goals for purchased items.

The four principal policy options to improve the energy efficiency of buildings are (1) Do nothing—"the market" will take care of it, (2) Pursue a purely command and control strategy that relies exclusively on mandatory codes, (3) Pursue a purely voluntary strategy where optional, market-based programs are the primary driver, (4) Adopt an integrated approach of mandatory measures coupled with voluntary programs benchmarked on required minimum performance levels. We believe Option 4 is the most effective path for policy makers.

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These criticisms of BEPS caused Congress to restrict mandatory building energy standards to the Federal sectors and voluntary for all other sectors.

V. Designing Effective Building Energy Codes

Designing a technically sound building standard is an important first step toward creating an effective energy code that saves energy in practice, not just in theory. However, many such standards have failed to save any real energy as codes because of insufficient market acceptance and inadequate administrative and enforcement infrastructure. Below, we discuss key components of a successful implementation program and how the technical content of the standard can be designed to facilitate implementation.

A. A Focus on Implementation

A well-designed code will have the goal of successful implementation at its core. In order to be effectively implemented, energy codes must be fully understood by the entire building market. Some studies have shown that simple codes are more likely to result in high levels of compliance. For example, Oregon's relatively simple mechanical system codes resulted in 96 percent compliance, while Washington State's more complex codes averaged only about 72 percent compliance.[16] Generally, the people implementing an energy code will have less

[15] "Residential New Construction Study." Prepared by Regional Economic Research, Inc. San Diego, CA, for Pacific Gas & Electric, 10 September 2001.
[16] Commercial Codes, note 14 above at 4.

education and technical experience than those designing the code.[17] If a code is more complex, better training and more carefully administered implementation approaches are needed.

An effective code must be one that enforcement officials and designers are capable of implementing and motivated to implement. It must be one that can be met in the field by available technologies and professional services. An agency that plans on enforcing an effective energy code should plan on the following activities:

1. *The development of guidebooks for design assistance and training.* These materials explain what is meant by the legal requirements in the code, and illustrate typical ways that designers can achieve and document compliance. Guidebooks for the designer may also be accompanied by training manuals that explain how this information can be conveyed to code officials. The best guidebooks explain the benefits of code compliance to the building owner or tenant, and encourage designers to go beyond the code. Examples of beyond the code measures and their additional benefits are provided.

2. *Provision of training for code officials.* Training is essential. Building officials are, at best, most accustomed to enforcing code provisions whose consequences are more visible when there is failure, such as structural or electrical or fire safety requirements. If they cannot understand energy efficiency requirements, they are not likely to enforce them. On the other hand, if they realize that these standards protect the financial well being of the consumer, reduce pollution, and maintain comfort, they will do a more effective job.

   Numerous studies in the United States show that training is necessary at regular intervals. In the United States, personnel in building inspection departments may change jobs frequently. Thus, a good training program in 2001, when a new code is introduced, may still mean most officials in the department have not been trained by 2004 when a new code revision takes place.

3. *Compilation of interpretations.* No matter how comprehensive the code and the design assistance materials, questions of interpretation are certain to arise. The code agency should make it easy for designers to look up interpretations, and to obtain new ones if necessary. This requires compiling the most commonly used interpretations as they are developed and making them easily available. It is helpful to have a toll-free telephone number or a website that a designer may access to get on-the-spot expert interpretation of how to enforce a particular element of the code. At the California Energy Commission, the staff that developed energy codes are required to answer these telephone lines because it gives them new perspective on what elements of the code are poorly written or inconsistent with field practice.

4. *Outreach and training for building designers.* Users of the code must be trained as well. The submission of incomplete or incorrect designs can cause significant disruption in the smooth working of the enforcing agency. Ideally, these training programs will familiarize

[17] Personal communication with Robert Kelly, Technical Director, National Conference of States on Building Codes and Standards.

users with complementary programs, incentives and information resources, to the extent they are available.

5. *Encourage public participation.* No matter how effective or well prepared the adopting authority is, field situations will arise that create difficulties for complying with the standards. Solutions to these problems can be found if there is a process for public participation during the implementation of the code as well as in its development. Local officials, builders, building supply industries, and other stakeholders should have regular opportunities to speak with the authorities responsible for developing the code to point out problems, thereby encouraging revisions that can most effectively achieve the same result.

   Energy codes often attract considerable controversy among advocates or opponents of particular technologies or levels of energy efficiency. In the United States, many building supply industries use code revisions to improve the market for their products. These attempts can be in the public interest when the product offers new ways to save energy and is effective to the building user. There is also general opposition from the construction industry to any sort of change. These concerns do not always go away by ignoring them or overriding them: they often show up as enforcement problems. A public process in which all stakeholders can comment on the proposed code and revisions and in which the code developers are required to respond substantively to requests for changes are generally valuable to all parties, even if they can be frustrating to participants. In many cases controversies over elements of the code can be resolved in a win-win fashion.

6. *Regular (3 or 5-year) revisions.* Technology and design strategies improve over time; what was considered a very energy efficient building when a code was initially adopted falls far short of the economically justified target a few years later. Therefore, code officials should plan on a regular cycle of revisions to the energy code. Having a regular cycle is highly preferable to only conducting irregular revisions. A regular revision cycle prepares the construction industry and the enforcement apparatus to adapt to change and reinforces the need for regular retraining.

   With a regular cycle--typically three years in the United States, but perhaps longer periods for other regions new to mandatory codes--the market can build in expectations of not only expanded sales of new energy efficiency technologies but also forecast the level of sales for existing technologies. Moreover, the engineering, design and construction industries also can plan for modifications to their current practices.

   The ability to revise a code on regular intervals allows for some of the more advanced energy efficiency measures to be phased in over time.[18] In addition, new technologies can be included in the prescriptive requirements for the energy code, resulting in additional energy savings. As discussed below, this automatically advances the stringency of the performance target as well.

[18] For example, the requirement that hot and cold air distribution ducts in homes in California be tested for elimination of air leakage was phased in over a 6-year time period. During the first three years, the method was optional and could be used to trade off against other energy efficiency measures. During the second 3-year period, it was required.

B. Tiered Energy Standards

Tiered Standards in Russia

The Russian Ministry of Construction (Gosstroi), in conjunction with NRDC and CENEf[1], a Russian non-governmental organization (NGO), developed a code that required the phased introduction of highly insulated wall panels.

The previous code had allowed compliance through reduced conductivity concrete, as is the case with Chinese codes. But the second phase of the Russian code, with a delayed implementation date, required the changeover to three-layer wall panels that included an insulating center layer between the interior structural layer and the exterior weather-resistant layer. The delayed implementation date allowed wall panel manufacturers to adapt to these changes over a few years.

One way of automatically integrating a revision in a building code is to adopt tiered standards. Tiered standards codify two or more increasing levels of efficiency, incorporating a later implementation date for the more stringent requirements.

As noted above, California adopted its requirements for solar-reflective fenestration systems in homes and for leak-free ducts in tiers. Since the mid-80s, residential windows standards had required low solar heat gain, but had effectively allowed clear-glass windows to be used because more credit was given for cheap (and uninspectable) white roller shades than for low-e coated solar reflective glass. The Commission decided in the 1998 code revision to reduce the credit for roller shades by about half, effective immediately, and to eliminate it in the subsequent code revision.

The leak-free duct requirement was also established in phases as described above. In the first phase, credit was given for tested leak-free ducts, but they were not required. In the second phase, it was understood by builders that the standards would require this measure in the reference house – that is, that builders would either have to install leak-free ducts or increase the stringency of other energy efficiency measures to compensate.

C. Design of Energy Codes

1. Prescriptive and Performance Options

NRDC is very encouraged by the progress that has been made by the Ministry of Construction in developing new national codes in China. We have supported their development, and will continue to support their aggressive implementation, because they will save substantial amounts of energy cost, and pollution in China and globally.

But China's standards fall far short of current technological potential. Their development was constrained in several different ways. Perhaps the most significant constraint is the recognition that design and construction practices, as well as the availability of building supplies, cannot change radically overnight.

Thus, for example, the use of insulating materials in load-bearing concrete walls, while undoubtedly a cost effective technology, could not be required in the current generation of codes because of the limited availability of appropriate materials and finishing techniques, as well as the limited familiarity of the building crafts and trades with their installation. Similarly, the lack of developed rating systems for energy components such as windows impedes the introduction of highly cost effective technologies into the code, such as solar reflective windows.

Virtually all of the most successful energy codes around the world offer two paths for compliance: a "prescriptive approach" and a "performance approach." The prescriptive approach dictates the performance of particular components of the building, such as the U-value for wall systems and shading coefficiencies for windows. The performance path sets an energy consumption or energy cost target for the entire building and allows designers to meet it through a variety of acceptable energy efficiency measures and design changes. Although these can be considered competing options, experience has demonstrated that the existence of both paths actually provides mutual reinforcement.

a. The Prescriptive Approach

The prescriptive approach demonstrates to compliance officials and designers, in concrete terms, what the standard requires.

Most building code officials prefer a prescriptive approach because it is simple to understand and enforce. Many builders also prefer it because they can simply know that if a wall is constructed in a certain way, or a window is labeled for a certain attribute, it complies. Others do not favor this approach because it limits options for how to build their buildings.

With a prescriptive code, there are generally fewer compliance problems. Fewer measurements are required, and fewer types of calculations are needed. Generally, a prescriptive code is the best first step in getting a building industry to accept the concept of regulating energy efficiency measures in a building. It allows the compliance and enforcement infrastructure to be put in place and, because it is simple and clear, will result in the fewest conflicts in the field.

A prescriptive code, however, is not a very effective means of promoting continuous improvement in the overall energy performance of buildings.

b. The Performance Approach

A performance standard requires that a given energy target be met without specifying the means for achieving it. Thus, it provides a market opportunity for new efficiency technologies to replace old ones.

In a well-functioning market that minimizes construction costs, which is typical of most economically successful regions in the world, builders will constantly be looking for new ways to achieve code compliance at lower cost than their competitors. While this is moderately beneficial to the economy, in that it leads to lower construction costs, it does not encourage further energy savings.

Although the performance approach is in many ways an alternative to the prescriptive approach, it is difficult to enforce or even understand the performance method without reference to a prescriptive method. This is because neither the designer nor the enforcement official has any intuitive idea as to what a complying building should look like. But, if the code is structured such that the performance standard achieves the same energy performance as required by the prescriptive standard, then the intuitive leap is possible.[19]

Because there are thousands of ways for calculating compliance and thousands of ways of calculating energy consumption for a given building, the performance path only works when simple and fixed rules and forms for calculating compliance are provided. Even the most expert individuals at modeling building energy performance can come up with significantly different results if they use slightly different methodologies. Thus, the question of what complies or does not comply with the performance approach can become ambiguous. The way to avoid ambiguity is to provide firm rules and algorithms for doing the calculations.

These complex calculations are best done by computer. Computers not only provide more accurate simulation of energy performance, but also assure automatically that all calculational rules are followed, and that the designer is not able to adjust, either accidentally or intentionally, parameters that are not part of the building design in order to make compliance easier.

Most performance-based methods in America are hardly, if ever, used. But this is because they are complex and often produce irreproducible results. This complexity causes some building officials to reject performance-based applications altogether.

But the two states, California and Florida where the performance method has been automated and simplified – simplified to the point where any building code official can understand the output and inspect the building to see whether it conforms – the performance method is used by 90% of the applicants for energy permits in new homes.

D. Design Intent vs. Field Performance

Energy codes regulate the design intent of a building, but do not necessarily regulate the actual use of energy in a real building.

It also has been demonstrated by measurements that identically designed buildings can have substantially different energy performance depending on the operation and maintenance of the equipment and the preferences and behaviors of the occupants. For example, for residential buildings in the United States, there can be a difference of as much as 10:1 in the heating energy consumption of homes with identical designs.[20]

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[19] A building, for example, that fails to meet the prescriptive requirements for most of its components, and fails by a significant margin, is unlikely to gain compliance through the performance method if it does better than the code in only one attribute. A building that purports to do this should be subject to much more careful scrutiny to determine whether it really complies.

[20] However, improvements in calculated energy performance consistently lead to improvements in actual energy performance. That is, while any individual energy-efficient building may use more heat than any individual non-energy-efficient building, a sample of 100 energy efficiency buildings will perform better than a sample of 100 inefficient homes, and the ratio of energy use will be about what is expected by the calculations.

Many buildings use more energy than predicted, particularly larger buildings. Most of this divergence is due to poor installation of equipment and poor operation and maintenance procedures. Problems of improper installation or insufficient testing can be ameliorated through properly commissioning buildings once they are complete. Commissioning protocols are currently under development in the United States by the New Buildings Institute, the U.S. Green Building Council and other organizations.

From an energy planning perspective, proper implementation of energy codes is very important. Even though the energy use of a code-compliant building can still vary significantly depending upon occupant behavior, the variance in energy consumption is substantially smaller compared to a building constructed without an energy code.

E. Energy Standards for Appliances and Equipment

Basic energy savings not realized by improved design through the building code can be captured by equipment standards.[21] Unlike buildings, energy efficiency in equipment and appliances has been regulated principally (but not exclusively) at the national level.

These performance standards for appliances and equipment have been the other cornerstone of regional and national energy efficiency policies in the United States to reduce energy consumption. In the United States as a whole, appliance and equipment standards are already saving 2.8% of total peak electricity use, or 21 GW; this will rise to 12.6% savings or 120 GW by 2020 due to standards that have already been adopted, but are not yet in force.

Equipment standards have an advantage over building codes in that they apply to equipment going into existing buildings as well as new buildings. But, as with building codes, appliance and equipment standards will not save energy if they are not enforced.

Outside of space conditioning, other building energy end-uses in the U.S. have grown significantly. By 1975, refrigerators had become the largest user of electricity in American households, with other appliances such as air conditioners, water heaters, clothes washers, and lighting systems also consuming large amounts of energy. Recently, small transformers used to power electronic equipment have also become significant energy users.

1. Performance or Prescription Standards

The issue of whether to use prescriptive or performance standards for equipment arose in the United States in the early 1970's. The appliance industry expressed a general preference for performance-based standards.

As with buildings, performance standards require the development of a test protocol—analogous to the computer-based calculation method for buildings—and then the establishment of a maximum energy use based on the test procedure. In all major countries, the appliance testing protocols have become the basis for ratings that are available to consumers and energy

[21] In California, savings from appliances and equipment standards augment the savings from building standards by about 50%.

officials throughout the country or region. These ratings, typically in kilowatt-hours per year, or kilowatt-hours per year per unit of output, can be the basis for incentive programs and other market-based programs to encourage energy efficiency.

a. Household Appliances

Minimum efficiency standards were first adopted for household appliances and certain commercial equipment in California in the mid-1970s.[22] California strengthened its standards in 1983 and several other states passed different sets of requirements. This diversity of standards encouraged the appliance manufacturing industry to seek a national standard that would preempt the state standards.[23] The National Appliance Energy Conservation Act (NAECA) was adopted into federal law in 1987 and amended in 1988.[24] The law prohibited the manufacture and sale of products that fail to meet the minimum efficiency requirements. NAECA required DOE to review prevailing standards periodically and strengthen them if technically and economically feasible. The 1992 EPAct added a number of other energy- and water-using products and established minimum regulations and a process for strengthening them.

Since these laws were passed, the Department of Energy has promulgated approximately ten amended standards requiring higher levels of efficiency. While this falls significantly short of the number of revisions required by the law (with deadlines that have already passed) it nevertheless has prompted noteworthy increases in appliance efficiency, as shown in Table 3.

Table 3: Examples of Efficiency Changes

Appliance	**1970-1975 Energy Use**		**2000-2001 Energy Use**	
	Average	Best	Average	Best
Refrigerator	1,725 kWh/yr	1,325 kWh/yr	2001 Standard = 475 kWh/yr	~400 kWh/yr
Clothes Washer	3.81 kWh/cycle		~2 kWh/cycle	0.7 kWh/cycle 2007 Standard is at this level
Central Air Conditioners	7 EER	9.5 EER	9.8 EER	13 EER 2006 Standard requires ~11.3 EER
Dishwashers	4.2 kWh/cycle		~2 kWh/cycle	~1 kWh/cycle

The largest number of standards have been established for refrigerators, which also have been subject to a number of other policies that are discussed in this paper. This example is so important that it is discussed separately in the section on Appliances and Equipment below.

[22] California's standards regulated refrigerators, freezers, stoves, residential central air conditioners, room air conditioners, water heaters, furnaces, fluorescent lamp ballasts and showerheads.

[23] The energy crises spurred by the Middle East oil embargo made the adoption of energy efficiency policies critical for states heavily dependent on oil, such as California and New York. The difficulty for manufacturers, which produced and sold to a national market, was that non-uniform requirements in different states made it extremely difficult to produce and ship the correct equipment.

[24] NAECA regulated energy in the appliances covered by the California legislation, as well as dishwashers and clothes washers, cooking ranges, fluorescent and incandescent lamp ballasts and low-flow toilets.

2. Lighting

In the United States, lighting accounts for approximately 25 percent of annual energy costs in the U.S., almost $37 billion.[25] Approximately 60 percent of lighting energy use is from fluorescent lamps, which require a ballast to provide a suitable starting voltage and then limit current flow during operation of the lamp. Ordinary ballasts dissipate about 20 percent of the total power entering a fixture. More efficient magnetic ballasts, introduced in the mid-1970s, make use of better materials, including copper windings and high-grade steel, to reduce ballast losses by 50 to 60 percent. Solid-state electronic ballasts, first introduced during the early 1980s, cut lamp/ballast system losses 15 to 20 percent further than efficient magnetic ballasts and increase lamp efficacy due to high-frequency operation.

By 1987, about one third of ballast sales were energy-efficient magnetic ballasts. In 1988, federal ballast efficiency standards were adopted. As a result, inefficient magnetic ballasts could no longer be sold or imported into the United States. In 1994, the DOE proposed new efficiency standards for fluorescent ballasts that require use of electronic ballasts. The standards were to be finalized by 2000 and take effect in 2005.[26] The Department estimated that these standards will save 57 TWh per year by 2015. The consumer will realize economic benefits of nearly $14 billion over a 35-year period.[27]

Incandescent lamps account for approximately 30 percent of electricity used for lighting in the United States.[28] The use of compact fluorescent lamps (CFLs) will result in energy savings of approximately 66 to 78 percent with equivalent light output.[29] CFLs also have approximately 10 times longer life than typical incandescent products. For commercial buildings, this also results labor cost savings since they need to be changed less frequently.

VI. Beyond Energy Codes

In addition to the regulatory push to rid the market of the worst performing technologies and practices, an incentive pull is necessary to encourage continuous improvement in energy efficiency. First we will discuss how codes can be integrated into a broader market transformation strategy, then we will describe the limitations of energy codes and advances in building research that have revealed the different ways buildings use energy that are not captured by typical energy-only standards. Finally, we will describe a number of successful market transformation tools that have been used to comprehensively improve energy efficiency beyond the mandatory requirements of codes.

A. Integrating Energy Codes Into A Broader Strategy

Energy efficiency codes work best when they are undertaken as part of a more comprehensive strategy that includes incentives, both short-term, actively-managed incentives

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[25] U.S. Department of Energy, Energy Efficiency and Renewable Energy network. See <http://www.eren.doe.gov/erec/factsheets/eelight.html>.

[26] Howard Geller and Steven Nadel, "Market Transformation Strategies to Promote End-use Efficiency," 19 Annual Review of Energy and the Environment, at 308 (1994).

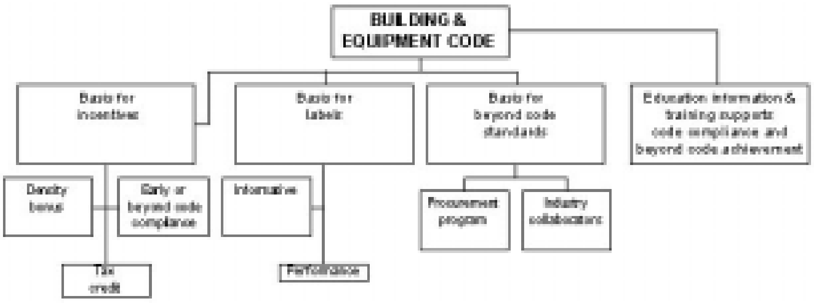
[27] *Id.*

[28] *Id.* at 311.

[29] *Id.*

and longer-term, fixed incentives, along with both informative and normative labeling policies that establish the value of energy efficiency in the marketplace; and, more broadly, education and outreach programs and research and development for new technologies and designs. As shown in Figure 2, all of these policies interact in multiple directions.

Figure 2: Energy Codes as the Basis for Beyond Code Activities



Although no jurisdiction has yet fully adopted a comprehensive approach, experience in regions that have adopted several of the pieces shows that each piece reinforces and strengthens all of the others. Standards generally constitute the basis from which these other programs can be designed. A well-designed, comprehensive program will intentionally build into standards the types of policy features that can be useful in designing incentive or educational programs.

B. Limitations of Codes

Energy codes are a necessary, but not sufficient element of a market transformation strategy. While codes have been the primary policy force causing improved energy efficiency in buildings, they also have severe limitations if they are the only policy tools available.

First, prescriptive codes usually can only require technologies already widespread in the market because they apply to all new construction without exception. If the code were to require a technology that is only minimally available in the market, builders may be unable to comply. If this is the case, compliance officials may have a tendency to look the other way if the code requires "impractical improvements." This will hinder enforcement and undermine the credibility of future code improvement efforts.

This problem can be partially mitigated by the performance approach, since no particular technology is required. However, if the code places reliance on one technology with very large energy savings, it could be very difficult or expensive to make up these energy savings using other technologies.[30] Therefore, it often is not good policy to develop building codes that require technologies that are not currently widespread in the market.

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[30] In the few cases where advanced technologies were relied on in prescriptive code development, all but one of them had already included a widely used or widely projected to be used performance option.

A second weakness of codes as the sole energy efficiency policy is that codes seldom include all cost-effective measures. This is more a political problem than a policy problem; there is no reason in theory why all cost effective measures could not be included, and indeed, there are a few examples where they were.[31] But in general, the building industry has trouble accepting changes in many different components in the building at once.

Standard Design Assumptions Can Waste Energy

The standard for energy loss in the ducts of a large commercial building – one of the biggest sources of energy waste – could be set based on a design in which the ducts are relatively large and the runouts relatively short, a common configuration that is inherently energy efficient. But, for a building with low floor-to-floor heights and a very large footprint, the ducts might be required to be small and the runouts from the central area to the remote parts of the building could be very long and circuitous. The pressure drops for such a system would be far larger than for the reference system, and the standard could be very difficult to meet.

To solve this problem, ASHRAE 90.1-1999 (and the previous version of this standard) was based on a worst-reasonable-case condition of static pressure drop in the duct system. The requirements – expressed as a limitation on watts per liter-per-second of air flow – are so loose that for any building without these extreme constraints, no energy efficiency measures are required.

A third limitation of energy codes is that they have trouble addressing complex systems. The best example is the heating ventilation and air conditioning (HVAC) systems of large, high-rise buildings. Much of the energy performance of HVAC systems is determined by operational characteristics such as equipment settings and programming of equipment. These are difficult, if not impossible, for building inspectors to identify and the inspected settings are a moot point once the building is certified for occupancy.

Complex systems have so many different options that prescriptive requirements tend to get very complicated. For each option, a different prescriptive requirement is needed. In practice this can lead to a different "reference case" in the performance standard for each variation in system design.

The problem with respect to energy savings is that either the standard is set based on some relatively simple prototype and could become difficult or impossible to meet in all cases, or else the standard is adjusted upward in energy consumption for certain hard-to-design systems and then ceases to encourage much efficiency.

Finally, building codes only address new construction. Energy efficiency in existing buildings must be addressed by equipment standards, incentives and education programs.

C. Operations Are Not the Only Way Buildings Consume Energy

As energy codes have improved over time, other aspects of energy consumption related to buildings can actually exceed the energy used to operate them. These aspects include a building's location, its site plan and landscaping, and its construction materials.

[31] The other problem that arises is that the definition of "cost-effective" for code purposes is defined based on a very short time horizon, often as a result of political pressure from stakeholders wishing quick profitability.

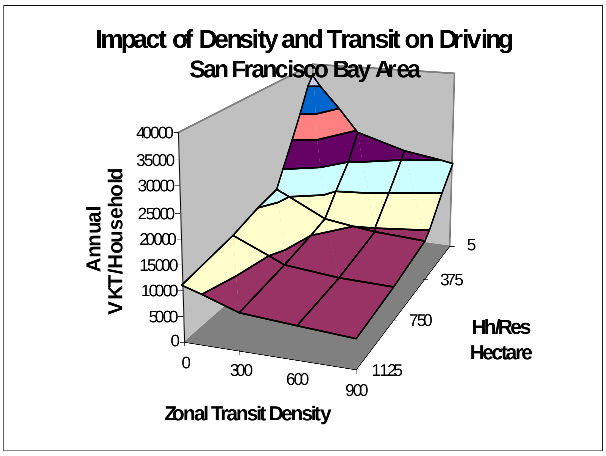
Location is perhaps the most significant of these in the United States. An efficient building in a remote location will result in more energy being used by the occupants commuting to and from the building than the building consumes itself. Even more remarkably, the total cost of driving cars to and from the remotely-located building in the U.S. can exceed the entire cost of purchasing the house.

It is possible to quantify the extent of driving and its related cost, energy use, in air pollution emissions, for a given location, at least in the United States. The extent to which these are lower than a worst-case location of "suburban sprawl" can be expressed as the "location efficiency" of the house and its neighborhood.

It has been found that differences in neighborhood characteristics, primarily the residential density, or number of housing units per hectare of residential land, and the level of provision of transit service (number of buses or rail vehicles per hour passing within walking distance of the residence) have the largest effects on location efficiency. Reasonable variations in these two variables alone can reduce the amount of driving by almost two-thirds, based on typical conditions in the United States, holding income and family size constant. The results are displayed below in Figure 3.[32]

While these results are based on U.S. data only, they are consistent with findings whose database is global.[33]

Figure 3. Vehicles per Household vs. Households per Residential Acre – San Francisco



Proper site planning and landscaping can reduce urban heat islands and the water required for irrigation. Heat islands can increase ambient temperatures by 6-8^0 F (4-5^0 C), significantly increasing air conditioning levels. Water purification and pumping are one of the largest single municipal energy consumers in the arid western United States.

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[32] See D. B. Goldstein. Research Ideas for Transportation presented to the U.S. National Research Council Surface Transportation Environmental Cooperative Research Program advising board's Research Priorities Workshop, Washington DC, 26 September 2000.

[33] P. Newman & J. Kenworthy. Cities and Automobile Dependence: An International Sourcebook. GoverPublishing, 1989.

Finally, the embodied energy of a building can be significant, particularly where energy intensive cement and steel are the dominant building materials. As noted above, industrial energy consumption to manufacture building materials in China is nearly equal to the energy used in the buildings themselves. This seems a particularly ripe area for intervention, either in the building sector or in the industrial sector.

D. Model or Voluntary Standards

In the United States, relatively few jurisdictions have the budget or the technical expertise to develop their own energy standards for buildings. In most instances, they incorporate other organization's standards into their building codes instead. A number of these model energy standards have been developed since the 1970s.

1. Association Standards

The ASHRAE/IESNA 90.1 Standard is the predominant national standard for commercial buildings.[34] Although Standard 90.1 is a national standard, it is not a Federal standard. Ongoing upgrades of Standard 90.1 have resulted in commercial buildings that save as much as 50 percent of energy consumption compared to non-complying buildings before the first standard was adopted in 1975.[35] The standards also have reduced construction costs by cutting excessive lighting and window area.[36] ASHRAE has developed a standard that also applies to residential buildings, Standard 90.2, although it has yet to be adopted by any code-enforcing jurisdiction. ASHRAE standards have also been instrumental in the model federal building efficiency standards and guidelines developed by DOE. However, in the area which accounts for the largest fraction of energy use in commercial buildings—lighting—DOE adopted requirements in about 1990 that went significantly beyond those in the ASHRAE standard. Implementation of ASHRAE commercial standards is expected to reduce energy bills by $2.1 billion annually by 2010.[37]

The International Codes Council (ICC), is the sponsor of the International Energy Conservation Code (IECC).[38] The IECC is a voluntary code principally used for low-rise residential construction, although it covers all commercial buildings as well. About 40 states have adopted some version of the IECC, or used it as a basis for their state code, while a couple of states have adopted the commercial building version. Several studies have found that the IECC energy requirements are highly cost-effective. An analysis by the Alliance to Save Energy, for example, suggests that if the 34 States with codes less stringent than the 1995 version of

[34] The American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE) and Illuminating Engineering Society of North America (IESNA) are national and international professional engineering associations. More than 40 of the 50 states enforce energy efficiency standards derived in whole or in part from ASHRAE Standard 90.
[35] David B. Goldstein, The American Experience with Establishing Energy Efficiency Standards for New Buildings: Case Studies of California and National Energy Studies, Presented at the Third Soviet American Symposium on Energy Conservation, October 2-15, 1988, at 1.
[36] *Id.*
[37] Sustainable Energy Strategy: Clean And Secure Energy For A Competitive Economy, National Energy Policy Plan Pursuant to Section 801 of the DOE Organization Act, 30 (July 1995). (Hereinafter National Plan), at 30.
[38] Earlier versions of the IECC were released in 1983, with updates in 1986, 1989, 1992, 1993, and 1995.

IECC adopted the model code, the resulting changes in new homes would achieve paybacks of less than 2 years. Furthermore, the Alliance found that in some regions of the country codes stricter than IECC would provide a 4-year payback.[39]

2. Federal Model Standards

Two federal agencies, the DOE and Department of Housing and Urban Development (HUD) have been active in the development of model or actual building energy codes and standards. Although the number of buildings constructed annually for Federal government is limited, the government directly finances about 27 percent of new home mortgages through the Federal Housing Administration, the Veterans Administration, and the Farmers Home Administration. Eligibility requirements for Federal financing can directly influence building design and construction.

Through a variety of legislation, Congress directed the Department of Housing and Urban Development (HUD) to issue an energy standard for housing programs within the agency and for manufacturing homes. The Federal government first issued the Minimum Property Standards (MPS) in the 1950s to establish energy criteria for homes using federally financed mortgages. The standard limited the level of household utility expenses and reduced the rate of default on home mortgage loans. The 1990 version required that "all detached one and two family dwellings and one family townhouses not more than three stories in height shall comply with the MEC.[40]

E. Rating & Labeling Systems

Market based rating and labeling systems are a bridge between mandatory codes and information systems. These systems can convey a signal to the market that a building delivers superior performance. These ratings or labels are often based on standards or specific performance criteria. In addition, these programs can convey information of comprehensive environmental performance in addition to energy efficiency.

Building labels could be a key component of a comprehensive energy efficiency program. As discussed below, a variety of incentive and purchase programs to encourage energy efficiency could also encourage widespread use of labels. If rating and labeling systems are designed properly, they could serve as effective tools to building owners and managers and to the property sales and lending marketplace in encouraging better buildings as well as greater energy efficiency.

1. LEED Rating System

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[39] Ted Jones and Douglas Norland, The Alliance to Save Energy, "The 1993-95 Model Energy Code: Energy and Environmental Savings, Costs, and Benefits by State" 1996 ACEEE Summer Study on Energy Efficiency in Buildings, Washington, DC, ACEEE, 1996.
[40] U.S. Congress, Office of Technology Assessment, Building Energy Efficiency, OTA-E-518 (Washington, DC: U.S. Government Printing Office, May 1992). [Hereinafter Building Efficiency], at 108.

The Leadership in Energy and Environmental Design (LEED) Green Building Rating System is the next wave of beyond-code programs in the United States. Developed by the U.S. Green Building Council,[41] LEED has 64 requirements in 5 categories including Site, Water, Energy, Materials and Indoor Environmental Quality.[42] Buildings receive LEED ratings ranging from Certified to Platinum.[43]

After two years, LEED is in use by over 6 million square meters of commercial and high-rise multifamily buildings, approximately 3% of the new construction market. LEED is anticipated to penetrate approximately 5% of the new construction market this year. Although small relative to the entire market, this represents almost 25% of the target market of Innovators, Early Adopters, and a portion of the Early Majority that comprise the top 25% of the building market. This market proportion is very similar to the segment targeted by the EPA's Energy Star program as discussed below. LEED's market share should grow as new products are being developed to address the specific market concerns of speculative developers, existing building owners and operators and sub-tenant spaces that only do interior renovations.

Operationally, LEED certified buildings are approximately 75% more energy efficient than average new commercial buildings, not including secondary energy savings.[44] About 40% of LEED buildings are infill development in urban areas and 60% of them are located within walking distance of mass transit. About 60% have taken landscaping measures to reduce heat islands[45] and have eliminated irrigation systems, while nearly every project has reduced landscape water use by at least 50%.[46]

2. Energy Star Label

The U.S. Energy Star system created by the U.S. Environmental Protection Agency (EPA) is another example of a normative label—one that establishes a recommended or "good" level of energy efficiency.[47] The Energy Star program encompasses appliances, office equipment and new and existing buildings.[48]

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[41] The USGBC is a voluntary non-profit organization of over 1,100 major stakeholders in the building industry. For more information visit <http://www.usgbc.org>.
[42] Although IEQ is not directly related to energy consumption, negative impacts on indoor air quality from improperly implemented energy efficiency measures have been used by opponents of energy standards to relax requirements or even to forestall adoption of efficiency measures.
[43] Certified buildings achieve 40-50% of the available points; Silver 50-60%; Gold 60-80% and Platinum 80% +.
[44] Based on the U.S. Environmental Protection Agency's Energy Star benchmarking system, an average new building scores a 50, while an average LEED building scores an 87. LEED currently references the ASHRAE 90.1 Standard and requires that buildings exceed it by 20 to 60% depending upon what level of rating the building desires to certify.
[45] Reducing urban heat islands in the U.S. could reduce annual energy bills by over $1 billion according to Lawrence Berkeley National Laboratory.
[46] Water treatment and distribution can consume up to 2.5 kWh per thousand gallons.
[47] Normative labels are used to provide simple and easy-to-use access to the marketplace. While economic theory says that consumers will optimize for energy efficiency, in practice, energy efficiency most often is totally ignored. The first step of improvement beyond ignoring energy efficiency is to make a simple "yes/no" distinction between energy efficient buildings or equipment and inefficient.
[48] The Energy Star program covers: New Homes and Commercial buildings, Furnaces, Heat pumps (Air-source, Geothermal, and Gas-fired), Central air conditioners, Boilers, Programmable thermostats, Insulation, TVs, VCRs, Light fixtures, Office equipment (Computers, Printers, Fax machines, Scanners, Multifunction devices, Copiers)

The use of a widely recognized logo such as Energy Star can provide market differentiation that will encourage both manufacturers and consumers to move towards higher levels of energy efficiency. For this to work, the label must be credible in terms of technical accuracy and in terms of distinguishing significantly better energy performance from merely average performance.

3. Informative Energy Labels: Theory vs. Practice

Informative labels are intended to provide objective estimates of energy consumption, often measured in cost to the consumer.

a. Residential Buildings

In theory, the presence of energy ratings will be incorporated into the marketplace for buildings, raising the valuation of energy-efficient buildings and reducing the valuation of energy-inefficient buildings.

Economic theory says that widespread availability of ratings should cause the market to solve all the problems of energy efficiency. There has yet to be any practical validation of this hypothesis. Indeed, it remains the case that in most of America, energy efficiency measures that could cut building energy use by 50% or more are almost universally ignored in the marketplace, except where required by code or encouraged by economic incentives.

Policy makers in the U.S have been trying to develop home energy ratings for over twenty years, with very limited success. These efforts have focused primarily on the residential sector, despite analysis suggesting that the commercial sector might be able to use the ratings more effectively.

As a result of these twenty years of effort, ratings for residential buildings finally are now available in the U.S. There is a national standard, adopted by the National Association of State Energy Officials, covering both the engineering calculations that lead to a uniform energy rating and the procedures for certifying individuals who are qualified to do energy ratings, assuring that they are well-trained and financially independent of the builder.[49] Energy Star also rates new homes and LEED is developing a national residential green building system. As shown in Table 4, about two dozen local homebuilder associations have developed or are developing green building rating systems.

Table 4: Local Homebuilder Association Green Building Programs

Program Name	Program Administrator	Date of Inception	Contact Information
Austin Green Building	City of Austin	1991	www.ci.austin.tx.us/greenbuilder
Built Green	HBA of Metro Denver	1995	www.builtgreen.org

Refrigerators, Dishwashers, Room air conditioners, Clothes washers, and Windows. See <http://www.energystar.gov>.

[49] See <http://natresnet.org/standards/default.htm>.

Innovative Building Review Program	County of Santa Barbara	1995	805-568-2507
Green Points	City of Boulder, CO	1996	www.ci.boulder.co.us/environmentalaffairs/green_points/gp_overview.html
Build a Better Kitsap	Kitsap County HBA	1997	www.kitsaphba.com
Green Builder	HBA of Central New Mexico	1997	http://www.hbacnm.com/green_builder/index.html
Green Building	MD National Capital Building Industry Assoc.	1998	301-445-5400
Build a Better Clark	Clark County (WA) HBA	1998	www.cchba.com/green.asp
Scottsdale's Green Building	City of Scottsdale (AZ)	1998	www.ci.scottsdale.az.us/greenbuilding
Earth Craft House	Greater Atlanta HBA	1999	www.atlantahomebuilders.com
Green Built Home	WI Environmental Initiative	1999	www.wi-ei.org/GBH/index.htm
Green Building	City of San Jose (CA)	2000	www.ci.san-jose.ca.us/esd/gb-home.htm
Built Green Colorado	HBA of Colorado	2000	303-421-4889
Built Green	Master Builders Association of King & Snohomish Counties	2000	www.builtgreen.net
Earth Advantage Homes	Portland General Electric (OR)	2001	www.earthadvantage.com
Vermont Built Green	Building for Social Responsibility	2001	802-658-6060 ext. 1016
The Heart of America Green Builder	Metropolitan Energy Center (Kansas City)	2001	816-531-7283 www.kcgreen.org
Program under development	Western North Carolina Green Building Council	?	828-251-5888 www.main.nc.us/wncgbc
Program under development	Southern Arizona Green Building Alliance	?	520-624-6628
Program under development	Florida Green Building Coalition	?	http://floridagreenbuilding.org
Under development	Alameda County (CA)	?	510-614-1699
Under development	City of Chula (CA)	?	619-409-5870
Program under development	HBAs of Hudson Valley and Schenectady (NY)	?	518-355-0055 (Schenectady) 914-562-002 (Hudson Valley)

Despite the number of programs these ratings have been negligibly used to date. Over 1,000,000 new homes are constructed annually in the United States, but fewer than 100,000 ratings of any type are performed in the year for all these programs combined. One of the barriers to wider use of ratings is the cost of ratings and the availability of raters. This can be a vicious circle: if ratings are expensive or hard to get, no one will request them; but if almost no one requests ratings, then there is no business opportunity in becoming a rater, and raters will be unavailable.

Ratings are required as part of the newly adopted regional energy codes in the Russian federation. But there is a lack of standards to assure uniformity in the ratings and to provide recommended procedures for doing them, so compliance with this aspect of the code is lagging.

b. Commercial Buildings

Energy ratings for commercial buildings should, in theory, become important in the marketplace. This is because estimates of property value, which are used for informing banks about loan amounts, as well as helping to establish selling prices for buildings, are often based on energy costs.

For example, more than half of buildings are appraised by the "net operating income" method, in which the value of a building is obtained by projecting the net operating income– that is, the rental income for the building minus the cost of operation – and multiplying it by a capital recovery factor, which typically has a value of over 10 years. Energy is considered explicitly (in theory) in evaluating operating costs. Thus, a building that saves $10.00/square meter in energy costs compared to an alternative building is valued at more than $100/square meter higher than the inefficient building.

But this theory does not work out in the real world because of a lack of detailed energy consumption figures. Instead of filling in an energy cost estimate specific to the building, appraisers use regional averages in calculating that aspect of operating income. All buildings are treated as if they had the same energy efficiency. To correct some of these deficiencies, The Institute for Market Transformation, a U.S.-based NGO, is working with appraisers to establish procedures for using building-specific figures for energy costs.[50]

c. Improving Building Labeling Systems

The most effective labels would provide two different types of calculations, following the model used in the Russian regional codes as described next.

First, the label would provide an estimate of annual energy use, measured in units of costs, and based on energy calculations using the design of the building. This would provide a uniform scale for rating efficiency without regard to the behavioral variations between buildings. Thus, two buildings with a given rating would provide a prospective owner with the same level of energy performance, whether that individual would prefer to heat their home to 15°C in the winter or 25°C. The cost target provides both a way of comparing one building to another and a way to verify that energy is really being saved in a single building – or to diagnose why energy is being wasted and figure out what to do about it.

As is in the case in the Russian document, a list of the energy efficiency measures used to meet the calculated energy level of efficiency should also be provided. This list is essentially part of the input used to calculate the design-based energy consumption. It is an important part of the document because it can complement code enforcement efforts by providing a permanent record of the types of measures that supposedly were installed to make the building energy-efficient. If subsequent owners find that the performance of a given component falls short of the level in this document, they can hold the builder responsible for the variance between claimed and actual energy efficiency. The risk of such litigation provides a powerful backstop to keep the code compliance process honest.

Second, the labels should provide an estimate of actual consumption. This actual value can be compared with the predicted value, which will provide several useful inputs for the building owner or operator. The Energy Star program relies on estimates of actual energy consumption over the course of a year. This requirement is obviously a barrier to the participation of new buildings in a labeling system. This impediment is particularly severe

[50] See M. Chao, "Energy Costs and Valuation of Commercial Properties by Appraisers and Lenders," 1998 ACEEE Summer Study on Every Efficiency in Buildings, Washington, DC, ACEEE, 1998.

because for large buildings, the full occupancy may not be achieved until several years after construction.

The Russian Energy Passport also requires estimates of actual energy consumption. But, perhaps due to the newness of the program, such estimates are not available yet. So there is no evidence to date as to whether the requirement for adding estimates of actual energy consumption to compare with the projections is being implementable.

Actual energy consumption provides the best added value in making markets work for energy efficiency by allowing comparisons, not just on an annual average basis but monthly, between projected energy use and actual energy use. For example, if the actual energy use is higher than predicted energy use for a given level of intensity of usage and weather conditions, then it is a sign that something is not working correctly in the building. Perhaps an examination of installed equipment compared to specified equipment will show that the original design intent was not followed. Perhaps an evaluation will show that a piece of equipment is adjusted improperly or is malfunctioning or is worn out. Perhaps controls were installed improperly or not programmed correctly.

Indeed, examinations of month-by-month comparisons of projected and actual energy use can often provide “signatures” for specific types of malfunctions. Many of these malfunctions can be identified simply by the pattern of deviation between predicted and actual by month.

In some cases, the equipment needed to measure energy use can be integrated by the building’s energy management system to provide a very detailed comparison of projected and actual energy use, which can determine whether the installed equipment and the program controlled strategies are working in the field the way they were intended, and provide instant feedback on how to correct them if they are not.

It also could be the case that actual energy use is lower than predicted. In some cases, this is because thermal comfort or other elements of indoor environmental quality are not being maintained at a sufficient level in the building. For example, reduced energy consumption might be due to inadequate ventilation or lighting, or due to uncomfortable thermal conditions in the summer or the winter.

d. Appliance and Equipment Labels

In the U.S. and the European Union, energy performance labels are also required for major appliances. In the U.S., this requirement has been in existence since 1978. Labels are present on almost all major energy using equipment, but are mostly ignored by consumers. Some studies have suggested that the U.S. labels are hard to understand by the consumer, who often is confronting the label only once in ten or twenty years when their appliance breaks down they need to purchase a new one.

Despite their relative ineffectiveness in influencing consumer markets, utilities operate incentive programs for energy rated equipment and rely heavily on these ratings and labels to administer their programs.

Equipment labels appear to be more effective in the European Union. The labels are easier to understand, rating products by letters of the alphabet from “A to C” in terms of relative efficiency. Perhaps the European market is more sympathetic to environmental claims than the American market.

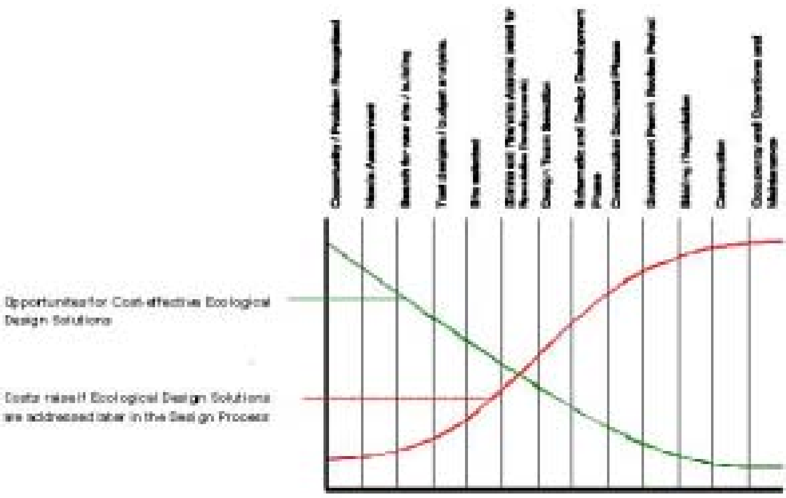
VII. Incentives

Energy efficiency markets are not generally well understood, and when they are understood, this comprehension tends to be on a theoretical level rather than on a practical level. Thus, it is hard to write an advance plan for “how to encourage energy efficiency” in a particular city in a particular type of building.

However, as a complement to energy codes, one of the most effective policies in the United States for encouraging increased efficiency in buildings is the use of financial incentives. In incentive-based systems, projects that achieve defined levels of increased energy efficiency are rewarded in some fashion. These rewards can be very broad in nature and provided over a long period of time, or they can be very targeted and be in effect for only a short while.

The necessary level of efficiency can be defined prescriptively, such as the required use of certain technologies, on a performance basis – for a subsystem, such as the watts per square meter used for lighting in commercial buildings; or on a building-wide basis, such as a percentage reduction from an energy code. Incentives can also be based on achieving the performance set out in building and equipment labeling and rating systems.

Figure 4: Opportunities to Influence Design



Design and construction of a building can take several years. Thus, a key question involves when to target incentives. As shown in Figure 4, the opportunities to influence the energy efficiency and green attributes of a building decrease farther along in the project timeline.

Incentives targeted early in the process can result in large changes for relatively small cost, but it has been extremely difficult to identify and reach projects at this stage of development. Conversely, it has been much easier to find projects that have already begun construction, but it is much more difficult and expensive to alter their choices.

In addition, there are some trade-offs involved with how incentives are targeted. In general, program evaluation has shown that targeting incentives to producers of energy efficient products or designers of energy efficient buildings is more effective—more efficiency AND lower cost. However, producer-targeted programs are much less visible and less popular programs than incentive programs that target consumers. If policy makers want to make a big splash and public gesture that they are saving energy, then they could offer a consumer-oriented program that is supplemented or complemented by a behind-the-scenes producer-oriented program. Producer-oriented programs tend to be longer-term, while consumer-oriented programs tend to be shorter-term, in part because of the cost of maintaining the short-term programs.

A. Long-Term Incentives

Many of the important decisions affecting energy efficiency such as the orientation in massing of the building, its ability to use solar energy for natural daylighting or for passive solar heating, its ability to shade itself from excessive solar heat gains, the integrated design of heating, ventilation and air conditioning HVAC systems and the insulation used in the building envelope, are made early in the design process. The actual energy savings of these choices will not be realized until the building is finished, which is often several years later.

Unless incentives are assured to available in the future, structural efficiency measures will not be encouraged by economic incentives. In order to affect these long-term design processes, and in particular to allow better integration of the architectural design processes of the building and the various engineering design processes, long-term incentives are needed. In the U.S., at least, about the only way to provide such long-term assuredness for incentives is through the tax system.

For example, if a building is being designed in 2002 with expected occupancy in 2005, an architect that is designing a system for greatly reduced heating and cooling loads would need to spend extra money, time and effort on the design. They would not likely be able to do so unless they had some assurance that an incentive would be available in 2005 when the building is completed.[51]

The method that is being discussed in the U.S. Congress currently is to provide incentives at a fixed level of money (per dwelling unit or per square meter of occupied floor area) for a mid-term length of time, such as six years. In S.207, a bill which has been used as basis for both Republican and Democratic energy legislation (H.R. 4 and S. 517), the amount of incentive provided is approximately 25%-35% of the estimated costs of energy efficiency measures, based on conservatively high cost projections.

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[51] Paying an incentive for the architectural aspect in 2002 would not work because the actual energy savings will not be known until the rest of the building systems are designed and specified. For example, an envelope designed for dayligting would waste energy rather than saving if the electric lighting system is later designed to be the same as it would have been for a non-daylit space.

Several states are considering using the LEED rating system as the basis for providing tax incentives.[52] The proposals would offer an incentive equal to 4% of the building's construction cost as an incentive for achieving the LEED Certified level, up to a 7% credit for a Platinum achievement. New York State has an interesting way of incentivizing broader participation in green construction. Their tax law offers a 5% credit for the main structure of the building, but 7% if the tenants all participate.

If incentives are going to be frozen for a modestly long period of time, they should demand very high levels of performance that are uncommon or unknown in construction. If the incentives are based on levels that are currently being achieved by even a modest number of buildings, then the cost of the incentives will be relatively high due to "free ridership". In addition, it is quite possible that nearly 100% of the market will jump to the incentivized level of efficiency, which could become quite costly.[53] In this case, it may be more cost-effective to incorporate this level of efficiency into the building code.

But if the levels of efficiency demanded are high enough, then even a 100% participation rate in the incentive will be good public policy because it will cause such a large change in the markets for energy-efficient designs and equipment that maintaining these levels should be sustainable after the tax incentive is phased out.

While it is important to establish incentives that will be fixed for a moderately long period of time, the incentives should not go on in perpetuity. Periodic evaluation of the successes and failures of the program is needed to offer possible mid-term corrections. Perhaps the tax incentive program encourages the use of labels or ratings to such an extent that the market will continue to provide high levels of energy efficiency even without the economic incentives. Perhaps the market will provide these results up to a certain level of efficiency, but further incentives will be needed for even higher levels in the future. Perhaps unforeseen problems or advantages will arise which should be considered in developing energy efficiency policy in the future.

Another key characteristic necessary for long-term incentives is that procedures for demonstrating compliance must be simple, but accurate. They can be based on the procedures used for demonstrating performance-based compliance with energy codes, with a slight modifications to account for energy efficiency measures that policy-makers might want to credit in terms of achieving additional energy savings but not credit in terms of making trade-offs against other minimum measures with the code.[54]

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[52] This structure is being proposed in legislation under development in Maryland, Massachusetts and Pennsylvania.

[53] A 100% market share for only modest efficiency gains suggests a second problem: perhaps the cost of building in the extra efficiency is much less than expected. If the incentive level exceeds the incremental cost of efficiency, it could actually hold back further gains in efficiency by reducing cost competition between different technologies.

[54] An example is: indirect evaporative cooling as a replacement for vapor compression cycle air conditioning to provide credit for indirect evaporative cooling in a code compliance program would be self-defeating. The energy saved by the more efficient cooling system would be used to justify the larger cooling loads—perhaps so large that the evaporative cooling system would no longer work effectively. But, if the cooling loads are already minimized to comply with the basic code, indirect evaporative cooling systems ought to be available for incentives for going beyond the code.

Tax incentives or long-term incentive programs should automatically generate labels and ratings that are designed to be useful in the marketplace. The types of documentation needed to establish compliance with the tax or administration authorities should also be useable, with minor adaptation, to meet the needs of the marketplace in crediting energy efficiency.

Non-monetary long-term incentives can also be put in place. Examples of such incentives currently used in the United States allow increased development density for projects incorporating the LEED Rating System. Other incentives used to spur early code compliance provided expedited construction permitting and project review.

B. Short-Term Managed Incentive Programs

Short-term, actively managed programs can have a number of advantages where the ability to adjust to unforeseen conditions is particularly important, such as in markets where incentives or efficiency codes have not been widely used.

Generally, electric utility companies or state energy conservation offices have been the principal sponsors of short-term managed incentive programs in the U.S. Often these programs are offshoots of a policy that emphasizes energy conservation as a means to meet society's growing energy needs at a lower cost than the development of new energy supplies. With proper regulatory incentives, energy efficiency programs can be more profitable for utilities than purchasing power or building new generating facilities.

Utility incentive programs are considered "short term" when they are created with one-year budgets and renewal for the succeeding year is not assured. These programs are actively managed by the utility and can be changed to adapt to the observed conditions if the market is responding to the program differently than expected. These programs are most effective when they are administered in a flexible manner: operate the program based on an initial design, observe the results, and make changes as appropriate, given the market response.

Sometimes experience will determine that additional technical information or assistance is needed. Perhaps the incentive levels are too high or too low. This can be determined by market research and other analysis provided by the utility, by the program administrator, by state officials, or universities, as appropriate. The resulting adjustments to the program can be relatively simple or profound. If a program is found to be failing because of the lack of supplies, the utility can attempt to contact suppliers and provide encouragement for them to offer the product locally. To the extent that the regional market may be too small to interest suppliers, programs can be coordinated across regional boundaries to provide sufficient market power that it is of interest to manufacturers.[55]

[55] On the west coast of America, changes in window requirements encouraged a changeover from aluminum-framed windows, which waste energy because of aluminum's high thermal conductivity, to vinyl-framed and wood-framed windows. But these changes were facilitated by the availability of incentives. In both California and the Pacific Northwest, active utility intervention in building markets that was explicitly aimed at facilitating code changes achieved its desired result.

The higher success rate of the flexible approach has been the experience of U.S. utility-sponsored programs. They have been extremely effective at encouraging changes in the "last-to-be-built" components of the building, such as lighting systems, and can produce some relatively modest improvements in the HVAC system. Again, this is illustrated by the right-hand side of Figure 4. But they have been less successful in encouraging innovative HVAC system designs for the total system and they will have very little impact at all in encouraging architectural changes unless specifically targeted in the context of going beyond code requirements – the processes of the left side of Figure 4.

1. Technology-Based Incentives

Technology based programs are simpler to administer and evaluate than integrated, whole building programs. They can also produce very large energy savings quickly if comprehensively implemented. They are applicable to new construction and existing buildings in both the residential and commercial sectors. These programs risk failure through "cream-skimming" because by targeting the easiest energy savings, they can foreclose the option of installing the even larger, though more difficult to capture, energy savings that result from a more comprehensive approach.

2. Compact Fluorescent Lamps

The success of compact fluorescent lamps (CFLs) in penetrating the U.S. market is attributed to several factors, including utility incentives, especially among residential consumers. According to the Electric Power Research Institute, utility incentives were estimated to be involved in half of integral CFL sales in 1991. However, in the commercial sector, utility incentives are less pervasive, since there is a greater economic incentive to purchase CFLs because of the high usage levels and the maintenance cost savings from having to change the bulbs much less often.

3. Windows

In California, utilities intervened to speed the introduction of low U-value windows. They did this not only by providing incentives for the thermally improved windows, but also by funding the creation of a window-testing infrastructure. The test procedures for labeling windows required computer simulation and then physical testing of a sample of windows. But when the program was being developed, there were no laboratories in California certified as being qualified to do the testing. The utilities helped create this testing infrastructure, which in turn led to the availability of labeled windows that could be used for code compliance.

4. Lighting

For non-residential buildings, utilities achieved dramatic successes in the mid-1990s in incentivizing the use of new lighting technologies that allowed lower power densities in non-residential buildings. The 1992 code in California required less than 17 watts per square meter of connected lighted power. But, due to utility incentives, a large number of buildings were constructed with power densities in the range of 10-12 watts per square meter. This allowed the

California Energy Commission in 1998 to adopt a reduction in the maximum power standard to 13 watts per square meter with no opposition from the lighting or building industries.[56]

5. Whole-Building Incentive Programs

Many of the most successful utility programs in the U.S. have achieved their success through active management. One of the best examples is the California new construction program operated by Pacific Gas & Electric Company, which modified its program design sufficiently that by the mid-1990's, it was achieving well over 50% market share of participation in its new construction program.

Super Good Cents (SGC) was a voluntary regional program initiated by the Bonneville Power Administration (BPA) to encourage early adoption of the ambitious new Model Conservation Standards (MCS) in the Pacific Northwest of the United States. At first, this program encouraged builder familiarity with higher levels of efficiency and created markets for new building supplies. Later, utilities agreed to pay for compliance with the codes even after it was required for a period of 18 months. This offer to ease the pain of transition for builders was instrumental in achieving credibility and widespread compliance with the codes.

In 1992, Seattle City Light implemented the SGC conservation program in the multifamily sector because of very high construction rates. Seattle then used its experience with the SGC program to develop new specifications and terms for a replacement program. The Built Smart program for energy and resource efficiency in multifamily new construction projects began operation in spring 1997.

Seattle's evaluation of SGC found that the program provided significant benefits: tenant energy savings of over 17 kWh/m2 and annual energy savings to the owner from common-area lighting of 16 kWh/m2. Energy bill savings for program participants with buildings completed in 1993-94 amounted to $75 per unit for tenants and $50 per unit for building owners.[57]

> Despite this success, the evaluation recommended that SGC could by improved by developing ways to underscore the value of improved energy efficiency in participating building through follow-on services.[58]

C. Industry Collaboratives

The Super Efficient Refrigerator Program (SERP), also known as the "Golden Carrot" Program was the result of a broad-based partnership between NRDC and other NGOs, the Federal Government and electric utility companies. The "Golden Carrot" program coordinated

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[56] J.A. Johnson, "Transforming Markets in California: Ratepayer Funded Codes and Standards Successes," by New Buildings Institute for PG&E, October 2001.
[57] Marc Schuldt et al., *A Tale of Two Cities: Boosting Energy Efficiency in Multifamily New Construction*, presented at 1997 Energy Evaluation Conference, Chicago, IL, August 27-29, 1997, at 550.
[58] *Id.* Follow-on service would provide building owners and tenants with ongoing information about energy bills and saving. Assistance with operations and maintenance could ensure that the proper lams are replaces in high-efficiency lighting fixtures. Follow-on services also serve the utility, but supporting the persistence of impacts and reinforcing consumer demand, along with the opportunity to provide non-energy customer services.

utility incentives to stimulate the development and commercialization of advanced technologies and superior efficiency levels. The first "Golden Carrot" program was a competition among manufacturers of refrigerators that resulted in the design and production of refrigerators that were 30-40 percent more efficient than the 1992 standard for comparable sized conventional units.

The SERP product became the design basis for the 2001 DOE national refrigerator standard, which is now in effect. Interestingly, for the first time in history, U.S. manufacturers agreed to accept a standard at the 2001 level. Previously, they had opposed all proposed energy efficiency standards. The result was a four-fold improvement in energy efficiency between the mid 70s and 2001, which came in the face of continually increasing size and features and declining price (in inflation-adjusted dollars).

Similar approaches are being used for products such as high-efficiency gas and geothermal heat pumps in the DOE's Technology Introduction Partnerships.[59] The success of the "Golden Carrot" program strengthened efficiency standards and the existence of promising advance technologies. This program allowed rewarded manufacturers in producing refrigerators with higher efficiency standard than required.

Equipment Covered by CEE

Residential
• Clothes Washers • Room A/C • Refrigerators • Dishwashers • HVAC Installation • A/C & Heat Pumps • Gas Heating • ENERGY STAR® CFLs • ENERGY STAR® Fixtures
Commercial
Clothes Washers • A/C & Heat Pumps • HVAC Installation
Industrial
Premium-Efficiency Motors • C&I Transformers
Government
Energy-Efficiency Traffic Signals

The Consortium for Energy Efficiency (CEE), is a national, non-profit public benefits corporation that promotes the manufacture and purchase of energy-efficient products and services. CEE's goal is to induce lasting structural and behavioral changes in the marketplace, resulting in the increased adoption of energy-efficient technologies.[60]

CEE members include utilities, statewide and regional market transformation administrators, environmental groups, research organizations and state energy offices. Also contributing to the collaborative process are CEE partners - manufacturers, retailers and government agencies. The U.S. Department of Energy and Environmental Protection Agency both provide major support, through active participation as well as funding.

D. Procurement Programs

Procurement programs involve large purchasers setting internal standards for the goods and services they obtain in the market. These standards can be based on a label or rating system,

[59] Sustainable Energy Strategy: Clean and Secure Energy for a Competitive Economy, National Energy Policy Plan pursuant to Section 801 of the DOE Organization Act, 30 (July 1995). [Hereinafter National Plan].
[60] In the United States' restructured utility market, some states are continuing with utility administration of energy-efficiency programs; other states are designating public agencies for this work. CEE serves the needs of both, providing a forum for the exchange of information and ideas. See <http://www.cee1.org>.

such as LEED or Energy Star, or they can be based on a certain benchmark, such as percentage of recycled content or renewable energy purchased or exceeding miles per gallon regulations by a certain amount. Government entities, large corporations and even electric utility companies tend to be the major participants in procurement programs.

In addition to the market transformation role government plays in setting standards, government can also help transform the market as a major consumer of goods and services. For example, Presidential Executive Orders 12873 and 13101 almost single-handedly established the market for recycled paper, by requiring that all paper used by the government contain a minimum of 20% then 30% recycled fiber.[61]

Similarly, at least six Federal Executive Orders[62] governing energy efficiency in federal buildings, transportation fleets and other energy and environmental aspects of the government operations. State and local governments likewise are significant market drivers. About 30% of the LEED projects are some type of government building. The architects, engineers, construction companies and product manufacturers involved with these projects all carry the experience of working on an energy and environmentally efficient building into other projects, thus producing a significant “free driver” effect.[63] While procurement has not been used as heavily as direct consumer or manufacturer incentives in the United States, it has played a significant role in a few market transformation programs.

One of the earliest and most noteworthy of such programs is ENERGY STAR computers. In one of the first uses of the normative label “ENERGY STAR,” the U.S. Environmental Protection Agency established a specification for energy efficiency computers in the early 1990’s. A key step towards making this program successful was a U.S. government procurement decision to buy exclusively computers that met the ENERGY STAR level shortly after it was introduced. This encouraged manufacturers to design to the ENERGY STAR specification. Once they had done so, it was easier to sell all of their products at the complying level than to maintain separate product lines for a trivial difference in cost. This program was quite successful, with the overwhelming majority of computers complying with the specification.

SERP could also be considered a procurement program. SERP was a consortium of utilities that offered a $30 million competition for manufacturers to produce the most energy efficiency and environmentally clean refrigerator that they could; based on program designs put together by the U.S. EPA, the Washington State Energy Office, and NRDC, with strong participation from the American Council for an Energy Efficient Economy, the utilities designed the equivalent of a competitive procurement of some 200,000 refrigerators. The entire contract would go to the single refrigerator manufacturer that offered to sell the most cost-effective “green” refrigerators – the ones that saved the most energy for the least amount of payment per unit. SERP received 14 bids, selected two finalists, and offered the contract to one winning refrigerator company. This program led the way to the 2001 DOE energy efficiency standard

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[61] See<http://www.epa.gov/cpg/paprman.htm>.
[62] Executive Order 13150; Executive Order 13149; Executive order 13148; Executive Order 13134; Executive Order 13123; Executive Order 13101. The text of these rules may be found at <http://www.ofee.gov/greening/greening.htm>.
[63] The free driver effect refers to the impact of a program or project beyond its immediate scope.

and to the existence of ENERGY STAR rated models that save 10%-15% more than required by that standard in the year 2001.

There are limits to the effectiveness of procurement programs in the absence of broader market-based and regulatory tools, especially if present alternatives are perceived as preferable. The purchase of alternative fueled vehicles in government fleets, for example, had little impact on overall market penetration of this technology beyond the vehicles purchased by the government. There can be many reasons for this failure: lack of market acceptance, inferior performance, inconvenience, non-competitive price, etc. For this reason, it tends to be preferable to specify a certain level of performance and allow the interplay of consumers and producers find the best solution.

E. Education/Information/ Training Programs

Education/Information/Training (EIT) programs are necessary, but not sufficient components to any market transformation strategy. Education programs are distinguished from training programs in that they are focused on students preparing to become practitioners, while the training tends to focus on professional development. Information programs have two principal targets: (1) information and analysis about energy trends in consumption, production and price are targeted to policy makers and advocates, (2) consumers, either as individuals or procurement agents for larger entities are provided information about energy in general and specific to certain technologies. Too often the expectations of EIT programs are set either too high, or too low.

When the expectations are set too high, EIT is used as a lower cost substitute for more substantial programs that put actual technology in the hands of users. The assumption is that with a certain kind of knowledge, market participants will act a certain way. This assumption flies in the face of reality, which is that the lack of EIT is only one of the barriers to increased penetration of ideas or technology.

When expectations are set too low, EIT is avoided altogether and people misapply good technology or ideas or pursue unrealistic or ineffectual policies. Then because they don't work properly, otherwise good building design ideas or technologies are abandoned or underused.

1. Energy Efficiency Demonstration Centers

One particular kind of targeted education, the efficiency demonstration center, appears to be quite effective at influencing the markets towards greater energy efficiency. Such centers target commercial sector users. Some examples include—

- The Seattle Lighting Design Laboratory
- The Pacific Gas and Electric Energy Center
- The Southern California Edison Customer Technology Application Center
- The Southern California Gas Company's Energy Resource Center

These centers provide hands-on educational and demonstration materials concerning equipment and design practices for increased energy efficiency, provide lectures and reading materials to promote efficiency, conduct user-oriented demonstrations of energy efficiency, including in some cases mock-ups of user lighting designs. In some cases they provide direct consulting services (although not explicitly building design) and a library of materials.

Two evaluation studies have recently been issued concerning these centers, both of which find significant positive market response:

• The PG&E Energy Center Market Effects Study[64] concluded "the [Energy Center] is responsible for significant changes in relevant market-related behaviors. Substantial portions of relative decision makers responded to surveys that they were specifying more efficient equipment and that this change was due entirely or in part to the Energy Center's influence. Eighty percent of respondents said that the changes [in their behaviors] had influenced at least one commercial building. More than 20% said that the changes in behavior had influenced 21 or more buildings. An even higher percentage (32%) said they felt the change would influence 21 or more buildings over the next two years."

• The CTAC study[65] concluded, "CTAC's market intervention strategies appear to be linked to a reduction in barriers to market effects [originally hypothesized.]" This study places a relatively greater emphasis on identifying market barriers and evaluating the extent to which these barriers were overcome.[66] Based on customer interviews study concluded that "nearly all [respondents] agreed that awareness had significantly increased and...[m]any felt strongly that increases in demand have been observed for energy efficient lighting equipment…[and that] some HVAC manufacturers...report that sales of energy efficient HVAC equipment have been positively influenced by utility programs."

2. Education Program Examples

Most State Energy Offices have Energy Extension Programs that provide consumer information for distribution to retailers, schools, libraries and other information outlets. For many years, these programs were supported by special government funds established when it was found that oil producers had been price-gouging consumers. Currently, these programs are co-funded between the federal and state government budgets.

a. Texas Energy Education Development (TEED)

TEED is a non-profit organization, and is the Texas Affiliate of the National Energy Education Development (NEED) program. TEED is unique among curriculum-related programs because it combines a "hands-on" out-of-classroom series of activities and projects with a

[64] John H. Reed and Nicholas P. Hall, PG&E Energy Center Market Effects Study, Arlington, VA: TecMRKT Works, May 1998, at vii.
[65] CTAC Market Effects Study, Volume 1 Final Report, prepared by Hagler Bailly Inc., San Francisco, for Southern California Edison.
[66] The key barriers it analyzed were: Information Costs; Performance Uncertainty; Information Asymmetry; and Bounded Rationality.

comprehensive classroom curriculum suited for use in science, math, social studies, language arts and special education. Utilizing a "Kids Teaching Kids" philosophy, schools (K-12) teach themselves, their fellow students, and the community about energy resource issues and energy conservation. The school projects are submitted annually to the Texas Association of Student Council and are eligible for state and national awards.

Highlights of the TEED program:

1. An Energy Kit of resource material for energy conservation projects and activities
2. Community Weatherization Project for Low-Income Housing
3. Awards program in conjunction with the Texas Association of Student Councils
4. Annual Summer Energy Camp for high school students
5. READ with TEED Curriculum Book aligning energy materials with all disciplines in the classroom
6. Governor's Proclamation/visit to the Capitol to declare March as "Texas Energy Education Development" Month
7. TEED Scholarship Program

b. Policy Information Program Examples

As noted above, information programs can have two primary focuses: decision makers and consumers. For example, the New York State Energy Research and Development Authority[67] (NYSERDA) provides general energy statistics and data on energy consumption, supply sources, and price and expenditure information for New York State and a comprehensive set of New York state-specific energy statistics. In addition, the Energy Analysis Program focuses on using energy, regulatory, and environmental policies to help New York State businesses grow and to meet the needs of New York State's energy consumers. Energy Analysis Program staff analyze important energy issues, publish comprehensive statistics and data, and respond to energy supply disruptions or shortfalls. Staff are viewed as a source of objective information about all aspects of New York's energy picture.

In addition to providing timely and relevant analytical information, NYSERDA Energy Analysis staff study current energy issues to assess energy requirements and available supplies to determine their effect on the State's economic and environmental well-being. For example, Energy Analysis staff participated in a national policy dialogue in cooperation with the Center for Clean Air Policy, utilities, state agencies, and public interest groups from across the U.S. to determine the effects that restructuring the electric industry could have on air quality, electric system operations, and consumer costs.

[67] NYSERDA, a public benefit corporation, provides energy-related technical and financial packaging assistance to businesses and institutions to promote energy efficiency and economic development. NYSERDA sponsors energy research and development programs that promote safe and economical energy production and efficiency technologies in New York State, issues tax-exempt bonds and notes for energy-related projects, and analyzes the effect of New York's energy, regulatory, and environmental policies on the State's business, institutional, and residential energy consumers.

c. *Energy Audit Information Programs*

Energy audits are another kind of information that can be provided by government entities to consumers, in this case building owners. Generally, audits are conducted on a cost-share or free-of-charge basis. This analysis provides insight to the most cost-effective and feasible ways to save energy. The results of this kind of analysis can also be very useful to policy makers.

For example, when evaluating the impact of energy efficiency measures on a commercial building in Beijing, the analysis showed that energy consumption for heating was extremely small, while energy consumption for lighting and cooling was extremely large. Up to this point, it was believed that heating was the dominant energy factor in commercial buildings and early attempts to develop a commercial building energy code had focused on measures to reduce heating energy consumption. In the absence of this new information, a significant public policy opportunity could have been missed.

The California Bright Schools (CBS) Program helps schools with upgrading to energy efficient equipment. CBS provides information and evaluates the work needed. The California Energy Commission, California Conservation Corps, the local utility company and other qualified energy service companies (ESCOs) have teamed up to guide schools through the steps of an energy upgrade project:

- Identifying and determining a project’s feasibility;
- Securing financing for the project; and
- Purchasing and installing the new energy efficient equipment.

The Schools receive the following benefits from the program:

- Improved classroom comfort for a better learning environment
- Energy cost saving accrue year after year to use for other school needs
- Free energy audits and energy usage consultation;
- Integrated package of project planning and management services
- Assistance in securing best financing options
- New school design review assistance
- Bulk pricing on energy-efficient lighting equipment purchases through the state’s Office of Procurement
- Procurement assistance on selected equipment purchases
- Low cost installation by trained professionals

School districts through this program received more than $150,000 in utility energy efficiency rebates and more than $115,000 through energy efficient projects each year.

VIII. Applying the Tools of Market Transformation to Specific Markets

To transform the Chinese building market for energy efficiency, policy makers will need to apply the various tools discussed above to the various markets described in Table 1. Although China's construction industry is much more centralized than that of the United States, Chinese building markets are still essentially local in nature as is the case in the U.S. These measures will need to be adapted locally to achieve full penetration of the Market.

Lost Opportunities: It Pays to Build it Right the First Time

Energy Efficiency is easiest and least costly to build into new constructions. Once a building has been constructed, it is more expensive and sometimes even infeasible to meet comparable levels of energy efficiency. Design mistakes can last the life of a building, so it is important to *get it right the first time.*

Table 5 lists the most successful tools that have been used to improve energy efficiency in the different building markets. This Table distinguishes appliance and equipment markets from the buildings markets because the policy and programmatic measures used to improve efficiency can be applied independently, although greater results can be obtained through the synergy of a combined approach.

Below we will evaluate each of the tools as they apply to (1) New Residential, (2) New Commercial, (3) Existing Residential, (4) Existing Commercial and (5) Appliances and Equipment.

Table 5: Tools of Market Transformation Applied to the Building Sector

Buildings	**Commercial**	**Residential**
New	Building Codes Incentives Labeling ETI	Building Codes Incentives Labeling ETI
Existing	Standards Incentives Labeling ETI	Standards Incentives ETI
Appliances & Equipment	Standards (mandatory within codes; voluntary) Incentives Industry Collaboratives Labeling Procurement Programs	

A. New Residential Buildings

Residential buildings account for 21% of U.S. energy consumption.[68] In China, this sector consumes approximately 13% of the nation's total energy.[69] Nearly 400 million square meters of residential construction are on going in China at any one time.[70]

[68] Energy Information Administration, Annual Energy Review 2000, at 38. [Hereinafter AER2000].
[69] Lawrence Berkeley National Laboratory, China Energy Data Book v.5.0, May 2001.
[70] See <http://www.chinavista.com/business/cnedc>.

Figure 5: Super Good Cents: Standards and Label Incentives and EIT=Code

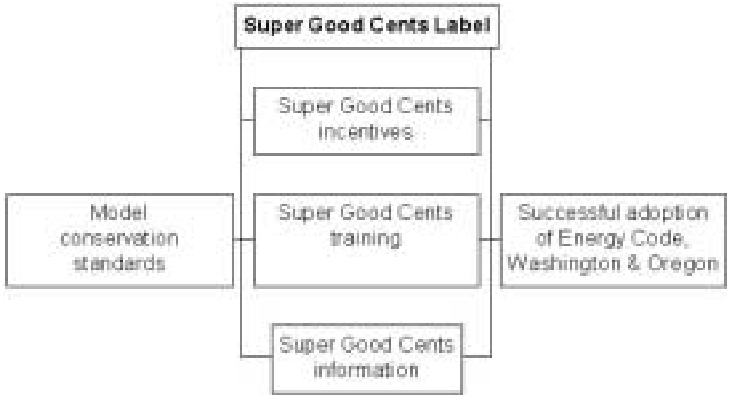
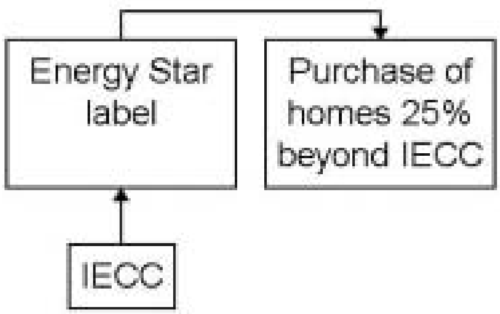


Figure 5 illustrates how the Super Good Cents program successfully used incentives and training to ensure rapid adoption and widespread compliance with a new energy code. The Energy Star label identifies homes that are 30% more efficient than the IECC. The Energy Star program has rated approximately 40,000 homes since its inception in 2000.[71] The interplay between the different market transformation tools is shown in Figures 6 and 7.

Figure 6: Energy Star Homes: Code and Label = Beyond Energy Savings



B. New Commercial Buildings

Commercial buildings account for approximately 17% of U.S. energy consumption.[72] In China, this figure is approximately 9% of total consumption, but is forecast to grow rapidly with China's accession to the WTO.

For the commercial sector in the U.S., the New Buildings Institute estimates that savings this year exceed $775 million per year, or 1% of the commercial sector's entire utility bill. This is all the more remarkable of an achievement because the typical codes in use in the United States are not very stringent in their energy efficiency requirements.

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[71] See <http://yosemite1.epa.gov/estar/homebuyers.nsf/content/NEWSWhatsNewSnapshot.htm>.
[72] AER2000 at 38.

For the commercial sector in the U.S., the New Buildings Institute estimates that savings this year exceed $775 million per year, or 1% of the commercial sector's entire utility bill. This is all the more remarkable of an achievement because the typical codes in use in the United States are not very stringent in their energy efficiency requirements.

Figure 7: Existing Residential

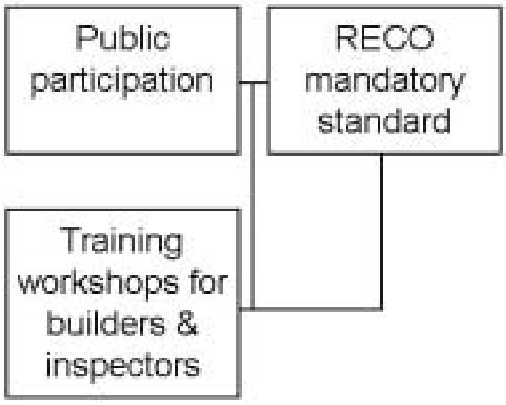
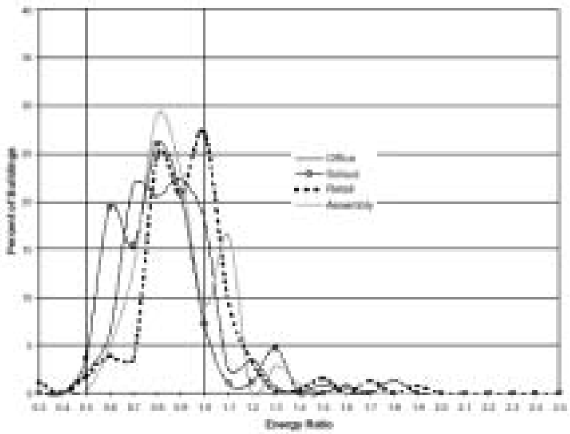


Figure 7 is a frequency distribution of building energy use compared to the energy code in California in the mid-1990s.[73] It illustrates, for four different building types, what percentage of buildings consumed a given level of energy compared to the energy code. The scale on the "X –axis" of 1.0 indicates a code-compliant building. Energy ratios of, for example, 1.3, indicate 30% more energy consumption than would be allowed by code; an energy ratio of 0.7 indicates 30% savings.

Figure 8: Distribution of Building Energy Use Compared to Code: California 1990s

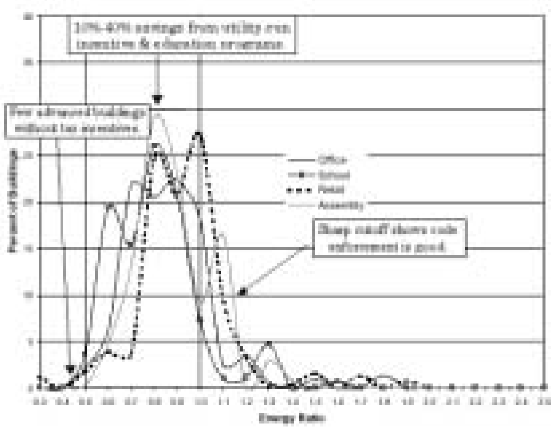


[73] Eley & Associates, Architectural Energy Corp., California 2001 vs. ASHRAE 1999: *Comparison of ASHRAE/IESNA Standard 90.1-1999 and the 2001 California Nonresidential Energy Efficiency Standard*, Prepared for the California Energy Commissions, August 2, 2001.

This graph was prepared from data collected in California in the mid-1990s, when there was an active program of energy code outreach and enforcement along with utility-based incentives. As shown in Figure 8, the result is entirely consistent with the theories discussed in this paper.

The first noteworthy result observed from the graph is the sharp cutoff of buildings with energy ratios above 1.0. With the slight exception of schools, where enforcement of the energy code is not fully mandatory, we can see that the overwhelming majority of buildings comply with the code. Even those that fail to comply are typically only a few percent out of compliance. This shows good code enforcement. Good enforcement has been complemented by extensive training and education programs promoted by the California Energy Commission.

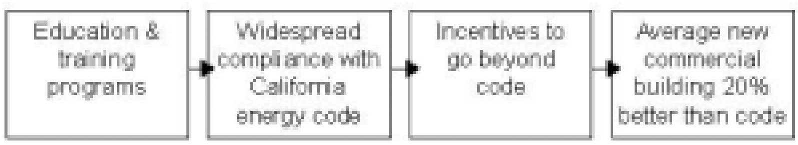
Figure 9: Interplay of California Building Code with Market Mechanisms



The second noteworthy observation from the graph is the broad plateau between code compliance (an energy ratio of 1.0) and 40% savings (an energy ratio of 0.6). Most buildings do not merely comply minimally with the code, but save 10% or 20% or 30%, or even 40% beyond the code. This is consistent with the widespread use of short-term incentives and education and outreach programs during the mid-1990s by California utilities.

A third observation from the graph is the sharp drop-off of buildings at energy ratios of .5 or lower (equivalent to 50% or better energy savings). This is not unexpected given the absence of long-term incentives. Indeed, the regulatory environment for utilities was so volatile at this point in history that the utilities were not in a position to make even informal commitments about the availability of the incentives two or three years in the future.

Figure 10: Code and EIT and Incentives = Beyond Code Energy Savings



The paucity of buildings saving 50% or more is not an indication of the technical limits on energy efficiency, however. NRDC designed new buildings for our own occupancy in the late 1980s and mid-1990s, relying only on technologies and designs that were available in the marketplace and had a financial rate of return higher than NRDC's cost of borrowing money for construction. Our buildings saved between 70% and 80% compared to the code, clearly demonstrating that the limiting factor on large energy savings is not technological or economic.

C. Existing Residential buildings

This is one of the toughest markets to penetrate comprehensively because they are very diffuse, essentially comprised of millions of households. Major architectural elements are difficult and expensive to retrofit, particularly in a multifamily market. The largest and most easily captured potential to reduce residential energy consumption resides in new appliance and equipment mandatory standards, as described below. Incentive programs do work for existing households but are expensive and complex to administer.

The U.S. Department of Energy's (DOE's) Rebuild America Program facilitates voluntary community partnerships in improving their buildings through energy efficiency. When communities, businesses, and housing agencies form Rebuild America partnerships, they tailor their programs to local needs and choose which buildings to renovate, how much energy to save, and the best technologies to use. Rebuild America lets partnerships select the best ways to improve their communities. Rebuild America supports partnerships with technical and business experts, resource materials, and a national network of peers who are working on the same issues and developing innovative solutions.[74]

Rebuild America focuses on six different market sectors: colleges and universities, kindergarten through twelfth-grade schools, state governments, local governments, commercial buildings, and housing. Each of these sectors represents a particular customer group that has similar or related characteristics, has common needs, and responds to the same motivation.

An example of a Rebuild America program implementation is the Knox Housing Partnership, Inc. (KHP) is a private, charitable corporation facilitating affordable housing for low-income residents of Knoxville and Knox County, Tennessee. KHP teamed with Knoxville's Housing Development Corporation (KHDC) to undertake a joint housing revitalization project involving 146 single-family detached homes that will revitalize two inner-city neighborhoods. The goal of the $6.8 million project is to bring renters into home ownership by providing a pool of quality, affordable housing and assisting families in obtaining below-market rate financing. More than two-thirds of the revitalized homes are being sold to the existing renters or other low-income buyers. The remainder of the houses are being made available for continued rental to current clients to avoid displacing those who cannot afford to or do not wish to move into home ownership. The results of this program are shown in Table 6, below.[75]

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[74] Mark P. Ternes, Oak Ridge National Laboratory, Jim Cavaio, Argonne National Laboratory, Cara Applegate, D&R International, LTD, "Successes from Rebuild America's Housing Partnerships." 2000 ACEEE Summer Study on Energy Efficiency in Buildings, Washington, DC, ACEEE, 2000 at 2.299.
[75] *Id.* At 2.307

Table 6. Monthly Housing Costs Before and After KHP Rehabilitations

	Before rehabilitation	After rehabilitation
Rent/mortgage	$260-325	$270- 430
Energy costs	$100	$66
Total housing costs	$360-425	$336-496

Some communities have developed mandatory programs for improving the energy efficiency of existing residential buildings. In 1981, the California city of San Francisco adopted the Residential Energy Conservation Program (RECO), a prescriptive code designed to improve the energy efficiency of existing housing. RECO has reduced the amount of energy the average home uses in San Francisco by more than 15%, without any cost to the city treasury.[76]

RECO has proven to be simple to understand and easy and inexpensive to enforce. RECO requires such energy-saving measures as adding insulation; caulking and weather-stripping doors, windows, and other openings in the building shell; insulating hot water heaters and pipes; installing low-flow faucets and shower heads; installing low-flush toilets or flush reducers on existing toilets; and insulating heating ducts. Once RECO is triggered, homeowners or landlords must hire a private contractor to install the prescribed energy efficiency measures or do it themselves. A compliance inspection is then required to assure the work was completed.

Several events can trigger the need for compliance with RECO, including the sale of a building; metering conversions (changing from a master to individual meters, for example); improvements greater than $20,000 for single and two-family homes, $6,000 per unit for buildings with three or more units, or $1,000 per unit for residential hotels; condominium conversion; or a complete building inspection (for adding or combining units, for instance). To give the ordinance teeth, an Order of Abatement can prevent the transfer of property unless the owner complies with RECO.

In spite of initial sharp opposition from the real estate community, the ordinance is now a routine part of doing business in San Francisco. Acceptance was helped along by extensive publicity, an informed public, involvement of the private sector from the beginning and training workshops for both city and private inspectors. The simplicity and cost-effectiveness of the measures required for compliance also play a part in RECO's success.[77]

D. Existing Commercial Buildings

RECO has a commercial building counterpart aptly named CECO. RECO established the political and administrative basis for CECO, which took effect in July 1989. The story of San Francisco's Commercial Conservation Ordinance (CECO) illustrates the complexities of designing energy standards for use in a competitive commercial real estate market.

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[76] Department of Energy, Tomorrow’s Energy Today for Cities and Counties: Commercial Energy Codes Lay Foundation for Saving Money 3 (February 1995). [Hereinafter, Commercial Codes]
[77] *Id.*

California mandates energy efficiency standards for all new buildings, but does little to improve the performance of buildings already built. Support was strong in San Francisco to find ways to conserve energy, but translating energy efficiency policy into a workable ordinance presented some challenges. Commercial codes are more complicated than residential ones and the city is examining the commercial ordinance to simplify its requirements and streamline its enforcement.

Presently, the events that can trigger CECO review and enforcement include the transfer of a building's title, an addition to a building that increases the heated space by more than 10%, and renovation and improvements valued at more than $50,000. After a trigger event, CECO review is required. A private inspector conducts an inspection for a fee and identifies the areas of the building that do not comply with the ordinance. The building owner must then implement prescribed energy efficiency measures up to a simple payback of 4 years.

Small Business Standard Performance Contract Program: The SBSPC is a statewide incentive program in which third-party (i.e., non-end user) project sponsors are paid for measured, verified savings, based on a fixed schedule. End users cannot self-sponsor projects. A minimum savings of 20,000 kWh per year is required for an application. Aggregation of like customers is allowed and encouraged. A standard contract between the program administrator (utilities) and third-party sponsor specifies incentives, simplified performance measurement and verification (M&V) options and protocols, payment terms, and other operating rules. Sponsors are responsible for M&V. Incentives (specified amounts per kWh saved) are paid to project sponsors, with 40% after installation and 60% after one year, based on verified savings. The project sponsor incentive includes a fixed “participation incentive” of $1,000 for lighting projects, $2,500 for HVAC projects, and $1,500 for motors/other.[78]

Table 7. Basic Program Data Summary for 1999 California SBSPC Program*

Utility	Applications	Total Incentives	Customers
SCE	91	$768,510	56
SDG&E	20	$234,834	21
PG&E	70	$698,919	62
Total	181	$1,702,263	133

*Notes: These figures are based on data received by the authors from the utilities in early 2000 and are not official figures. Final official participation figures for 1999 will likely differ slightly from those reported here.[79]

E. Appliances And Equipment

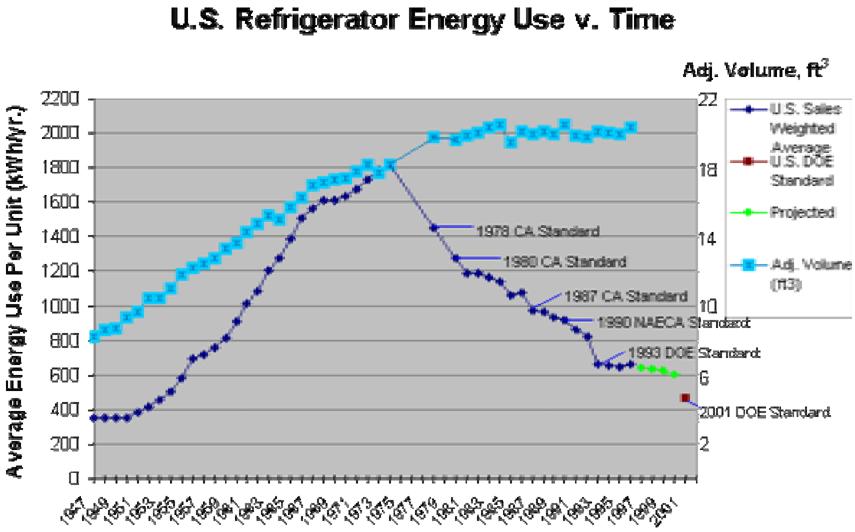
Figure 11 shows the evolution of refrigerator energy use in the United States over the past sixty years. Up until the mid-1970’s, refrigerator energy consumption was increasing at an annual rate of over 6% compounded. This increase was due to a growth in size and in features, as well as an absolute decline in energy efficiency. Had this growth trend continued until today,

[78] Market Assessment and Evaluation of California’s 1999 Small and Medium Nonresidential Energy Efficiency Programs, Michael Rufo, XENERGY, Inc., Mary O’Drain, Pacific Gas & Electric Company, Allan Lee, XENERGY, Inc., John Cavalli, Quantum Consulting Inc., Julia Larkin, XENERGY Inc. 2000 ACEEE Summer Study on Energy Efficiency in Buildings, Washington, DC, ACEEE, 2000.

[79] *Id.*

refrigerators would be consuming over 150 GW of electricity in the United States, well above the output of the entire U.S. nuclear energy program.

Figure 11: Trends in Refrigerator Energy Consumption



This trajectory changed dramatically with the adoption of energy efficiency standards by California in a proceeding that took place in 1975 and 1976. These standards influenced the market for refrigerators nationwide, as manufacturers quickly realized that it was cheaper to comply with the California standards nationwide than to produce separate products for different states.

The California standard was based on the most efficient products at the time. Ironically, they were introduced by a manufacturer who marketed their advantages in terms of greater energy efficiency, but was unsuccessful in the marketplace; it eventually went out of business.

Following 1980, the shallow slope towards more efficiency was likely encouraged by utility-based incentives for products that were 10% or so better than the standards. Utilities in California, several states in the Pacific Northwest, New York, California set new standards in 1984 with effectiveness dates of 1987 and 1992. These were nationalized with a three-year lag time for the first tier, and contributed to the observed drop in energy consumption at these dates.

IX. Funding Market Transformation Activities in China

Funding sources for market transformation tools can be as diverse as the tools themselves. Funding for standards development can come from the government at the national or province level. The macroeconomic benefit-cost ratio to governments for establishing energy efficiency standards is on the order of 100:1. It is also possible that a professional engineering or design association may wish to use its funds and donation of in-kind expertise to develop an energy standard, if there were some reasonable expectation that it would be received well at the Ministry of Construction.

Government can also be a source of incentives. Indirect monetary incentives, such as tax credits, or reduced tax rates reduce government revenues, but do not require additional budget to achieve. Similarly, local governments can use non-monetary, but still valuable incentives, such as increased density allowances and expedited permitting and review. In the U.S. the largest source of building market transformation incentives has been the electric utility industry, which was putting up to 2 billion dollars per year into this area at the peak of activity. These funds were supported by very modest increases in electricity tariffs of less than 3%. NRDC co-authored an extensive discussion of utility funded programs in the Chinese context.[80]

Energy and environmental labels or ratings for buildings and equipment can be funded in similar ways to the development of standards. A government-sponsored label, such as Energy Star would be funded out of the government budget, while a privately sponsored rating system such as LEED would be developed using the resources of an organization like the U.S. Green Building Council. For example, if a group of enterprises and government agencies wanted to form an independent China Green Building Council, they could fund the development or adaptation of a green building rating system similar to LEED.

Procurement programs require little to no additional funding beyond normal budgets for materials and equipment, the only difference being the emphasis on certain levels of energy and environmental performance in the purchased materials.

Industry collaboratives would be funded through voluntary in-kind contributions from participating entities that could be covered within existing staffing levels or the creation of new positions, depending upon the level of commitment of the participant.

X. Conclusion & Recommendations: A Comprehensive Policy For Encouraging Energy Efficiency In Buildings

China is already engaged in several of the market transformation activities mentioned in this paper, although in an uncoordinated fashion. A comprehensive policy to improve energy efficiency in buildings should be based on the following elements that have been shown to be effective instruments for promoting improved comfort and building performance, as well as ever increasing levels of energy efficiency. China could be the first nation to fully implement such a comprehensive program.

1. The first step is to develop standards that encourage performance-based compliance and achieve 30%-50% energy savings compared to prevailing practice. China has already completed or is actively pursuing the development of standards for residential buildings in the heating, cooling and transition zones. Plans also exist to begin development of a commercial building standard. In addition, China also has developed voluntary energy efficiency performance standards for air conditioning equipment, refrigerators and certain lighting products. China should identify emerging trends in equipment energy use and develop standards to reduce energy consumption of these devices.

[80] Barbara Finamore, Dr. Hu Zhaoguang, Dr. Zhou Fuqiu, Professor Yang Zhirong, Mr. Li Weizheng, Mr. Liu Jing, *Utility demand-Side Management in China Opportunities and Policy Options*, February 2002.

2. The next step is to develop mandatory codes based on these standards. The will require moving energy standards into the same legal category as health, life, safety and structural standards. Compliance with the performance standards should be universally required as a prerequisite to building occupancy or to the sale of equipment or appliances in the market.
    - Agencies in authority should plan now for regular revisions to the standards to achieve higher levels of efficiency in the future.
    - Standards should include criteria for energy ratings through associated labeling, rating and incentive programs as part of the performance approach.

3. Through government agencies or by encouraging professional associations, China should develop its own simple normative labels to distinguish the most efficient buildings and equipment. As a complement to normative labels, informative labels that can be used to establish the entire range of energy values in the marketplace should be developed.

4. The Chinese Government should establish procurement programs based on normative and informative labels that require the purchase of the most efficient equipment or appliances and design of the most efficient buildings for use by government agencies. Incentives could be developed for large enterprises to participate individually or collaboratively.

5. Short-term, managed incentive programs should be developed through government agencies or the electric and natural gas utility industries that promote modest improvements (about 15% to about 30% beyond the standards) based on labels or voluntary beyond-code standards.

6. Tax incentives or other long-term, fixed incentives for achieving 50%-75% savings beyond the code, possibly based on labels or rating systems, should be approved by the government.

7. China should continue its efforts in research and development of new technologies and the implementation of innovative design principles.

8. In conjunction with the development of energy codes and standards, education, outreach and training of designers, engineers, builders and code officials should be budgeted for and staffed as an integral part of the code development process. These programs could possibly be funded through multilateral development bank loans or grants from the World Bank, in conjunction with its municipal heating system reform project or as a separate proposal to the Asian Development Bank.

生态办公示范楼节能设计及能耗模拟分析

卜震　陆善后　范宏武　曹毅然　李德荣　（上海建筑科学研究院）

摘　要　本文介绍了上海市生态建筑办公楼集成运用的节能围护结构、自然通风、新型空调和再生能源等多项建筑节能技术，采用 DeST 和 TAS 软件对其全年的能耗进行了动态模拟计算，并分析了各种节能措施的节能效果，为节能方案的进一步优化和完善提供了可靠的依据。生态楼示范楼的建造将促进各种先进节能技术在我国的应用和推广。
关键词　生态建筑；节能技术；能耗模拟

Introduction to Energy Efficiency Technologies and Simulation of Energy Consumption for Shanghai Ecological Building

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Abstract　This paper introduces the energy efficiency technologies applied to Shanghai ecological building, which includes high energy performance envelope, natural ventilation, humid dependent air-conditioning system and renewable energy. To achieve better energy performance, simulation tools DeST and TAS were used to calculate the annual energy consumption of the eco-building and analyze the energy effects for the energy efficiency technologies. The eco-building is helpful to promote the application and spread of advanced energy efficiency technologies.
Key words　ecological building, energy efficiency technology, energy simulation

随着上海市城市建设的持续发展和人均GDP的增长，人们对工作、生活的质量和舒适性要求的不断提高，致使建筑使用能耗在整个城市能源消耗中的比重逐年增大。从可持续发展的战略角度来看，节约能源、保护环境已成为上海建设“生态型城市”的重要方面。因此针对现代化建筑，如何在改善生活质量和保证工作效率的前提下，更为有效而科学的提高能源利用效率就成为目前各类建筑发展的主要目标。正在建设中的上海市生态办公示范楼（以下简称“生态楼”），针对国内外生态建筑发展现状，通过大量生态建筑关键技术的集成研究、示范和推广，建立具有上海特色的生态建筑集成技术体系。作为上海市科委重大攻关课题“生态建筑关键技术研究与系统集成”的主要内容，该生态样板楼将为生态建筑关键技术集成、测试、实验、改进提供科技平台，并将成为上海生态建筑和技术的展示、教育和培训场所；同时结合上海经济发展水平和市场需求，通过推广示范生态建筑适用技术体系，将整体提高上海生态建筑技术水平，为2010年世博园建设提供生态建筑技术支撑，推动我国生态建筑领域的产业发展和科技进步。

1　概述

生态楼坐落于上海市建筑科学研究院莘庄实验园区，占地面积 904m^2，建筑面积 2000 m^2，地上三层。按照使用功能进行划分，该楼西向为环境实验室，东向为展示区和办公用房，在东向中部

设有中庭，中庭上部设计天窗，保证了建筑内部的白天照明，建筑效果见图 1。为了尽可能的减少不可再生能源的消耗以及减少由此带来的环境负面影响，并给生态楼的使用者提供健康、舒适、高效的工作环境，该楼分别从建筑围护结构、自然通风、高效新型空调、太阳能利用、自动控制等多个方面，采用了多种先进的技术措施，最终目标是使该示范建筑的全年采暖和空调能耗降低到普通办公建筑的 1/4。为了验证采用多种节能后的节能效果，本文还采用了动态能耗模拟分析软件对生态办公楼的全年能耗进行了分析计算。

图 1　上海市生态办公示范楼建筑效果图

2　建筑节能措施

1. 围护结构设计

生态楼围护结构节能设计主要包括墙面、屋顶、门窗的保温隔热设计以及建筑外窗的遮阳设计。作为示范建筑，该生态楼在各向围护结构设计方面又分别采用了多种不同的技术措施，以起到节能技术集成和示范的作用。

对外墙，参考欧洲建筑节能设计标准，针对该楼的不同朝向，分别采用了四种外墙外保温体系，具体构造见表 1。生态办公楼的屋面结构包括平屋面和坡屋面，屋面的节能措施则分为两种平屋面保温体系和一种坡屋面保温体系，此外平屋面均采用屋顶绿化技术，结合保温材料和防水技术，达到了节能和改善顶部房间室内热环境的良好效果，同时有利于减弱建筑物的热岛效应，其构造形如表 2 所示。对外窗，在提高保温隔热性能的同时，重点考虑其遮阳效果，对窗墙面积比比较大的南向外窗（达 0.59）以及开窗面积较大的天窗（达 100m^2 以上）还采用了多种外遮阳措施，实现冬季最大限度利用太阳能、夏季遮挡太阳辐射的作用，同时基本满足了室内的自然采光。天窗和各朝向外窗的热工性能见表 3。

表 1　外墙外保温体系汇总表

序号	应用部位	保温体系主要构成	传热系数 W/(m^2·K)	热惰性指标 D
1	东向外墙	混凝土砌块(90)＋298 凯福发泡(60)＋砂加气砌块(240)	0.32	4.3
2	南向外墙	EPS 外保温(140)＋混凝土砌块(190)	0.27	3.2
3	西向外墙	混凝土砌块(90)＋298 凯福发泡(85)＋混凝土砌块(240)	0.29	4.3
4	北向外墙	XPS 外保温（75）＋混凝土砌块(190)	0.33	3.2

表 2　屋面保温体系汇总表

序号	应用部位	保温体系主要构成	传热系数 W/(m² · K)	热惰性指标 D
1	不上人平屋面	屋面绿化(600)＋泡沫玻璃(150)＋陶粒混凝土找坡层(100)	0.31	3.2
2	上人平屋面	屋面绿化(600)＋XPS(95)＋陶粒混凝土找坡层(100)	0.31	3.2
3	东向坡屋面	发泡聚氨酯(180)	0.16	5.0

表 3　节能窗汇总表

序号	应用部位	窗户类型	玻璃传热系数 W/(m² · K)	玻璃遮阳系数	可见光透过率 (%)
1	坡屋面天窗	PET LOW-E 双中空玻璃窗	1.82 (考虑窗框)	0.62	68
2	各向外窗	LOW-E 中空双玻窗	1.65	0.58	65

2. 自然通风利用

从节能和舒适的角度考虑，应优先采用被动方式，依靠自然手段来维持室内的热舒适环境。根据上海的气候特点，完全可以在春秋过渡季节和夏季夜间，充分利用室外气流，带走室内产出的余热，保证室内的热舒适性，并缩短了空调系统的运行时间，达到节能环保目的。

根据生态办公楼本身和周围环境以及气候特点，利用热压通风和风压通风相结合的方式，通过运用了 CFD 模拟分析技术，确定并优化室内合理的气流组织方式，以期实现有效的、可调节的自然通风。在建筑北部顶端设计深色的玻璃“烟囱”，并在中庭内开启多处通风通道，起到烟囱效应（图 2）；同时尽量使建筑位置沿夏季主导风向进行设计（图 3），在建筑外立面的正压区和负压区的适当部位开窗，起到通风口的作用，增强室内穿堂风的冷却效果。

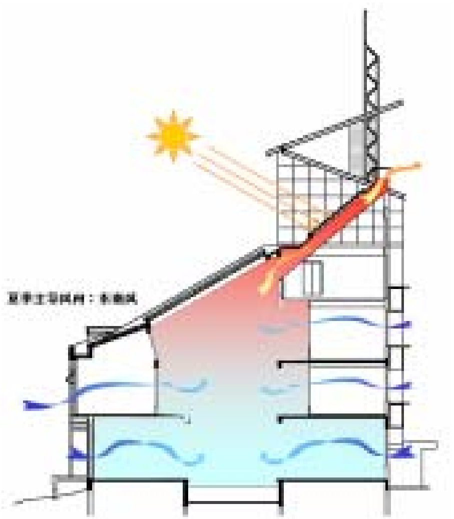

图 2　热压自然通风示意图

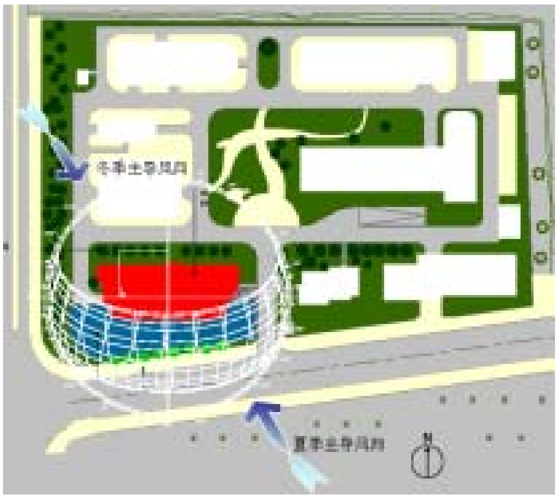

图 3　生态办公楼位置及主导风向示意图

3. 新型空调和太阳能利用技术

在上海地区，冬夏两个空调季的室外相对湿度较大，因此要满足室内环境的舒适性、健康性要

求，空调系统就必须对室外新风进行除湿处理。传统的除湿方法基本上是冷冻除湿，即首先将空气温度降低到露点以下，除去空气中的水分后再通过加热将空气处理到设计工况，由此使冷热抵消，造成了能耗的浪费。同时，为了达到除湿要求的低露点，要求制冷设备产生较低的温度，设备的制冷效率较低，从而也导致了高能耗。此外，空调冷却面、风道又为霉菌的滋生提供了生存条件，易造成室内空气质量的恶化。

为了避免上述情况的发生，生态办公楼对新风采用了热湿独立处理的方式，新风通过带全热回收的新型液体除湿机组的除湿降温处理过程，可以给室内提供干燥的新风，用来消除室内湿负荷，满足人员的新风要求，从而有效的改善了室内空气品质，提高了整个空调系统的能效比。而除湿系统的溶液再生可以通过高温热泵或太阳能热水来实现。

生态楼还在屋顶上沿坡屋面方向架设了 150m^2 的太阳能集热器（见图 1）供应全楼热水。冬季可利用太阳能用于地板采暖；夏季则采用太阳能热水型吸附制冷机组和干盘管相结合的方式用于空气显热负荷的处理；在春秋过渡季，可以利用太阳能对坡屋面顶部的斜通风风道进行加热，增强了热压的 " 拔风 " 作用。

3　节能效果分析

为了验证该生态楼采用各种节能措施后的节能效果，本文采用了两种动态建筑能耗模拟计算软件：DeST 和 TAS，对生态楼全年逐时的采暖和空调能耗进行了模拟分析。计算中暂不考虑空调机组 COP 提高所产生的节能效果。

1. 软件 DeST 模拟

DeST（Designer's Simulation Toolkit）的全称是 " 建筑热环境设计模拟工具包 "，是清华大学建筑技术科学系研制开发的面向各类建筑的能耗模拟、性能预测及评估并集成于 AutoCAD R14 上的辅助设计计算软件。本文的模拟计算首先采用的是 DeST 最新的 2.0 商业建筑版，对生态楼建模如图 4。

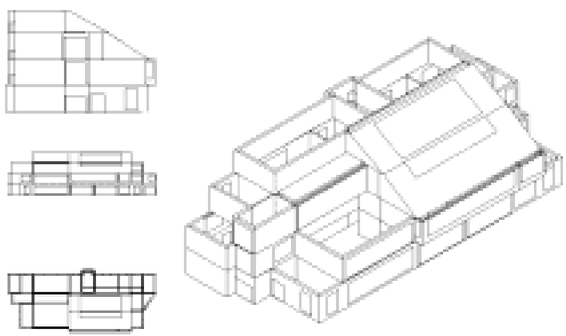

图 4　生态楼模拟图（DeST）

建筑能耗模拟所需要的输入计算参数主要包括建筑内部热扰参数、通风空调作息表、室内环境控制参数等。对该生态楼，这些计算参数的选取上基本上都参照 " 上海地区公共建筑节能设计标准 " 进行设置。在此基础上，本文采用 DeST 软件对采用围护结构（主要包括外墙和屋面）保温隔热措施、节能窗，活动外遮阳和夜间通风等几项节能措施后，生态楼的节能效果进行了模拟分析，并与不采取节能措施的建筑能耗进行对比。对应四种不同的节能措施，可以分为以下多种计算模拟工况：

- 计算工况 1*：不采用节能措施（对比基准）
- 计算工况 2：采用外遮阳

* 不采用节能措施的建筑即普通办公建筑，外墙 K=2.0 W/(m^2·K)，屋面 K=1.5 W/(m^2·K)，外窗 K＝6.4 W/(m^2·K)，外窗无遮阳设施。

♦ 计算工况 3：采用外遮阳，采用节能窗（表 3）

♦ 计算工况 4：采用外遮阳，采用节能窗，提高围护结构保温隔热性能（表 1～2）

♦ 计算工况 5：采用外遮阳，采用节能窗，提高围护结构保温隔热性能，夜间通风

模拟计算结果如下图所示：

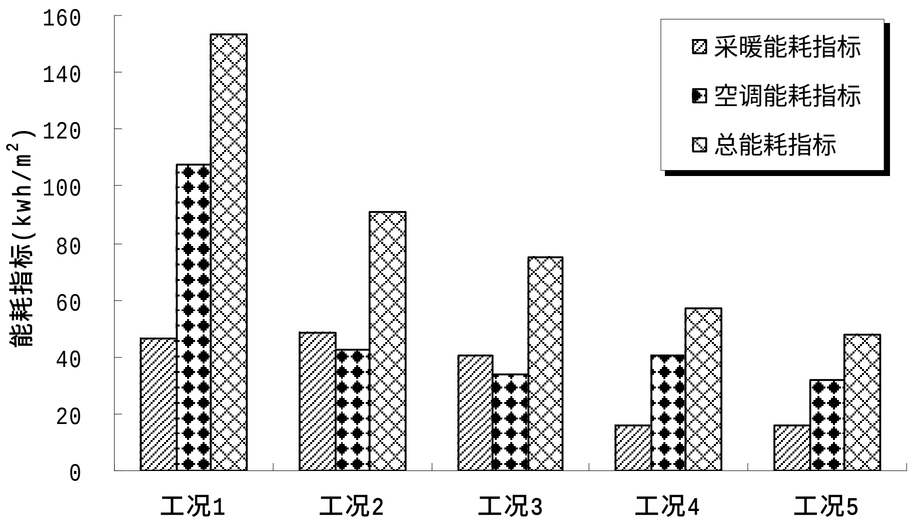

图 5 生态楼能耗模拟结果（DeST）

由此通过与无节能措施的建筑能耗相比较，可以分析各种节能措施的节能效果（表 4）和节能比例（图 6）。

表 4 各种节能措施的节能效果汇总

模拟工况编号	1	2	3	4	5
节能效果（%）	—	40.6	51.3	63.0	68.9

分析模拟计算结果可以看出采用不同的节能技术，产生的节能效果也不相同。由于该生态楼通透性很好，南向窗墙面积比高达 0.59，坡屋面上设置 150m^2 大面积的天窗，造成全年的空调能耗巨大，远大于采暖能耗，而遮阳技术是降低夏季空调能耗最为直接和有效的措施，从模拟出的节能效果也反映了采用活动外遮阳比单纯提高围护结构和窗户的热工性能等技术更为有效（工况 2）。而且通过良好的自动控制，采用活动外遮阳可以在显著降低空调能耗的同时，基本上不增加采暖能耗。在遮阳的基础上，通过提高围护结构保温隔热性能和改善窗户的热工性能，可以进一步降低该建筑能耗（工况 3、4）。此外在夏季和过渡季节，通过合理的自然通风设计，利用夜间通风技术，可以有效的消除室内的余热，从而可以降低白天空调系统的制冷能耗（工况 5）。计算结果还可以反映出，对上海地区的通透性办公建筑，提高围护结构和窗户的热工性能主要有利于降低全年的采暖能耗，对空调能耗的减少作用不明显；而采用活动外遮阳和夜间通风技术，能够显著的降低全年空调能耗，但采暖能耗会略有增加。综上通过合理采用以上几种节能技术措施以后，可使生态楼的总能耗指标降低了 68.9%，通过进一步分析，活动遮阳在其中占 41.2%的节能比例，节能窗占 18.3%，围护结构占 24.5%，夜间通风占 16.1%。此外生态楼还采用了高能效比的空调系统，通过天窗可以

节约一部分照明能耗，同时利用太阳能供热水、采暖和制冷，如果考虑这几项额外的节能因素，该生态楼完全可以达到节能 3/4 的预期目标。

2. 软件 TAS 模拟

TAS（TAS Building Designer）是英国 EDSL 公司（Environmental Design Solutions Ltd）研发的建筑热环境分析软件包，在欧洲被广泛用于建筑能耗模拟、建筑环境优化和热舒适性分析。应用 TAS 软件对生态楼建模，见图 6。

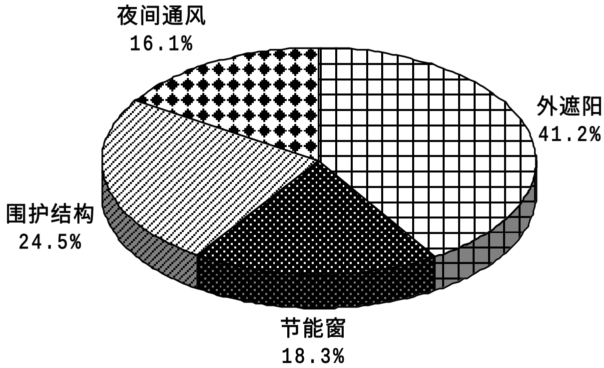

图 6 节能措施所占的节能比例

TAS 模拟所需要的参数与采用 DeST 模拟的相似。与 DeST 模拟相比，TAS 的模拟过程主要针对生态楼采用不同的环境控制策略的全年采暖和空调能耗，所有工况计算中建筑围护结构和外窗按照表 1～表 3 选取。根据环境控制的几种不同方式，TAS 模拟工况分为：

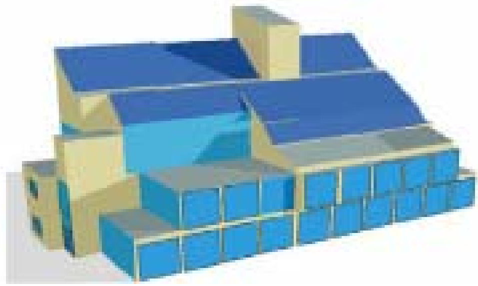

图 7 生态楼模拟图（TAS）

- 计算工况 1：完全空调模式（对比基准）
- 计算工况 2：自然通风模式
- 计算工况 3：提高窗户的遮阳效果
- 计算工况 4：自然通风模式，提高窗户的遮阳效果
- 计算工况 5：自然通风模式，缩小 50%窗户面积

其中以 TAS 的计算工况 1 作为基准工况，此时生态楼已采用节能围护结构（表 1～2）和节能窗（表 3）。工况 2 将生态楼划分为不同区域，采用相应的通风控制策略，以最大程度的利用风压和热压自然通风来降低室内温度，提高室内舒适性，并降低建筑空调能耗。工况 4 和工况 5 是对不同的设计方案进行对比计算。

模拟计算结果见下图：

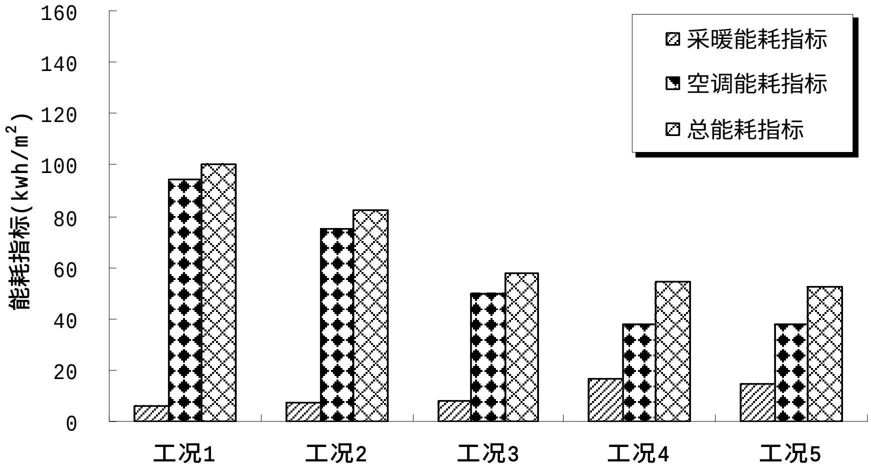

图 8 生态楼能耗模拟结果（TAS）

与基准计算工况 1 的完全空调模式相比，其他工况的节能效果为：

表 5　各种控制策略的节能效果汇总

模拟工况编号	1	2	4	5	6
节能效果（%）	—	9.0	42.6	45.5	47.8

与 DeST 软件相比，TAS 软件的模拟结果同样说明遮阳对降低生态楼空调能耗起到了最为显著的作用，这主要是因为窗户是夏季空调能耗的最为薄弱环节，大量的太阳辐射热量通过窗户进行生态楼内部，是造成空调能耗增加的主导因素，而采用遮阳技术（包括外遮阳和 Sc 较小的节能窗）可以发射大部分的太阳辐射能，减少了太阳辐射得热量。另外工况 4 和工况 5 的计算结果差距很小，说明减小建筑的窗墙比可以达到相同的节能效果，但鉴于大面积外窗更有利于减小照明负荷，并有利于自然通风，还可以增加人的视觉舒适性，所以应优先选择采用遮阳技术的大窗墙比设计方案。此外，TAS 模拟的冬季采暖能耗比 DeST 的普遍偏小，分析原因是由于两种软件采用的上海地区气象参数有所差异，室内环境控制参数也稍有不同，具体结论还有赖于通过实验手段来进行验证。

4　结论

综上本文通过对上海生态办公楼进行节能措施介绍和能耗模拟分析，得出以下结论：

1、超低能耗是上海市生态办公示范楼的一大亮点，它采用多种先进的节能产品，集成了低能耗围护结构、高效节能窗、活动外遮阳和自然通风等多种节能技术，充分利用了太阳能资源，并采用热湿独立处理的新型空调系统，为推广和应用新型的节能技术和措施提供了科技平台。

2、通过模拟软件 DeST 和 TAS 对生态楼的全年采暖和空调能耗进行计算和节能分析，结果说明通过各种节能措施的集成应用，该生态楼的节能效果十分显著，接下来的研究工作将通过现场的实验测试对模拟结果进行验证。

3、模拟分析结果说明，对上海地区大窗墙比的办公类型建筑，活动外遮阳比采用高性能的围护结构和外窗可以更有效的降低空调能耗，因此，从节能角度应优先采用活动外遮阳。

最后感谢英国 WSP 公司为本文提供的 TAS 软件模拟计算结果，以及 DeST 软件的提供者清华大学建筑技术科学系。

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夏热冬冷地区旅馆建筑节能途径的探讨

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摘　要　公共建筑的能耗是相当大的。因舒适性要求高和运行时间长旅馆建筑的能耗尤为可观。本文对旅馆建筑空调的节能问题进行了探讨。对采用不同空调方案的同类旅馆建筑，进行实地调查。可以发现它们的能耗费用相差十分悬殊。为了深入进行分析，对同一旅馆建筑进行能耗分析：采用三种不同的空调方案，计算其全年能耗费用。并加以分析，可以比较出最佳方案。在调查研究和计算分析的基础上，作者提出了旅馆建筑的节能途径，并指出了水源热泵空调方案在旅馆建筑中的节能优势。

前言

从 90 年代以来，我国国民经济迅速增长。上海市的 GDP 平均每年增长 11.9%，与此同时，各类建筑像雨后春笋一样拔地而起，建筑投资增长了 9 倍。

十多年来上海市新建各类高层建筑总数接近五千幢。这些高层建筑体量大、标准高、设备全、每年消耗的能源十分可观。

我国政府对节能问题十分重视，已颁布了一系列标准。2003 年上海市建委发布了《公共建筑节能设计标准》，并从 2004 年 2 月开始执行。公共建筑的节能问题，已经引起各方面的重视。

作为公共建筑一个重要方面的旅馆建筑，因为日夜运营而能耗最为突出。上海地区共有旅馆数百家，研究旅馆节能具有很大的现实意义。降低旅馆能耗，不仅可以减少城市的电力负荷，减少因发电而排放的污染物，而且可以降低旅馆运营成本，增加效益。

1　旅馆能耗调查

作者先后对上海市中、小型旅馆的能耗进行了调查。此处选其中较有代表性的、规模相当、建筑构造类似的三家进行分析：同济大学外国专家大楼、杨子饭店、宁夏宾馆。

1.1　同济大学外国专家大楼

同济大学外国专家大楼 是一家二星级宾馆，八层框架结构，外墙用三孔砌块，外窗为单玻铝合金窗，窗墙面积比 0.35，建筑面积 4200m^2。夏季用活塞式冷水机组供冷，冬季用燃油蒸汽锅炉采暖。锅炉也承担了全年的热水供应。其单位面积能耗费用如图 1 所示。

1.2　杨子饭店

杨子饭店是一家三星级宾馆，框架结构，建筑面积为 10000m^2，外墙采用一砖墙，外窗为单玻铝合金。窗墙面积比为 0.30。一层为大堂、二层为餐饮、三～八层为客房。宾馆采用两台直燃式溴化锂冷（热）水机组，夏季供冷、冬季供热，同时提供生活用热水。其单位面积能耗费用如图 2 所示。

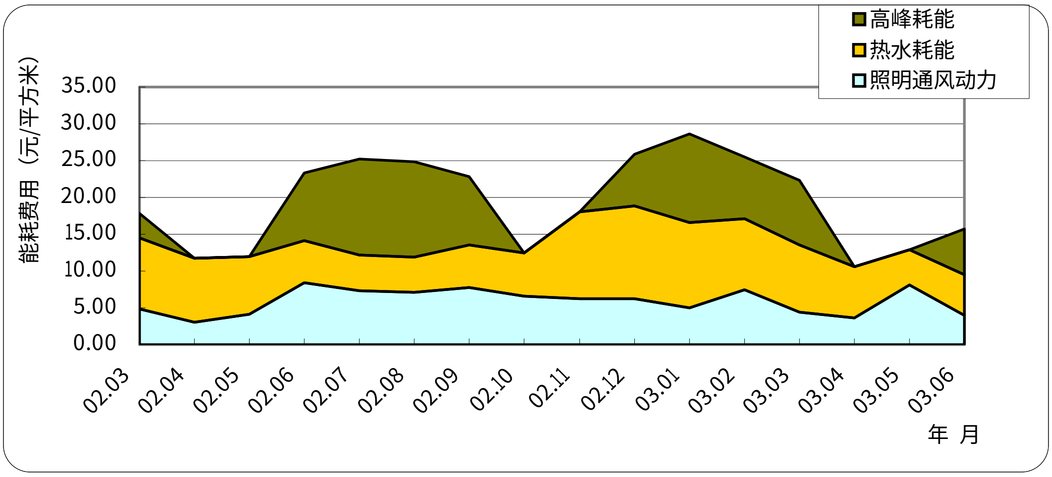

图 1　2002 年同济大学外国专家楼能耗费用分布曲线

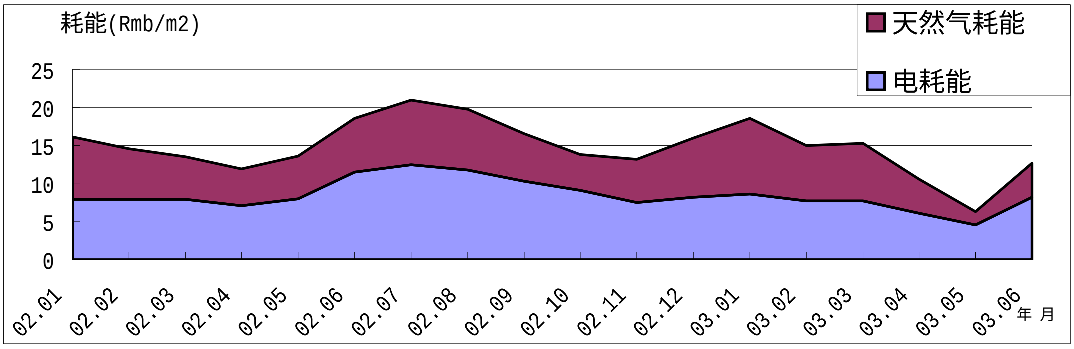

图 2　2002 年杨子饭店全年能耗费用分布曲线

1.3　宁夏宾馆

宁夏宾馆是一家二星级宾馆，四层框架结构，外墙采用空心砌块，外窗为单玻铝合金窗。窗墙面积比 0.25，其中三层和四层为客房，建筑面积为 5000m^2，空调采用水环热泵供冷和供热。另设二台燃气热水锅炉，其中一台用于全年热水供应，冬季运行二台，同时作为空调的辅助热源。其单位面积能耗费用如图 3 所示。

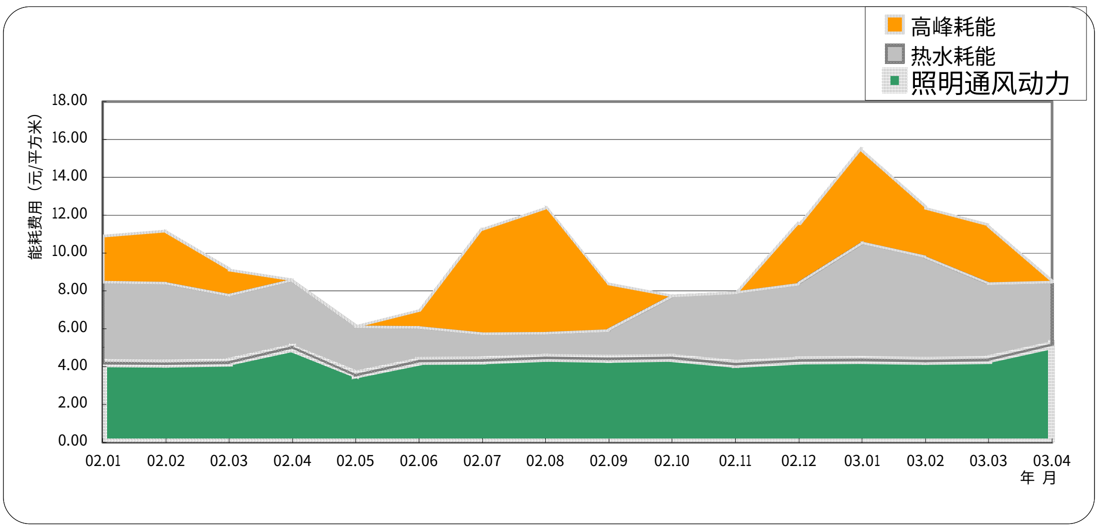

图 3　2002 年宁夏宾馆全年能耗费用分布曲线

三个旅馆总能耗费用的比较见图 4。

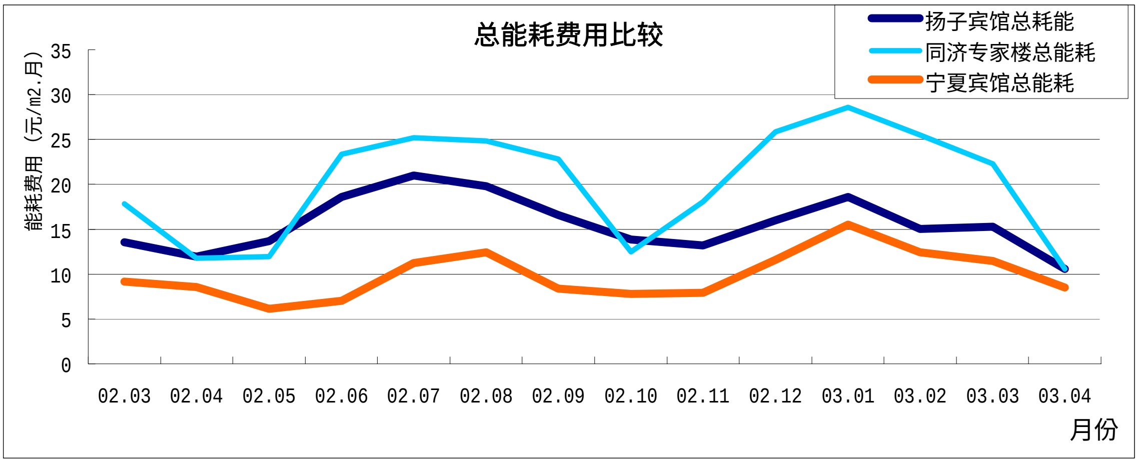

图 4　三旅馆全年总能耗曲线

根据以上调查结果，作如下分析：

1）旅馆建筑能耗费用的分布曲线，在一年中出现两个高峰，这就是空调引起的夏季高峰和冬季高峰。三个宾馆的夏季空调能耗有较大差别，分散式水源热泵由于 COP 较高且每个房间独立控制，客人不在室内时自动关闭，大大节约了能源，仅为集中冷水机组的 1/3 左右，为能耗费用最低的系统。

2）冬季采暖和热水负荷叠加出现高峯耗能，燃料价格和蒸汽锅炉的热效率问题是主要原因。

3）吸收式三用机在中、小型旅馆中的应用使能耗曲线趋于缓和，总能耗居第二位。

2　旅馆能耗的构成

旅馆的能耗主要有以下几个方面：空调能耗、热水供应、照明用电、动力用电。

根据调查分析的结果，旅馆能耗费用及其构成都是变化的。它们与建筑构造、设备情况、燃料选用、经营管理、气象条件（季节）等诸多因素有关。图 5 所示为同济大学外国专家楼 2002 年夏季最热月和冬季最冷月各项能耗费用所占的比例。

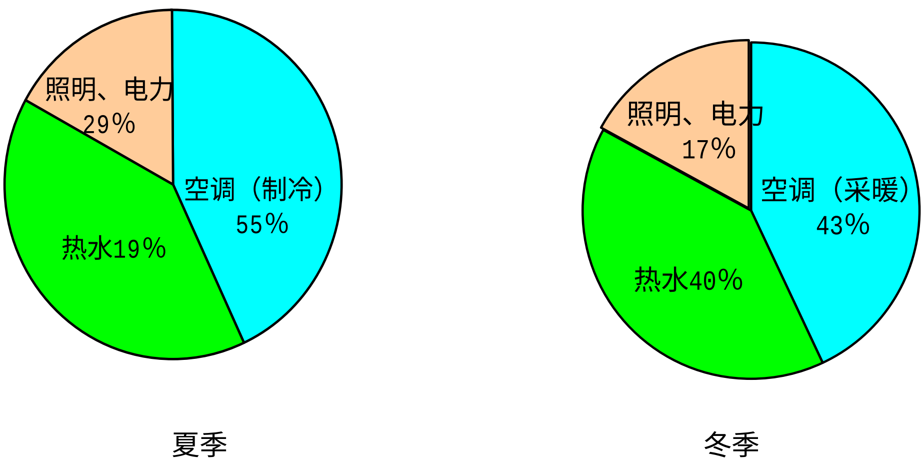

图 5　旅馆能耗的结构

该大楼夏季采用冷水机组中央空调，热水供应与冬季采暖采用燃油锅炉，这种供能方式在上海地区的中、小型旅馆中具有一定代表性。从图中可以看到，旅馆的能耗以空调能耗为最大，约为40～50%。热水能耗也占有相当的比重，尤其是冬季，热水供应的费用可达总能源费的 40%，这和燃料价格、锅炉效率有密切的关系。由于节能灯具的推广使用，照明用能在旅馆中并不很高，图中电力还包含了动力用电。

3 空调方案的技术经济比较

为了深入分析旅馆空调系统的节能问题，作者对同一家旅馆建筑用软件加以计算，进行了不同空调方案的技术经济比较。设计对象为浙江耀江大酒店，建于诸暨市，总建筑面积为 62325m^2，地下一层，地上 26 层。要求舒适性空调并利用城市电厂的区域供热。

用软件对耀江大酒店进行空调负荷计算之后，对该项目提出了三种空调方案：

1、集中式电动离心冷水机组方案

2、分散式水源热泵方案

3、区域供热蒸汽吸收式空调机组方案

三种方案空调系统费用比较见表 1。

表 1 三种方案空调系统费用比较表

	集中电动冷水机组	分散式水源热泵	区域供热蒸汽 吸收式空调机组
初投资（万元）	1340	1300	1360
运行费（万元/年）	300	227	316

从初投资看，三种方案相差不大，而年运行费则以分散式水源热泵的费用最小。

4 结论

通过调查研究和计算分析，对旅馆建筑的节能提出以下几点看法：

（1）在夏热冬冷地区，旅馆建筑的全年能耗分布出现夏季、冬季两个高峰，空调系统是主要能耗项目，而分散式水源热泵空调方案因其 COP 值较高，单间主机独立控制，对旅馆节能明显有利。

（2）集中式使用冷水机组必须重视制冷机组的 COP。冬季热源和燃料的选择至关重要。对小型旅馆来说，采用燃油蒸汽锅炉能耗费用明显增加，利用区域供热或高效燃气锅炉，可以降低能耗费用。

（3）在电力紧缺地区，采用高效的吸收式空调可以利用余热削减峯时电负荷，缩小旅馆供电配置功率，并做到冷、暖、水三联供，但燃气价格是关键。

（4）在大型旅馆的新建项目中，由于情况较复杂，建议在前期进行空调冷热源方案的技术经济比较，以便合理地进行空调的节能设计。

荷兰 Ecolonia 节能住房项目节能效果评估

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摘　要　Ecolonia 是在荷兰住房、空间规划与环境部和荷兰经贸部的支持下，由荷兰能源环境署和荷兰市政住房基金会联合开发的环保住房小区。本研究采用问卷调查、现场观察、访问居民、对比研究等方法，对 Ecolonia 能源节约项目进行了效果评估。结果表明：Ecolonia 能源节约项目在天然气节约上实现了预期目标，Ecolonia 的天然气消耗量仅相当于全荷兰平均水平的 47%，只是电能节约目标并未如期实现，且电能消耗仍呈逐渐增长趋势，与全荷兰平均水平相当。居民对该项目总体上比较满意，但对部分设计和设备指出了缺陷。Ecolonia 项目具有的优越性和存在的不足，对于将来设计更好的环保住房提供了十分有意义的参考价值。

关键词　Ecolonia 示范项目；可持续发展建筑；节能住房；能源节约措施；可再生能源；评估；能源消耗；居民满意度

Abstract　Ecolonia is an environmentally aware housing state developed jointly by Netherlands agency for energy and the environment (Novem) and Building Fund Dutch Municipalities, with the support of the Ministry of Housing, Spatial Planning and Environment and the Ministry of Economic affairs. This research carried out energy conservation evaluation for the 3 energy conservation projects (39 dwellings) in Ecolonia through questionnaire, on-site visits/observation, open interview, comparative analysis, and other research methods.

The findings show that the 3 Ecolonia energy conservation projects are successful for gas saving over the 11 years, and the gas consumption in the Ecolonia energy conservation projects is only around 47% of the average energy consumption in the Netherlands houses. But the initial electricity requirement for Ecolonia seems too optimistic, and the practical electricity consumption is similar to the average level in the Netherlands.

Residents are generally more satisfied with the energy saving measures comparing to the past research. At the same time, they pointed out some shortcomings of the measures.

The experiences, lessons and advantages learned from Ecolonia will be a useful reference when considering a better environmentally aware house in the future.

Key words　Ecolonia demonstration project, sustainable building, energy saving house, energy saving measures, renewable energy, evaluation, energy consumption, residents' satisfaction

1　研究背景

十多年前，当具有环保意识的住房还是理想主义者为了改进世界所创造的一种近乎异想天开的，令人联想到粘土墙、草屋顶及堆肥式厕所的概念时，Ecolonia，这个在荷兰 Alphen aan den Rijn 城市的住房小区示范项目首先尝试并打破了这种离奇的想法。该示范项目建立在可持续发展建筑理论尚未被荷兰房屋建造部门所广泛接受的时代，它并非特意为那些环保意识较高的居民所建，而是为满足普通居民对住房的普遍要求建造的更具有环保意识的住房小区。

Ecolonia 是在荷兰住房、空间规划与环境部[Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer －VROM] (Ministry of Housing, Spatial Planning and Environment)和荷兰经贸部[Ministerie van Economische Zaken－EZ] (the Ministry of Economic Affairs)的支持下，由荷兰能源环境署[Nederlandse maatschappij voor energie en milieu bv－Novem] (Netherlands Agency for Energy and the Environment)和荷兰市政住房基金会[Bouwfonds Woningbouw] (Building Fund of the Dutch Municipalities)联合开发的。其目的在于建造节能的和具有环保意识的住房示范小区，验证一些可持续发展住房设计方案在实践中必须受市场约束，同时提供可以广泛应用到住房产业的环保措施的信息。这些住房不是参考已有的特定目标住房而设计，并且适合于更广泛的住房建设。

Ecolonia 示范项目由比利时著名城市规划建筑师 Lucien Kroll 进行初步规划，他采用不同寻常的设计手法，考虑居住与环境因素的协调，尽可能多的将各种“ 自然 ”因素容纳到设计中。Ecolonia 示范项目是向居民采用一种节能的，具有环保意识的生活方式发出的挑战。

Ecolonia 示范项目的建成在各部门引起很大反响，反馈意见有来自 Ecolonia 居民的，也有来自公众、建筑师、当地政府、研究人员和其他对“环境”主题感兴趣的人们。人们关心的是这个项目的优缺点是什么？它是否达到预期的环保目标？我们从这个项目能得到哪些启发，又如何借鉴于将来其他的节能建筑和环境保护？

对 Ecolonia 项目的评估，已有的研究仅局限于建成且居民迁入后的前三年，之后未进行持续的跟踪研究，本研究在该项目建成 11 年后，对其进行一次较长期的评估。资料显示，建筑能耗通常占据全世界总能耗的 40%，CO_2 排放量占全世界总排放量的 35%，全世界 50%仍在使用的含氯氟烃(chlorofluorocarbons－ CFCs)也是来自建筑物[1]。据统计，荷兰 2002 年建筑占有 24%的全国电能使用量和 16%的全国天然气使用量[2]。因此，本研究重点放在 Ecolonia 项目中三个 “住房能源节约”子项目，共 39 幢独户住房，通过比较住房实际能耗和设计能耗目标，结合 10 年前的能耗数据以及荷兰平均住房能耗，评估 Ecolonia 节能住房项目的节能效果，并为今后设计新的节能住房区提出建议。在这次评估中，同时通过发放问卷调查和深入居民家庭实地采访，评估居民对于能耗以及能源节约措施（设备）的满意程度。

2　Ecolinia 住房小区示范项目概况

2. 1　Ecolinia 住房小区示范的九个子项目

Ecolonia 地处荷兰城市 Alphen aan den Rijn 边缘，位于阿姆斯特丹、海牙、鹿特丹和乌得勒支城市之间的被称之为荷兰“绿色心脏”的地带。Ecolonia 住房小区占地 27 英亩，建筑面积为 8129 m^3，建成于 1992 年。该住房小区围绕可供娱乐和蓄水的中心湖泊展开布局，共有 101 幢独立住家，含一层、两层、三层或带有错半层的多种设计风格。该项目很好的体现了一个住房小区所应考虑的社会、城市、建筑、公众生活心理和生态学等诸多方面，给荷兰可持续发展建筑市场带来了重要影响。

据 Novem 提供的报告，荷兰国家环境政策计划(National Environmental Policy Plan－NEP)对建设部门提出的三项要求为 Ecolonia 项目对节能和环保的设计起了很重要的指导作用。Ecolonia 项目的环保指导理念和措施正是依据了 NEP 设定的以下三个主题：

1. 能源节约(Energy conservation)：即用减少能源需求、用可再生能源和节能的采暖通风设备等措施减少对从有限的资源获取的能源的消耗。目标是建筑能耗在当地原有能耗的基础上节约 25%。

2. 综合链管理(Integrated chain management)：指的是环境管理贯穿于从原材料使用到废弃物回

1 National Science and Technology Council Preliminary Report 1993, and PTI Sustainable Building Technical Manual, 1996
2 Website of Energy Statistics about Netherlands http://www.energie.nl/index2.html?stat/trends020.html

收再利用的整个过程。关注从产品生产，到产品使用、废弃物，以及在整个过程中排放到空气、水和土壤中的物质对能耗和环境污染造成的影响。

3. 质量的提高(Quality improvement)：一个建筑产品如果能够经的起长期需求，便于维修，适合回收再利用，不产生危害环境的污染物，那么这个产品就具有很好的质量。房主在居住期间将不会受到有害物排放的影响。质量的提高必须考虑居民健康和室内环境需求的因素。

Ecolonia 项目包含三个项目组，分别以 NEP 的一个主题为设计要求，每一主题又分为三个子领域。来自荷兰 9 家设计单位的建筑师们各就一个子领域设计 8 户到 18 户的住房（见表 1）。而所有 101 户住房都必须满足一个基本的能耗指标，即平均每户天然气消耗不超过 1450m3，电消耗不超过 2000 kWh。对于 39 户节能住房，其能耗目标订的更为严格。Eolonia 由 EZ 与 VROM 联合投资，来自政府的补贴达 6 百万荷兰盾（约 270 万欧元），因而每户住房只需再投资约 2.3 万荷兰盾（约 1 万欧元）来完成建设。最终每户住房造价约在 18 万 ～ 30 万荷兰盾（约 8 万欧元～14 万欧元）。[3]

表 1　Ecolonia 小区 9 个子示范项目

项目组	子项目	户数	设计重点
节能住房(Energy conservation)	1	18	减少热量损失
	2	10	利用太阳能
	3	11	在建造和使用过程中减少能耗（提高能量使用效率）
整体链管理 (Integral chain management)	4	10	减少水的使用；水和建材的回收与循环利用
	5	12	建材的维护和持久性
	6	10	灵活布局，使用的方便性
质量的提高 (Quality improvement)	7	10	住房之间和住房内部的隔声处理
	8	12	健康与安全
	9	8	生态住房

2.2　Ecolonia 三个节能住房项目的基本节能措施

Ecolonia 节能住房项目组中有三个独立的子项目，分别出自不同建筑师的精心设计，并在为达到建筑节能的设计目标中表现出了各自的设计倾向。

子项目 1 主要节能措施是通过减少能源损耗，尤其是减少热量损失来实现，因而屋顶、地面、窗体和墙体的高效保温隔热措施成为主要节能手段。18 幢住房都采用封闭的厨房、玄关、走廊、阁楼、楼梯间等，目的在于减少房间气流。总体设计布局紧凑，并减小北面朝向的窗口面积。各住房之间也采取了热绝缘措施。子项目 1 的南北朝向的住房在其南面起居室外都设有“温室”（Conservatory/Greenhouse）以帮助居民控制室内气候。所有住房采用一种集空气加热、通风为一体的综合设备(Balanced Heat-Recovery Ventilation(BHRV) combined with air heating)实现房屋采暖通风。该设备同时综合了热水的功能。

子项目 2 的设计特点是利用可再生能源，主要强调对太阳能的利用。10 幢住房全部为南北朝向，“阳光起居室”（Sun-lounge）设在南面，室外都设有“温室”；增大的南面窗户面积可以更充分

[3] Website of Alphen aan den Rijn: The Dutch test case for sustainable town planning

的获取阳光。所有家庭都安有太阳能热水器，部分家庭装有 PV(Photovoltaic)光电板。目的在于综合主动式太阳能和被动式太阳能(Active and passive solar energy)的利用。项目采用暖气散热设备(Radiator heating）实现房屋采暖，平衡式热恢复通风设备(Balanced Heat-Recovery Ventilation－BHRV)实现通风要求。房屋也采用了保温隔热措施以辅助建筑节能。

子项目 3 的特点是在建造和使用过程中减少能量使用。该项目共 11 家住户，都采用错层设计以更好的获取阳光。采暖方式采用暖气散热和地板加热设备 (Radiator heating along with floor heating)，通风也是采用平衡式热恢复通风设备 (BHRV)。另外，每家设有一冷藏橱(Cool cupboard)用于储备物品。房屋同样的使用了高效太阳能热水器，辅助以很好的房屋保温隔热措施以便减少能量使用和提高能量使用的效率。

作为三个子项目的共同点，三个子项目中所有南北朝向的住房都安装有太阳能热水器，燃烧天然气供应热水的设备仍安装于每一家，以作为没有安装太阳能热水器家庭的热水供应方式，或作为太阳能提供热水的补充方式。通常住房采暖和热水分别占天然气使用的 45%和 35%，因而采暖和热水设备成为主要的天然气消耗设备。

3 Ecolonia 节能住房项目评估

本文参照可持续发展建筑项目评估方法，采用定性与定量相结合的方法对 Ecolonia 节能住房项目的节能效果和居民满意度进行评估。

3.1 能源消耗评估

按项目设计要求，Ecolonia 节能住房的年天然气消耗目标是每户住房不超过 1150 m^3。根据调查数据（见表 2）分析，1993～2003 年平均年天然气消耗，三个子项目都达到最初设计目标。但在 2001 年后，子项目 1 略微超出设计目标，其他两个仍达标。另一方面，每年每住房 2000kWh 的用电目标似乎显得有些过于理想化，三个子项目都难以达到，且 11 年间三个子项目电能消耗有逐渐增长趋势。

1993～2003 年间，Ecolonia 节能住房平均年天然气使用量为每住房 996 m^3，远低于整个荷兰的平均使用量。

据“荷兰能源”（http://www.energie.nl/）统计，2000 年荷兰住房共约 686 万户，全国平均每户天然气使用量从 1991 的 2150 m^3 逐渐下降到 1999 年的 1940 m^3。在用电方面，1993～2203 年 Ecolonia 平均每户电消耗为每年 3385kWh，与荷兰全国平均水平 3000～3400kWh 相当。小区整体能源消耗略呈增长趋势。

能源消耗及其变化受很多因素影响，除节能措施为主要的影响因素外，冬季不同的温度、新迁入居民、家庭成员人数变化、购买新的家电设备、使用或改装原有的节能设备、在家工作的人数变化等都是可能的相关因素。为合理解释 Ecolonia 节能住房项目近年来的能源消耗情况，还需综合考虑其他相关因素的变化。

1996 年荷兰冬天温度为近十年来最低，荷兰平均为房屋取暖的能耗明显升高，但 Ecolonia 的三个节能住房子项目的能耗并未相应升高，很可能是其保温隔热措施所起的作用。

随着经济发展和生活水平的提高，增添新的家电设备在荷兰十分普遍。1990～2001 荷兰经济

以平均每年 2.7～2.8%的速度增长，能耗 11 年来增长了 14%，其中住房部门能耗增长了 4%。大多数 Ecolonia 节能住房的居民也增添了新的洗碗机、洗衣机、烘干机、烤箱、电冰箱等家电，这是导致能耗上升的重要原因。

1993～2003 年，Eolonia 节能住房项目的每户平均人数也在不断变化，10 年前最初迁入的居民多为年轻夫妇，而现在许多家庭添了子女，也有少数的成员离开家庭。三个子项目每户平均人数由 1992 年的每户 2.32 人变为 2003 年的 3.51 人，也提高了能源的消耗。

在 Ecolonia 的三个节能住房项目中，约 14.3%的家庭有成员在家办公，同样促使了住房能源消耗的升高。此外，部分居民对房屋设计的改造和对建筑材料的改变均影响了保温隔热的效果，也会导致了住房能耗的变化。

表 2　1993～2003 年 Ecolonia 节能住房项目能源消耗统计

平均每户天然气消耗（m^3/年）													
节能项目	原始目标	实际消耗											
		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	1993-2003 年平均消耗量
子项目 1	1150	808	1129	1024	1151	1060	985	1044	1045	1182	1229	1371	1102
子项目 2	1150	758	868	952	890	848	843	727	797	797	924	1130	877
子项目 3	1150	1021	1008	995	981	968	955	1103	920	1039	987	1055	1010
平均每户电消耗（kWh/年）													
节能项目	原始目标	实际消耗											
		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	1993-2003 年平均消耗量
子项目 1	2000	3094	3207	3241	3144	3000	3186	3407	3158	3419	3526	4353	3098
子项目 2	2000	2765	3511	3445	3346	3570	3598	3454	3891	4414	4513	4044	3778
子项目 3	2000	3217	3111	3004	2898	2791	2685	3007	2985	3713	3751	3540	3280

3.2　居民满意度评估

本研究根据 Ecolonia 节能住房项目的特点和不同的节能措施，设计了有针对性的调查问卷，调查并评估了居民的满意程度，结果见表 3。其中平均满意程度采用加权平均法求得，不满意、满意和很满意的分值分别计为 1、3 和 5。

表 3　居民对节能方式的满意程度

节能方式	不满意	满意	很满意	平均满意程度
减少能源损失	2.1%	69.2%	28.7%	3.53
使用可再生能源	17.4%	39.8%	42.3%	3.48
提高能源使用效率	10.9%	41.2%	47.9%	3.74

结果表明，三种节能住房的居民对节能方式总体上是满意的，平均满意程度均大于 3，其中采用提高能源使用效率节能方式的住房住户满意度最高。目前，Ecolonia 小区已进入稳定阶段，与 1994 年的调查结果相比，居民在 2003 年对能源节约措施比当时要满意的多。

经现场访问，居民对具体的节能措施或设备也表达了他们的看法。在使用初期，采暖和通风设备普遍存在一些问题，经过两年多的运行，这些设备均能发挥较好的效能，但目前仍存在一些难以

克服的小的缺陷，如平衡式热恢复通风设备 BHRV (Balanced Heat-Recovery Ventilation)的噪音较大，大多数居民更加喜欢自然通风，有的家庭甚至不使用平衡式热恢复通风设备，除非是在周末当朋友较多时才会偶尔使用。据子项目 2 的居民反映，这种 11 年前安装的平衡式热恢复通风设备会消耗更多的电能，通常是整个住房电耗的三分之一。子项目 1 中也有的居民不太满意综合采暖通风的多功能装置，认为其过于复杂，不便操作和维修，虽然节省了天然气，但电耗又过多，同时令房间空气变得干燥。

能源节约措施如高效太阳能热水器、错层设计、阳光起居室、理想的保温隔热、暖气散热设备和被动太阳能利用总是最受人们欢迎，而且他们在节能上也很有效果。子项目 3 的冷却储藏橱并不被住户所乐意接受，因为它并无真正的冷藏效果。对于 “ 温室 ”，多数居民喜欢这种设计手法，在冬季的保温效果较好，但在夏季温度太高。至于封闭的厨房、玄关等，不少居民认为这种设计给空间的利用带来了麻烦。在子项目 1 中，有 7%的家庭将封闭厨房改成了敞开式，21%的家庭为获得更大的起居室空间，将车库与起居室之间的连接墙拆除，使车库并入了起居室。在子项目 2 中，40%的家庭将封闭厨房改成了敞开式，20%的家庭改了车库。其中一家还在原车库上新建起了一间卧室，另有一家将 “ 温室 ” 也改建成了起居室的一部分。

4 结论

通过以上调查及对结果的分析，可得如下结论：

- Ecolonia 的三个节能住房子项目在节约天然气方面基本达到预期效果，取得了成功，但省电目标显得过于理想，均未能实现。三个子项目多年平均每户天然气消耗量仅相当于全国平均水平的 47%，用电量则超过全国平均水平的 6%。
- 在过去的 11 年间，节能住房的总能耗总体上略呈上升趋势。
- 居民对节能住房及其节能措施总体上是满意的，且与 1994 年相比，2003 年居民的满意度有了明显上升。
- 三个子项目均将房屋的保温隔热作为基本节能措施，实践中也取得了较好的节能效果，一直被居民所欢迎，尤其是双层窗体的高效保温隔热措施。太阳能热水器最受居民欢迎，它不仅节约了天然气，而且简单方便，易于操作与维修，价格也易于接受。
- 子项目 2 的太阳能利用是一种很有效的房屋节能方式，子项目 3 的错层设计也在使用被动式太阳能方面取得了较好的效果，居民也普遍喜欢这种建筑设计方式。子项目 2 和 3 的暖气散热方式既有好的节能效果，也很受居民欢迎。
- 三个子项目均安装的平衡式通风系统，实践表明这种通风系统不利于节约用电，且不十分受居民欢迎。冷却储藏橱、封闭的厨房、玄关等在实践中均存在问题，有待进一步改进。

5 建议

基于本次 Ecolonia 节能住房项目节能效果和居民满意度的调查评估所取得的经验教训，在将来节能建筑的设计和开发过程中，应考虑以下几点：

- 居民的舒适度要始终在设计过程中给予充分的考虑。
- 考虑地区的差异性和多种不确定因素。

- 给居民充足的信息和使用节能设备的指导。
- 促进节能设备的技术的改进，尤其是节电措施。
- 深受居民欢迎的节能措施如双层窗体和太阳能热水器应考虑重点推广使用。在太阳能较丰富的地区要积极推广太阳能利用。
- 在节能建筑建成后，建立能源监督信息中心以便定期记录能耗的情况、跟踪评估和改进。
- 比较并不断探索更好的住房采暖通风方式，如墙体加热采暖设备(Wall heating)，无热恢复的机械抽风设备(Mechanical extraction ventilation without heat recovery)和自然通风(Natural ventilation)等。
- 提高居民的环保意识，培养居民的良好的环保的生活习惯。

建筑业、交通运输和工业一直是三大耗能用户，在发达国家，建筑能耗已占总能耗的 40%。在中国，随着改革开放的进一步深入，人民生活不断提高，商品住宅开发已成为国民经济的主要支柱产业之一。据 1996 年统计： 已建成的建筑有 310 亿 m^2，在 1995～2000 年间新建住宅 55 亿 m^2，到 2010 年新建住宅将增至 150 亿 m^2。据预测，今后几年中国建筑能耗将持续增加，2010 年将接近发达国家的水平。如何做到建筑节能已越来越为人们所关注。荷兰 Ecolonia 示范项目体现了向可持续发展建筑迈进的重要一步，其节能住房项目所取得的实践经验对中国的节能建筑设计和开发也具有重要的借鉴意义。

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Properties Required for Subtropical Glazing Films to Achieve Energy Conservation

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Abstract Air conditioning is indispensable and required for almost half of a year for subtropical region. The major cause for raised indoor air temperatures is due to solar radiation through windows. The cooling load contributed from window through solar radiation accounts for about 14 55% of the entire cooling loads, which takes up 5 14% of the total building electricity consumption. To improve energy conservation of windows, it is required to balance the needs for day-lighting and thermal insulation. This study intends to explore the required thermal and optical properties of adhesive films for subtropical windows. Through the establishment of assessment methods, this study investigated the performance of 55 commercial film products and concluded that 30% visible reflectance and 80% near infrared reflectance are required to maintain 0.4 shade factor when 60% visible transmittance is achieved.
Key words building energy conservation, films for glazing, visible transmittance
摘　要　在亚热带地区，空调必不可少，在全年中需要运行近一半的时间。在这些地区，室内温度升高的主要原因是透过窗户的太阳辐射。太阳直接辐射造成的冷负荷约占全部冷负荷的 14～55%，折合建筑电力总消耗的 5～14%。为改善窗户的节能效果，需要在自然照明和保温之间寻求平衡。本研究针对亚热带窗户玻璃帖膜的传热和光学属性展开。在评价方法建立的基础上，本课题调查了 55 种商业玻璃膜的性质。结果表明，在 60%的可见光穿透情况下，为达到遮阳系数 0.4 的标准，玻璃膜应该具有 30%的可见光反射率和 80%的近红外反射率。
关键词　建筑节能；玻璃膜；可见光透射率

INTRODUCTION

In lack of natural resources, Taiwan has to import 97% of the required energy. Based on the Energy Conference of Taiwan in 1988, it concluded that to promote energy conservation and to increase energy efficiency are major goals to fulfill and the target for energy saving is to reach 4,187x10^4 KLOE till 2020. To reach the target, sectors of industry, transportation, residence/office, and power are assigned to take 31.6%, 16.4%, 19.9%, and 14.9% of the total saving, respectively. For the sector of residence/office, there are four approaches to reach the quota. They are (1) to raise the efficiencies of appliances/equipments; (2) to establish indices of energy consumption for building enclosure; (3) to set-up monitoring methods for building energy assessment; (4) to enforce total building energy consumption allowance. Among the four approaches, the third one is a supporting task, for which no saving quota is assigned. The rest approaches are assigned respectively to 40.3%, 16.1%, and 43.6% of the saving allocated to the residence/office sector.

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According to Taiwan Power Company, the electricity consumption of the residence/office sector has been increasing steadily since ’70’s and reached 31% of the entire electricity consumption in 2000, in which the residential part accounts for 20.1%, office and commercial buildings 10.9% (Lee, 2001). For residential building, three major items constitute the consumption pattern and they are air conditioning- 30%, lighting- 20%, and appliance- 50%. For commercial building, they are air conditioning- 30%, lighting- 47%, and power- 23%.

Based on the cooling load analyses of Taipei (Chao, 2004), it has been found that the cooling load contributed from window through solar radiation accounts for around 14 55% of the entire cooling loads, which takes up 5 14% of the total building electricity consumption. In addition, window provides day-light which can compensate the electricity used for artificial lighting. Therefore, to improve energy conservation of windows, it is required to balance the needs for day-lighting and thermal insulation.

This study intended to explore the properties of adhesive films required for subtropical windows to improve energy consumption. Adhesive films for glazings have long been developed for privacy and thermal insulation purposes. The common weakness is that the visible transmission is quite low and the total penetrating energy is too high when the films are applied to office windows. Through establishing assessment and measurement methods, this study examined commercial products and concluded the properties required for subtropical glazing films to achieve energy conservation.

METHODS

Based on the Japanese standard of adhesive film (JIS A, 1998) for glazing, two indices are chosen for assessing the optical and thermal performance of adhesive film. They are visible transmittance and shade factor. The measurements and calculations of the two indices are specified as follows.

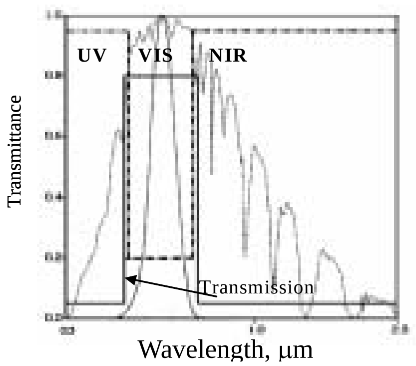


Figure 1 Solar spectrum and optical properties of an ideal material

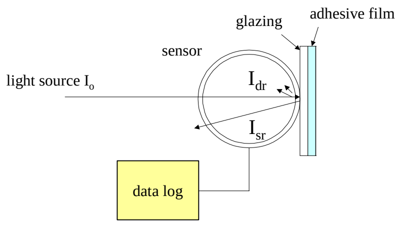


Figure 2 Experimental set-up for reflectance measurement

Visible transmittance and reflectance

The mountain-shaped curve shown on Figure 1 is solar spectrum, in which Ultraviolet (UV) covers 0.3 0.38 μm and accounts for 2% of the total energy, Visible (VIS) 0.38 0.78 μm and 47%, and Near Infrared (NIR) 0.78 2.5 μm and 51%. The solid line in Figure 1 depicts the transmittance of an ideal material with high visible transmittance value and low levels for both of the UV and NIR.

The optical performance, which is transmittance, reflectance, and absorptance, of a material is measured by a spectrophotometer and the measuring range covers 0.19 2.5 μm. The experimental set-up for reflectance measurement is shown in Figure 2. In Figure 2, I_o is the light source, I_{sr} the specular reflectance, and I_{dr} the diffuse reflectance. The diffuse reflectance and the specular reflectance of a measured material are expressed in Equations (1) and (2). The total reflectance of a material is the sum of R_s and R_d, shown as Equation (3).

$$R_s = I_{sr}/I_o \tag{1}$$

$$R_d = I_{dr}/I_o \tag{2}$$

$$R = R_s + R_d \tag{3}$$

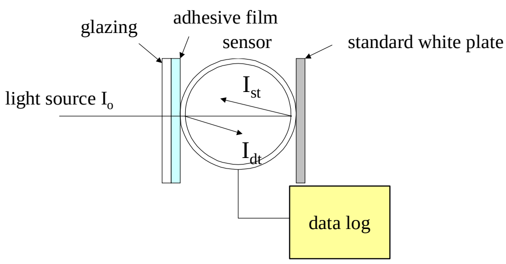


Figure 3 Experimental set-up for transmittance measurement

The experimental set-up for transmittance measurement is shown in Figure 3, in which the standard white plate- a special polymer is a reflective material rejecting light wave within 0.2 2.5 μm. In Figure 3, I_o is the light source, I_{st} the specular transmittance, and I_{dt} the diffuse transmittance. The diffuse transmittance and the specular transmittance of a measured material are expressed in Equations (4) and (5). The total transmittance of a material is the sum of T_s and T_d, shown as Equation (6).

$$T_s = I_{st}/I_o \tag{4}$$

$$T_d = I_{dt}/I_o \tag{5}$$

$$T = T_s + T_d \tag{6}$$

Shade factor

According to JIS A 5759, shade factor (SF) is expressed as Equations (7) and (8). SF is defined as the ratio of the total solar energy penetration between through a measured material and a 3 mm plate glass. The total solar energy transmitted through a transparent material is illustrated by Figure 4, in which A is the absorbed energy, A_{rout} and A_{rin} are the re-radiated parts from A. The sum of T and A_{rin} is the total solar energy entering indoor through the transparent material.

$$SF = (\tau_e+N_i(100- \tau_e - \rho_e))/(\tau_{eo}+0.35(100- \tau_{eo} - \rho_{eo})) \qquad (7)$$

$$N_i = (6.3\varepsilon_i + 3.9)/((6.3\varepsilon_i + 3.9)+(6.5\varepsilon_e + 12.2)) \qquad (8)$$

τ_e : transmittance of a transparent material
ρ_e : reflectance of a transparent material
τ_{eo} : transmittance of a 3mm glazing
ρ_{eo} : reflectance of a 3mm glazing
ε_e : emissivity of exterior air film
ε_i : emissivity of interior air film

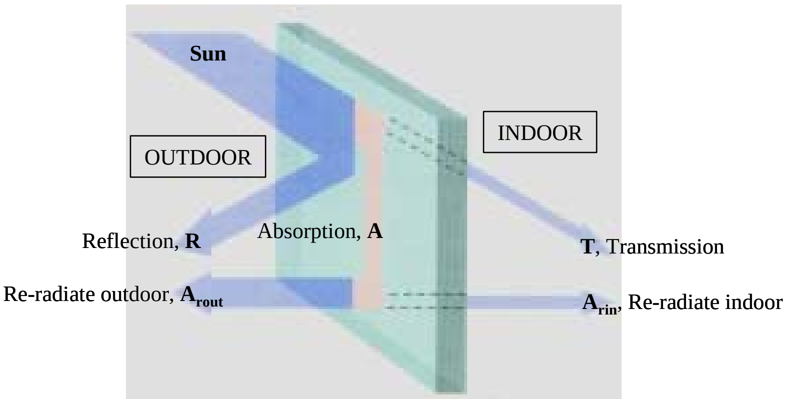


Figure 4 Optical properties of a transparent material

Assessment

Based on JIS A 5759, three performance categories of adhesive film for glazing are classified based on visible transmittance and shade factor. Class I- the best performance is for 60% and above visible transmittance and 0.4 and lower shade factor. Class II is for 30 60% visible transmittance and 0.4 0.6 shade factor. Class III is for 10 30% visible transmittance and 0.6 0.7 shade factor.

RESULTS AND DISCUSSION

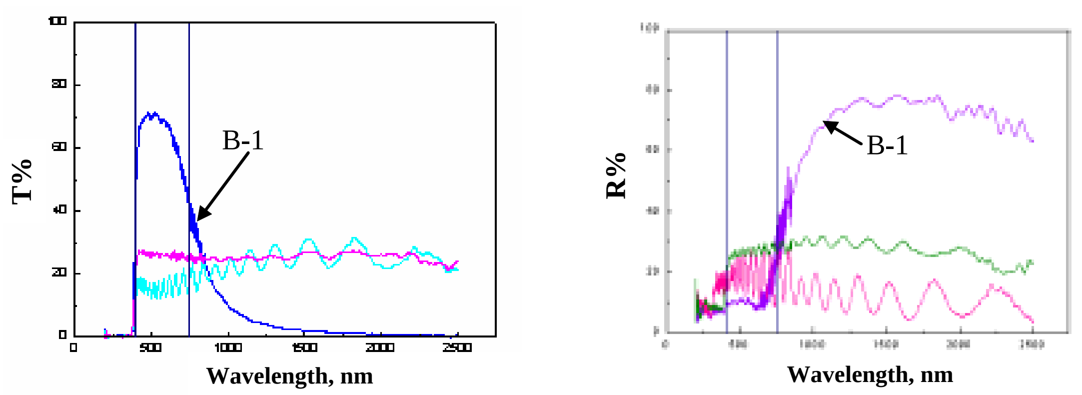
Performance Assessment

This study collected 55 film products from 10 makers. The visible transmittance and shade factor of each product is measured and listed in Table 1. From Table 1 one can observe that most of the samples fall into the category of the Class II and four samples have better performance. The four samples are B-1, G-1, F-4, and F-3, in which the performance of B-1 is close to Class I. Among the 55 samples, none of them reaches the performance of Class I.

From Table 1 one can find out that sample B-1 achieves high visible transmittance level while maintaining a low shade factor value. The situation can be further observed in Figure 5, in which sample B-1 has high visible transmittance (Figure 5(a)) and high near infrared reflectance (Figure 5(b)) as well. A higher near infrared reflectance value helps to reduce the total penetrating solar energy, which results in a lower shade factor. This phenomenon can be specified by the performance of sample D-11. From Table 1 one can find out that sample D-11 has high visible transmittance (67.07%) and high shade factor (0.8) values. The cause for D-11 to have a high shade factor can be observed in Figure 6, in which a high transmittance is shown in the near infrared region.

Table 1 Performance of film samples

Sample		visible transmittance, %	shade factor	Sample		visible transmittance, %	shade factor
A	A-1	43.56	0.57	F	F-1	11.28	0.26
	A-2	53.24	0.67		F-2	13.50	0.26
	A-3	60.76	0.71		F-3	57.39	0.67
B	B-1	63.36	0.46		F-4	65.93	0.61
	B-2	15.79	0.46		F-5	33.14	0.47
	B-3	25.91	0.46		F-6	22.75	0.39
C	C-1	30.44	0.49		F-7	6.35	0.19
	C-2	35.24	0.39		F-8	19.78	0.45
	C-3	23.04	0.59		F-9	38.81	0.45
	C-4	45.61	0.61		F-10	17.87	0.23
D	D-1	6.11	0.25		F-11	16.31	0.44
	D-2	16.26	0.29		F-12	41.66	0.58
	D-3	7.98	0.25	G	G-1	67.72	0.53
	D-4	9.19	0.23	H	H-1	63.19	0.76
	D-5	12.34	0.29		H-2	65.02	0.78
	D-6	87.24	0.97		H-3	61.32	0.74
	D-7	16.89	0.23		H-4	60.56	0.75
	D-8	86.81	0.96		H-5	59.65	0.74
	D-9	66.21	0.79		H-6	57.48	0.72
	D-10	18.02	0.26		H-7	57.33	0.72
	D-11	67.07	0.80		H-8	57.18	0.74
E	E-1	21.44	0.45		H-9	53.54	0.72
	E-2	41.28	0.54		H-10	52.62	0.72
	E-3	40.67	0.47		H-11	44.93	0.68
	E-4	22.72	0.29	I	I-1	85.27	0.83
	E-5	11.72	0.25	J	J-1	77.09	0.71
	E-6	36.47	0.58				
	E-7	20.58	0.42				
	E-8	54.01	0.69				



(a) (b)

Figure 5 (a) Transmittance; (b) Reflectance of sample B-1

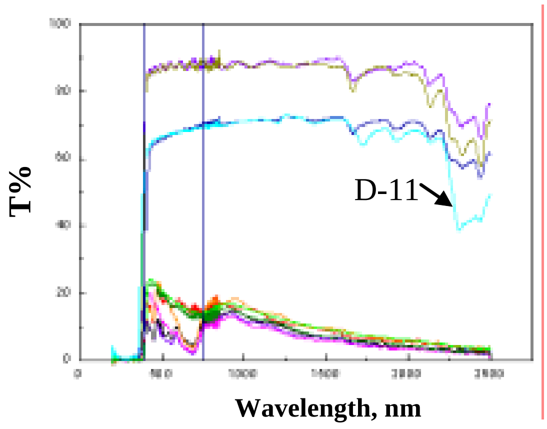


Figure 6　Transmittance of sample D-11

Properties analyses

From the performance analyses of existing products, one can conclude that an ideal adhesive film should possess high near infrared reflectance value while maintaining high visible transmittance level.　To estimate the optical properties required for achieving 0.3　0.6 shade factor, the Equation (7) is applied for the calculation.　Figure 7 depicts the results of the calculations, in which the influences from total reflectance and transmittance on shade factor are illustrated.　In Figure 7 shade factor, denoted as S in the legend, is calculated from 0.3 to 0.6.　To achieve the performance of Class I, the total light transmittance should not exceed 28.2% (marked in bold dashed line in Figure 7) when 60% visible transmittance is maintained.　The intersection between the vertical dashed line and the diagonal line of S-0.4 at the total reflectance is about 53%.　A total reflectance of 53% can be achieved when 30% visible reflectance and 80% near infrared reflectance are to obtain.

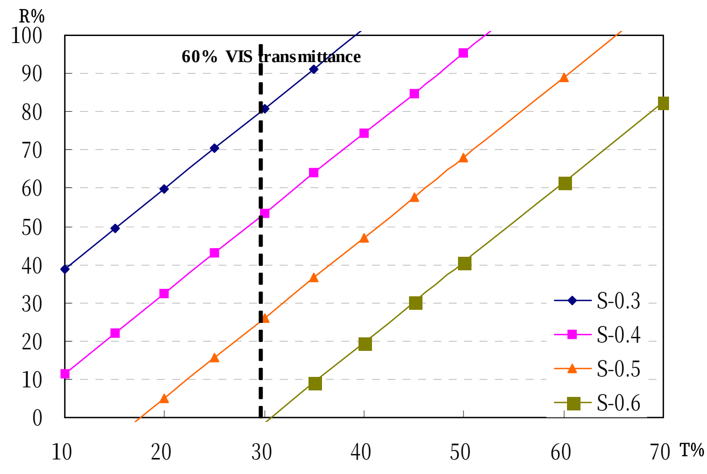


Figure 7　Impacts from total reflectance and transmittance on shade factor

Generally speaking, a higher visible transmittance brings forth a larger shade factor automatically.　To lift-up visible transmittance while maintaining a certain shade factor, it is required to increase the reflectance of near infrared.　This phenomenon can be illustrated with Figure 7.　When moving the bold dashed line right-ward, the total reflectance needs to be lifted up to meet the diagonal line.　It is therefore beneficial to maintain a 60% visible transmittance when product development is concerned.

CONCLUSION

To improve energy conservation of windows, it is required to balance the needs for day-lighting and thermal insulation. This study intends to explore the required thermal and optical properties of adhesive films for subtropical windows. To reach the goal, this study establishes measurement and assessment methods based on the Japanese standard of adhesive film for glazing. According to the established methods, this study investigated the performance of 55 film products from 10 makers. It has been found that most of the samples fall into the Class II category and four samples have better performance. There is only one sample has the performance close to the Class I. To reach Class I, it was observed that 30% visible reflectance and 80% near infrared reflectance are required to maintain 0.4 shade factor when 60% visible transmittance is achieved.

ACKNOWLEDGEMENTS

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Using Non-Energy Benefits (NEBs) to Market Zero and Low Energy Homes in New Zealand

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Albrecht Stoecklein, BRANZ Ltd.

Abstract For a research project in New Zealand on zero and low energy houses (ZALEH), the authors conducted in-depth interviews to quantify benefits of, and barriers to, advanced homes and technologies. The surveys included occupants of known ZALEH homes. The survey consisted of four major sections: an inventory of (advanced) equipment; a survey of technology performance issues, attitudes, and beliefs; questions to evaluate positive and negative Non-Energy-Benefits from various equipment; and detailed demographic and segmentation variables.

The research examined the overall non-energy benefits (NEBs), as well as the benefits from each of the range of advanced technologies included in the homes. The sources of NEBs was identified – including factors such as improvements in comfort, bill control, health, maintenance, noise, the environment, and other factors. We examined the both positive and negative impacts, and used a set of detailed questions to identify the value that the occupant placed on each of the net impacts or benefits. The results showed ZALEH residents place a high value on the energy efficiency features of their homes, and that the relative level of benefits is in the order of those seen in United States programs.

针对新西兰零低能耗建筑（ZALEH）研究项目，作者深入调查了该项目中先进住宅和先进技术的利益和障碍，以使其定量化。调查对象包括了解 ZALEH 的居民。调查主要包括 4 方面：第一方面是设备目录，技术性能、人员对设备的态度和信任程度；第二方面是不同设备对于的 NEBs 正面效应和负面效应的评价问题，第三和第四方面是统计和环节变量

本研究调查了整体 NEBs 以及在建筑内的设备效益。NEBs 的主要考虑对象包括舒适的提高、经济控制、健康、维护、噪声、环境和其他因素，其中正面影响和负面影响都必须分析。同时本文使用一套详细的问题来识别各个环节的纯效益和纯影响。结果显示 ZALEH 居民在其住宅里面对于能效特性考虑是非常重要的，相对的效益级别顺序参照美国项目。

Background on NEB Valuation

This project was designed to measure the non-energy benefits (NEBs) that might be found in a set of zero and low energy houses (ZALEH) in New Zealand. The authors conducted in-depth interviews with occupants to discuss, identify, and quantify the positive and negative impacts the owners recognized from advanced home technologies. The advanced features of these homes included: advanced house design (96%), solar water heating (96%), advanced glazing (91%), advanced space heating and cooling (91%), high insulation levels (83%), special house features (61%), micro energy generation[1] (35%), and other features (22%).

Over the past few years, research has been conducted to develop and test alternative valuation methods for commercial and residential NEBs (Skumatz 2002). This project provided an opportunity to quantify the array of NEBs that have been associated with low energy use homes – and develop information that serves at least two purposes:

- *Informs efficiency-related marketing, targeting, design, and outreach efforts*: Previous research shows that NEB analysis provides quantitative information that clarifies benefits and negative benefits/barriers associated with efficiency efforts – based on the field experience of those implementing conservation measures. Previous research demonstrated these methods for a variety of residential and commercial programs and measures (Skumatz 2002, Pearson and Skumatz 2001). The quantitative approach and information demonstrates which NEBs are especially important, and provides data on the relative size of the NEBs compared to direct benefits from energy savings and other direct sources. These findings can be sorted by demographics, measure type, or other factors that may affect the value and importance of the NEBs. These results point out which benefits are most important to various groups, providing opportunities to design program interventions and outreach activities to target groups such as builders, decision-makers, and other subgroups. It will permit them to address those energy technologies which show the greatest NEB benefits, using terms and benefits that the end users value and respond to.
- *Provides data for improved program benefit-cost analyses*: The quantitative values for program- or intervention-related NEBs can be and have been used in revised public purpose tests,[2] and to provide more complete information for assessing benefits and costs associated with programs. Dollar-related NEB benefits ("net" including positive and negative NEBs) can be added to direct cost and benefit information, enhancing program-related cost/benefit computations. The user may choose to include all NEBs, or only a subset of the overall NEBs in the cost/benefit computations – or there may be different cost/benefit computations depending on the perspective upon which the test is based. One specific application for quantified non-energy-benefits may include programs in which post evaluation shows that the projected energy savings have not been achieved. Rather than considering these programs as failures, the financial valuation of non-energy-benefits can demonstrate a quantifiable positive outcome nevertheless - albeit not the originally intended one.

Most of the previous NEB work has assessed benefits associated with measure-based programs or audits that lead to measure changes. This project was designed to see if benefits were recognized and attributed to features of zero and low energy homes (ZALEH) in New Zealand, and to see if actual dollar values – or ranges – could be associated.

[1] Micro generation is considered generation by households through technologies like PV, small wind and hydro, etc.
[2] Work by Skumatz for the California Utilities updating the Low Income Public Purpose Test, and information from Skumatz and other NEB analyses was used to develop NEB "adders" for Massachusetts PUC proceedings.

NEB Measurement Approach

The most challenging aspect of the research is quantitatively valuing these "hard-to-measure" positive and negative benefits. Skumatz Economic Research Associates, Inc. (SERA) has conducted extensive research to develop several measurement methods to quantify and "value" a wide range of participant and other NEBs. SERA pioneered the application of three different approaches in querying and measuring non-energy benefits, including "willingness to pay", comparative, and labeled magnitude scaling approaches (Skumatz 2002). For this project, two of these methods were used: a variation of the willingness to pay, and the comparative methods. The results were designed to provide information on the net value of the non-energy benefits emanating from the advanced technologies as recognized by the ZALEH residents.

The basic approach involved telephone interviews with residents in a sample of ZALEH homes. We asked about specific NEBs (both positive and negative) associated with individual measures. Previous NEBs research and some preliminary work was used to develop a list of likely NEBs associated with the ZALEH homes / owners.

We asked both prompted and unprompted questions on benefits. In the questionnaire, we asked, for each NEB category, whether there was a change, and whether it was positive or negative. The prompted benefit categories – phrased in the way that most people assigned the NEBs (positive) -- included:

- Appearance: Improvements in appearance of the home.
- Bill control: Measures (and bill impacts) led to a feeling of greater control over the energy bill.
- Comfort: ZALEH house features led to greater comfort in this home than others.
- Environmental: Features led to environmental benefits.
- Features: Energy equipment or measures had better features, options, or were nicer than non-ZALEH measures.
- Health: Features were perceived to make the home safer or healthier to live in.
- Maintenance: The features had lower maintenance
- Moving: The ZALEH home's special energy features led to them being able to avoid a move, either because of lower bills, greater benefits, value, and service from the home, or other reason.
- Noise: The ZALEH home had lower noise, either from outside the home, or from the energy using equipment inside the home, or both.
- Notices: The energy reductions due to the ZALEH home led to lower bills, which improve their ability to pay and therefore reduced late payment notices or similar calls from the utility on bill-related issues.
- Other: Other, unprompted benefits categories included higher cost (the major one), and a variety of other benefits or negative impacts and changes.

The results for overall valuations and for individual benefits categories are included in the following sections.

Total NEBs from the ZALEH Homes

The feedback and valuations from the respondents make it clear that there *are* NEBs deriving from ZALEH homes and they are highly valued. The results showed that the average estimate for energy savings from ZALEH home NZ$1,300 per year.[3] The values reported by individual homeowners ranged from NZ$400 to NZ$3,000. The NEB analysis found that, on average, residents estimated they recognized about NZ$3,600 worth of value from the NEBs – including both positive and negative impacts from the range of conservation measures and features included in their homes. Thus, as a fraction of energy benefits, the households reported that they received just over three times as much value from the NEBs from the ZALEH as they realized from the energy savings. If non-energy benefits were to be incorporated into the assessment of "payback" for the investment in the ZALEH measures, it would imply that the payback was significantly faster than the payback excluding these benefits.

Results by Type of NEB

Table 1 shows the fraction of the total NEBs that derive from each NEB category – on an overall basis. Most of the NEBs (almost three quarters) come from just a few categories:

- Comfort (28%),
- Environmental benefits (a feeling of "doing good" for the environment) (22%), and
- Avoided moves (22%).

Table 1 Share of Total Net NEBs from Key Categories

	Percent of total NEB value by NEB category
Appearance	7%
Bill control	4%
Comfort	28%
Environmental	22%
Features	0%
Health	3%
Maintenance	1%
Moving	22%
Noise	5%
Notices	0%
Cost	-11%
All other	-1%

Other sources of NEB value included improved appearance, noise reduction, bill control, and health benefits. It was somewhat surprising that health benefits were valued relatively low. Other New Zealand studies have found evidence of significant health improvements following insulation retrofits (Howden-Chapman et al., 2004). The low rating in the ZALEH houses might be attributed to the fact that the sample was self-selected

[3] Note that the residents were asked to estimate the energy savings from measures; actual data on savings were not provided.

and biased towards high income earners. These people might be able to heat their houses to comfortable healthy temperatures regardless of the thermal performance of the house and therefore might not have seen health improvements since living in a ZALEH home.

Improved features, maintenance, and benefits associated with late utility payments (notices) were fairly insignificant sources of recognized NEBs. Clearly, residents feel that ZALEH homes provide strong comfort, and environmental benefits, as well as benefits that allow or induce them to stay in the home and avoid moving. However, concern about the potential extra cost involved was a significant negative concern, representing 11% of the net NEBs assigned.

NEB Results by Measure

We also examined the measures that led to the greatest NEB value. The results, showing averages for homes with those measures, are provided in Table 2. Table 3 expresses these findings in percentage terms. The research indicates that the top three measures in terms of net NEB benefits were responsible for just under two-thirds of the overall NEB value provided in the ZALEH homes. The results show that the measures with greatest NEB values included:

- Special house design (26%),
- High insulation (24%), and
- Windows / double glazing (15%).

Other strong benefits were provided by solar water heating and space heating, representing another 19% of the benefits combined.

The strongest sources of benefits for each measure or feature are outlined below:

- Special house features: NEBs derived mostly from the comfort benefits, and the benefits it provided in avoiding moves.
- Insulation: Led to strong benefits in comfort and avoided moves.
- Better glazing: Improved windows provided especially strong comfort and noise benefits to residents.
- Water heating: Largest NEBs in this category came from environmental and comfort sources.
- Space heating and cooling: Comfort, environmental, and avoided moves were the greatest contributors to NEBs for these measures.
- Appliances: The biggest source of these benefits was environmental.
- Other special house features and micro-energy sources had fewer observations: Most of these benefits from other special house features came from environmental and avoided moving sources. The micro energy users reported a wide variety of positive and negative benefits.

Table 2 Annual NEB Values by Technology and NEB Type in New Zealand Dollars

	Appliance	Glazing	HVAC	Insulation	Micro Gen	Other	Special Design	Water Heating	Total NEB Value	Pct of total NEB value
Appearance	$12	$82	$69	$301	-$69	$440	$952	$3	$1,379	7%
Bill control	$11	$134	$58	$292		$0	$0	$205	$795	4%
Comfort	$2	$1,080	$695	$1,895	$31	$60	$1,707	$763	$5,574	28%
Environmental	$161	$248	$382	$432		$1,600	$633	$1,291	$4,227	22%
Features	-$3	$55	$48	$4	-$129	$60	$0	-$2	$61	0%
Health	$0	$150	$175	$322	$100	$0	$0	$58	$653	3%
Maintenance	$28	$418	-$28	$262		$220	$0	-$131	$232	1%
Moving	$0	$264	$407	$1,640	$510	$714	$1,802	$295	$4,307	22%
Noise	$35	$702	$3	$368	-$83	$0	$0	-$17	$925	5%
Notices	$0	$0	$0	$0	$0	$0	$0	$0	$0	0%
Cost	-$44	-$366	-$154	-$612		-$441	$0	-$361	-$ 2,240	-11%
All other	$66	$120	-$120	-$244	-$331	$0	$0	$93	-$187	-1%
Sum	$269	$2,888	$1,537	$4,660	$349	$2,653	$5,094	$2,198	$19,648	100%
% of houses with the measure	61%	91%	91%	83%	35%	22%	96%	96%	100%	
% NEBs for technology	1%	15%	8%	24%	2%	14%	26%	11%	100%	

While most of the benefit categories showed positive values, cost and maintenance were expressed as negative effects from the ZALEH homes and features. This matches findings from other work (Skumatz 2004). Interviews conducted as part of the other project indicated that participants were concerned that the maintenance for advanced measures might be more complex, that it might be hard to find contractors to repair some technologies, and parts might be difficult to find. Although these issues were not probed in the New Zealand work, concerns might be similar.

Table 3 Results on Percent of NEB by Technology

	Appliance	Glazing	HVAC	Insulation	Micro Gen	Other	Special Design	Water Heating	Total NEB Value	Pct of all NEBs
Appearance	5%	3%	5%	6%	-20%	17%	19%	0%	7%	7%
Bill control	4%	5%	4%	6%	n/a	0%	0%	9%	4%	4%
Comfort	1%	37%	45%	41%	9%	2%	34%	35%	28%	28%
Environmental	60%	9%	25%	9%	n/a	60%	12%	59%	22%	22%
Features	-1%	2%	3%	0%	-37%	2%	0%	0%	0%	0%
Health	0%	5%	11%	7%	29%	0%	0%	3%	3%	3%
Maintenance	11%	14%	-2%	6%	n/a	8%	0%	-6%	1%	1%
Moving	0%	9%	26%	35%	n/a	27%	35%	13%	22%	22%
Noise	13%	24%	0%	8%	-24%	0%	0%	-1%	5%	5%
Notices	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Cost	-16%	-13%	-10%	-13%	n/a	-17%	0%	-16%	-11%	-11%
All other	25%	4%	-8%	-5%	n/a	0%	0%	4%	-1%	-1%
% of NEBs from technology	1%	15%	8%	24%	2%	14%	26%	11%	100%	80%
% of NEBs excluding "Cost "and "Other"	1%	14%	8%	25%	13%	14%	23%	11%	100%	

Differences in Results by NEB Valuation Method

Table 4 shows the overall and measure-specific values and multipliers for the ZALEH homes. The table shows value in two ways:

- A variant of willingness to pay in which we asked how much they would need to be given to agree to have the item removed from their home, and
- NEBs computed from comparisons with value relative to perceived energy savings from the measures.

Table 4 NEB and WTP Results and Multipliers

	Total (rounded)
WTP -- average for those with measure($)	NZ$1,900
Individual NEB values adjusted to "total" ($)	NZ$3,600
Energy savings by measure adjusted to "total" ($)	NZ$1,300
Multiplier of NEB value / energy savings	2.8
Multiplier of WTP value / energy savings	1.5

The results for the willingness to pay (or be paid) shows that the homeowners estimated they would need to be paid an average of about NZ$1,900 to have the ZALEH features removed. The highest value in those terms was provided by insulation, with windows and special house design features also important or highly valued by residents.

When asked in relative terms how valuable the measures were to residents, the households provided information that translated into a net value of about NZ$3,600 per home.[4] The highest value items under the WTP method were again the highest valued items under this valuation method. The second method determined a value almost double the value provided through the willingness to pay method.

The energy savings that households estimated came from these measures was about NZ$1,300 per year. When the computed NEBs were compared to energy savings estimates, we found that:

- When measured from WTP estimates, the NEBs were 50% more valuable than the energy savings (multiplier of 1.5) and
- When measured in relative terms, the computed NEBs were 180% more valuable than the energy savings (2.8 multiplier in the table).

While these two valuation methods provide different estimates, both indicate that NEBs were perceived to have significant value, and that these other benefits were perceived to be significantly more valuable than the energy savings deriving from the measures and features provided in the ZALEH homes.

[4] We asked the information in terms of both individual benefits as well as the overall benefits. The individual benefits were corrected or “scaled down” in this table to sum to the overall benefits they estimated. That is, the sum of comfort plus each other individual benefit category came to a higher number than they estimated for the total / overall net NEBs. The total NEBs computed from the sum of individual categories was 61% higher than the figures in the table. This tendency to overestimate individual benefits relative to the sum has been found in other research (Skumatz 2002). One reason for this may be that some of the benefits tend to overlap, such as for example comfort and health leading to an overestimated sum for the individual benefits.

Discussion of Overall Results

This implies that, regardless of which measurement method is used for the NEBs, when cost-benefit analyses are used to justify expenditures in measures, the builder or other decision maker may be underestimating the value of the measures or investments to homeowners. The computed payback times are much longer than resident's experience in terms of overall value.

Reviewing the values assigned by measure in Tables 2 and 3 above shows that the measures with the highest value multipliers relative to estimated energy savings are insulation, special house design, and glazing. These measures may be ones that, in particular, builders could "overinvest" in (using simple payback criteria) and have that investment by builders highly valued by customers.

It should also be noted that it is likely that the survey participants overestimated their energy savings.[5] However, the estimated non-energy-benefits are internally consistent, at least as a multiplier relative to savings. This is because, during the interview, the subjects were explicitly asked to compare non-energy-benefits with the dollar energy savings, each time explicitly quoting the dollar value of the estimated savings. The likely overestimation of the energy savings through the ZALEH technologies means that the NEB multiplier is in fact a conservative estimate when compared to more realistic actual or engineering calculated energy savings. Further, the Willingness to Pay values were provided as a direct dollar feedback – not related to energy savings. The findings in either case imply NEBs are recognized as valuable to the homeowners. The results show particularly valuable measures as recognized by homeowners are:

- Special housing design,
- Insulation,
- Glazing,
- Space heating and cooling,
- Water heating,
- Other special features, and
- Micro generation applications.

Cost/Benefit Application

The potential implications of these results were explored using a typical cost/benefit analysis for insulation improvements. The New Zealand Building Industry Authority applies this type of analysis energy saving restricted cost benefit analysis when developing mandatory insulation requirements, which are legislated in the New Zealand Building Code and its related documents. New Zealand houses are cold compared to

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[5] A large New Zealand study on actual energy use in houses found that the average energy consumption is approximately 10,000 kWh (Isaacs, *et.al.* 2003). This excludes fire wood usage, which is still comparatively common in older New Zealand houses. Based on the self-reported ZALEH homes energy savings the ZALEH houses should save almost 100% of a standard house energy use. However, most of the ZALEH houses still report significant energy usage. The reasons for this can be varied. Possibly the ZALEH houses are kept at warmer temperatures, the houses might be larger than average houses or the occupants simply overestimate their energy savings, since they mostly have no baseline for their house to compare with.

international standards. Therefore it is also estimated that the potential health cost savings from improved housing insulation for New Zealand is significant.

The following example illustrates the common lifestyle-benefits-dilemma: Although it is widely accepted that there are significant non-energy-benefits (NEBs) from energy technologies, traditional cost/benefit analysis and evaluation of energy technologies does not account for these. One of the reasons is that non-energy benefits are inherently difficult to quantify in economic terms. However, excluding them from the analysis effectively assumes a $-value as well, which incidentally is $0. Therefore such an analysis will ultimately not lead to best-value-for-money solutions.

The following example illustrates this. Our research in zero and low energy houses indicates that house occupants value non-energy benefits from superior insulation more than twice as high as the associated energy savings. The following graphs show the impact of including quantifiable non-energy benefits in the cost effectiveness evaluation.

Figure 1 shows the net present value for insulating a light weight construction in Wellington. These values were used for the last update of the NZ Building Code insulation targets. The two graphs show that when non-energy benefits are not included (graph on the left) the slopes of the net present values are close to zero, indicating that the best value solution is near composite R-values of approximately 0.95ºC/W, and double glazing options (full circles) are less cost effective. If non-energy-benefit values at twice the value of the energy savings are considered, the graph changes dramatically and the best value options are double glazed solutions at much higher composite insulation levels (The lowest NPV option is to the right of the last calculated data point, i.e. higher than the last computed composite R-value of 1.4ºC/W).

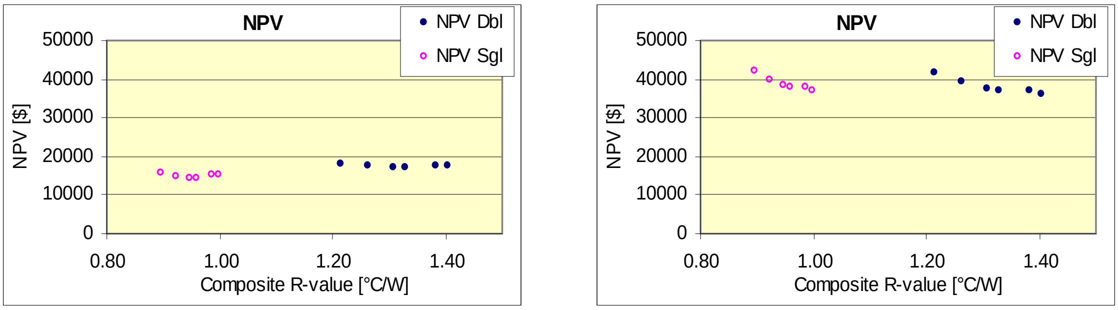

Figure 1: Change of net present value for different accounting of non-energy benefits: left: only energy saving with no non-energy benefits, right: non-energy benefits are twice as high as energy cost savings. (Open circles represent single glazed cases, filled circles double glazed cases.)

Until now this research has focused on advanced housing. It is necessary to capture other segments of the housing stock, as well. The current results indicate for example that health benefits from energy technologies are of low value to the generally high-income occupants of the low energy houses, whereas other New Zealand retrofit evaluation projects showed that health was a highly valued non-energy benefit for the lower-income participants in that project.

Summary and Implications

The analysis shows that comfort, environmental benefits, and avoided moving benefits each represent more than one-fifth of all the non-energy benefits realized by residents in the ZALEH.

- Residents gain the comfort from higher insulated homes, better space heating, double glazing, solar water heating and special house design.
- One of the major NEBs associated with energy efficient appliances and solar water heating is environmental.
- Environmental benefits represent about a fifth of the NEBs delivered by these measures.
- Negative benefits (concerns) – largely costs and maintenance issues – can be associated with the advanced energy measures.

The results show that investment in ZALEH features may be lower than residents would be willing to accept. The data indicates that NEBs outweigh energy savings, and understate benefits recognized by homeowners by between 50% and 180%, or by NZ$1,900 to NZ$3,600 depending on valuation methods. Comparison to NEBs from other programs shows that these results are in line with savings from US residential programs. Skumatz (2001b, 2002) summarizes results from several low income and residential programs, and finds that participant NEBs on the order of 100-300% of energy savings are usual, depending on program type and target participant.

Further, marketing activities in relation to the ZALEH homes could emphasize some of the important benefits residents attribute to the ZALEH features, namely significant value from comfort, environmental benefits, and reduced need to move. Other important benefits include better appearance of the home, better control over bills, and health benefits.

Non-energy benefits (NEBs) are an often-ignored, but important set of benefits provided by energy-related measures and features in residential (and non–residential) buildings. Utilities may run energy conservation programs to reduce energy use, and builders may build homes that include energy saving features, measures, and designs. However, energy savings may not be – and appear not to be – the highest valued outcome of these measures and features to the residents or homebuyers. These results make sense to incorporate into:

- Initial decision-making about which measures / features to be included in new / remodeled homes (or into programs) and computations of costs and benefits from investment in energy using equipment, and
- Outreach / advertising to attract homeowners to these homes or to energy conservation programs that incorporate these measures. The value of these other benefits – may be stronger selling points for the measures than energy savings – and these benefits should be used as key sales messages in outreach program.

Acknowledgements

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Properties Required for Subtropical Residential Enclosure to Achieve Energy Conservation

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Abstract In lack of natural resources, Taiwan has to import 97% of the required energy. Along with the economic growth, the residential electricity consumption has been increasing steadily since '70's and reached 20.1% of the total consumption in 2000. It has been found that the cooling load contributed from residential roof and wall accounts for around 79% of the entire cooling loads, which takes up 20% of the entire residential electricity consumption. This study intended to improve the thermal insulation level of the opaque residential enclosure through identifying key properties for achieving high energy saving. Through cooling load simulations , U-value and surface absorptivity of an apartment at top level and at middle level are examined under natural ventilation and air-conditioned conditions. It has been found that a raised surface reflectance of a naturally ventilated space is effective in reducing cooling loads. It is also observed that to increase the roof surface reflectance is the first priority for an apartment at top level for cutting-off cooling loads. For a naturally ventilated apartment at middle level, the better way for energy saving is to increase the surface reflectance of walls, rather than to cut-off the U-values. For an air-conditioned space, a reduced U-value is equally important as a reduced surface absorptive level to obtain lower cooling loads. Considering workability, paint could be an effective material to increase the building surface reflectance for both of the new and existing residential buildings.

Key words building energy conservation, U-value, surface reflectance, cooling load

INTRODUCTION

In lack of natural resources, Taiwan has to import 97% of the required energy. Based on the Energy Conference of Taiwan in 1988, it concluded that to promote energy conservation and to increase energy efficiency are major goals to fulfill and the target for energy saving is to reach 4,187x10^4 KLOE till 2020. To reach the target, sectors of industry, transportation, residence/office, and power are assigned to take 31.6%, 16.4%, 19.9%, and 14.9% of the total saving, respectively. For the sector of residence/office, there are four approaches to reach the quota. They are (1) to raise the efficiencies of appliances/equipments; (2) to establish indices of energy consumption for building enclosure; (3) to set-up monitoring methods for building energy assessment; (4) to enforce total building energy consumption allowance. Among the four approaches, the third one is a supporting task, for which no saving quota is assigned. The rest approaches are assigned respectively to 40.3%, 16.1%, and 43.6% of the saving allocated to the residence/office sector.

According to Taiwan Power Company, the electricity consumption of the residence/office sector has been increasing steadily since '70's and reached 20.1% of the total consumption in 2000 (Lee, 2001). For residential building, three major items constitute the consumption pattern and they are air conditioning- 30%, lighting- 20%, and appliance- 50%. Based on the cooling load analyses of the residential buildings in Taiwan (Figure 1; Chao, 2004), it has been found that the cooling load contributed from the opaque parts of envelop as roof and wall accounts for around 79% of the entire cooling loads, which takes up

20% of the entire residential electricity consumption.

In Taiwan more than 77% of the population dwells in urban area and the major building type for urban residence is apartment. The requirement for new buildings has been decreasing since 1995 and the floor area ratio between existing and new ones is up to 85 to 1 in 2001. To improve the thermal insulation level of the opaque residential enclosure as roof and wall, it is required to consider an efficient and feasible way for both of the new and existing residential buildings. The goal of this study is to identify key properties of building envelop for achieving high thermal insulation level for low cooling loads.

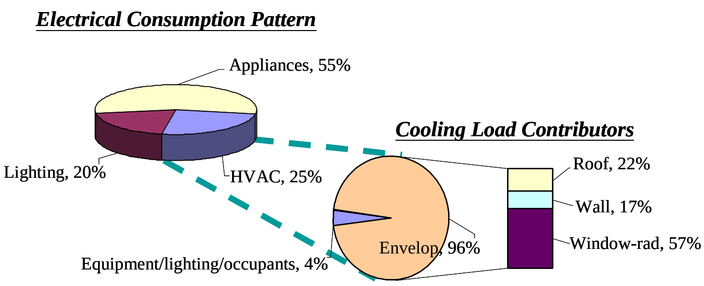

Figure 1 Electrical consumption pattern of Taiwanese residence

METHODS

Cooling load calculation

This study takes cooling load as the assessment index to identify key properties of building enclosure for better thermal insulation to achieve energy saving. Cooling load is calculated from heat gain (1) through structural components (walls, floors, and ceilings); (2) through windows; (3) caused by infiltration and ventilation; and (4) due to occupancy. Conductive heat gains and radiative heat gains do not enter the indoor air directly; thus, their contribution to the cooling load is delayed, and there is a difference between heat gain and cooling load. This study adopts commercial software for cooling load calculations. The software applies the cooling load temperature difference method (CLTD), in which cooling load temperature differences (CLTD), internal cooling load factors (CLF), and solar cooling load factors (SCL) are used to account for transient effects (Krei-der and Rabl, 1994).

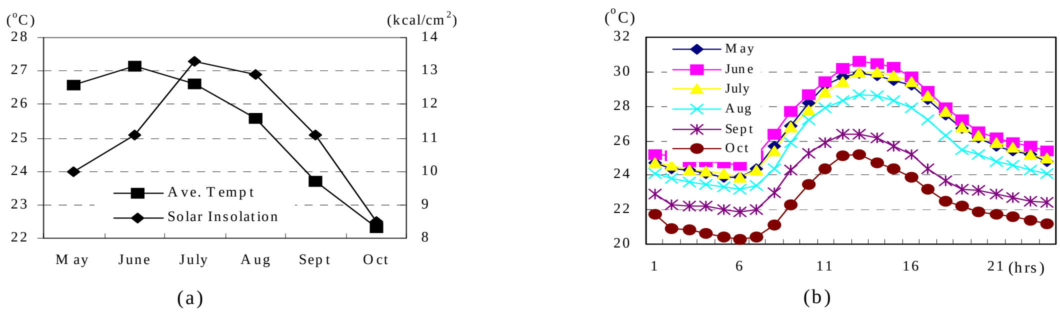

Figure 2 (a) Temperature and solar insolation; (b) daily temperature variation during summer months of Taipei.

This study considers a 2.5% fraction of design condition on cooling load calculations, which refers to the percent of summer hours when the climate will exceed the design temperature (Bobenhausen, 1994). For air-conditioned space, the indoor set-point temperature is taken as 25°C with 70% relative humidity. For naturally ventilated space, the indoor set-point temperature is taken as 28°C for the calculation. It has been found that a 20% of PPD (Predicted Percentage of Dissatisfied) is obtained when T-shirt and shorts are taken at 28^{o}C with 0.5m/s air motion (Chao and Chiang, 2001). The internal load from occupancy, lighting, and appliance is taken as 3.3 W/m^2 according to a 24-hour basis. The cooling load calculation is performed from May to October according to the climate of Taipei (Figure 2).

Table 1 Examined building types

building type	area, m^2			
	floor	roof	wall	window
apartment at top level (AT)	181.4	181.4	94.33	34.5
apartment at middle level (AM)	181.4	-	94.33	34.5

Table 2 Examined parameterS

building type	U, W/m^{2}K			solar absorptivity	
	roof	wall	window/SC*	roof	wall
apartment at top level (AT)	2.5	3.8	6.06/1.0	0.8	0.8
	1.2	2.0	-	0.6	0.6
	0.5	0.5	-	0.4	0.4
apartment at middle level (AM)	-	3.8	6.06/1.0	0.8	0.8
	-	2.0	-	0.6	0.6
	-	0.5	-	0.4	0.4

*Shading Coefficient

Examined parameters

Since apartment is the major residential type in Taiwan, two types of apartment are considered in this study. They are apartment at top level (AT) and apartment at middle level (AM). The two apartments have the same orientation (north-south facing), floor areas, and window areas , shown in Table 1.

The examined thermal properties of the building enclosure are U-value and surface solar absorptivity (A_s). Since the opaque enclosure is considered, the surface reflectance (R_s) can be expressed by Equation (1).

$$A_s\ (\%) = 1 - R_s\ (\%) \qquad (1)$$

The values for the examined parameters and other parameters for simulations are listed in Table 2. Most of the Taiwanese apartments are made of RC with thermal insulation blocks on roof and tile bricks on external wall. The U-value and the surface absorptivity of the roof are taken as 2.5 W/m^{2}K and 0.8; for wall 3.8 W/m^{2}K and 0.8. Since urban area is considered, the outdoor ground material is considered as pavement and the ground reflectance ($_g$) is taken as 0.3 for the simulations.

RESULTS AND DISCUSSION

Roof performance

Table 3 and Figure 3 illustrate the cooling loads of the AT case under naturally ventilated indoor conditions, in which the indoor air temperature is 28^{o}C with 80% relative humidity. From Figure 3 one can observe that a reduced surface absorptivity is effective in reducing cooling loads, particularly for poor insulation cases (higher U-values). For the base case of U-value 2.5 W/m^{2}K with 0.8 solar absorptivity, the cooling load (9925 kWh/yr) of the reduced U-value 1.2 W/m^{2}K (half of the original value) is 1.32 times higher than that (7534 kWh/yr) of the reduced solar absorptivity 0.4 (half of the original value).

Even more, if the U-value is further cut down to 1/5 of the original value, the cooling load (7969 kWh/yr) is still higher than that of the case by simply reducing the solar absorptivity by half (7534 kWh/yr).

Table 3 Cooling load variation at different thermal properties of roof

solar reflectance	solar absorptivity	U, W/m^2K 2.5	1.2	0.5
0.2	0.8	13842	9925	7969
0.4	0.6	10781	8240	7141
0.6	0.4	7534	6743	6559

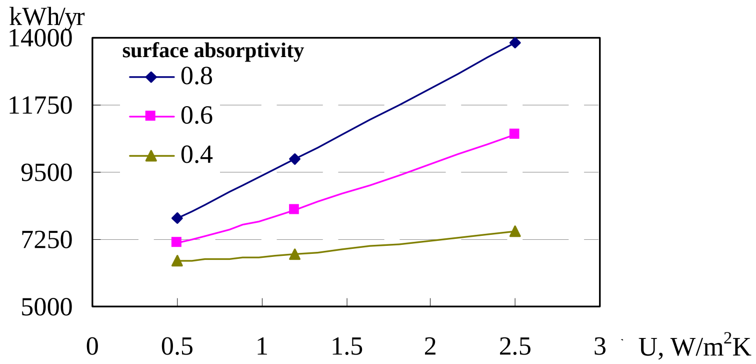

Figure 3 Impacts from roof U-value and surface absorptivity on cooling loads

Table 4 Cooling load variation at different thermal properties of wall - AT case

solar reflectance	solar absorptivity	U, W/m^2K 3.8	2	0.5
0.2	0.8	13842	13015	12709
0.4	0.6	13200	12740	12556
0.6	0.4	12433	12496	12433

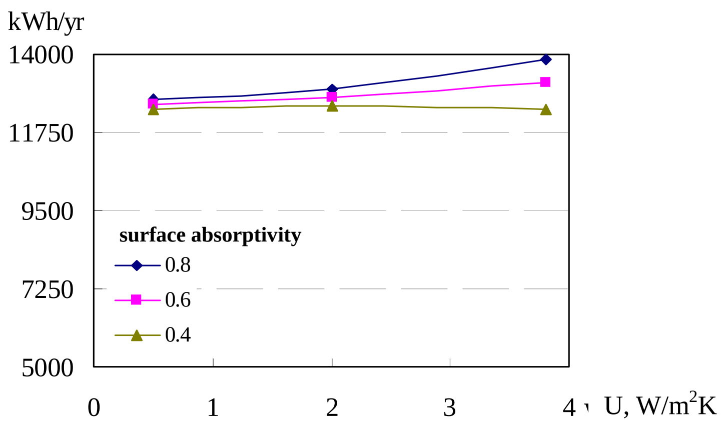

Figure 4 Impacts from wall U-value and surface absorptivity on cooling loads- AT case

One can observe that the slope in Figure 3 is getting flat when solar absorptivity is decreasing. In addition, the differences between cooling loads are getting smaller when U-value is reducing. What can be concluded from the observations is that the room for improvement is getting smaller for either reduced U-value or reduced solar absorptivity.

Wall performance- AT case

Table 4 and Figure 4 show the cooling loads of the AT case under naturally ventilated indoor conditions, in which the indoor air temperature is set at 28^{o}C with 80% relative humidity. From Figure 4 one can observe that a reduced surface absorptivity is effective in reducing cooling loads, particularly for poor insulation cases (higher U-values). For the base case of U-value 3.8 W/m^{2}K with 0.8 solar absorptivity, the cooling load (13015 kWh/yr) of the reduced U-value 2.0 W/m^{2}K (half of the original value) is 1.05 times higher than that (12433 kWh/yr) of the reduced solar absorptivity 0.4 (half of the original value). Even more, if the U-value is further cut down to 1/7.6 of the original value, the cooling load (12709 kWh/yr) is still higher than that of the case by simply reducing the solar absorptivity by half (12433 kWh/yr).

One can observe that the slope in Figure 4 is getting flat when solar absorptivity is decreasing. In addition, the differences between cooling loads are getting smaller when U-value is reducing. What can be concluded from the observations is that the room for improvement is getting smaller for either reduced U-value or reduced solar absorptivity.

From Figure 3 and Figure 4, one can find out that the reduced surface absorptivity of roof is more efficient in reducing cooling load than the same improvement done on wall for the AT case. The cooling load (7534 kWh/yr) achieved by the reduced roof absorptivity to 0.4 is 40% less than that (12433 kWh/yr) achieved by the reduced wall absorptivity to 0.4. The reason is that most of the solar radiation falls on roof than on walls during summer due to a higher solar angle. One can conclude that to increase the roof surface reflectance is the first priority for an apartment at top level for cutting-off cooling loads.

Wall performance- AM case

Table 5 and Figure 5 show the cooling loads of the AM case under naturally ventilated indoor conditions, in which the indoor air temperature is set at 28^{o}C with 80% relative humidity. From Figure 5 one can observe that a decreased surface absorptivity is more effective in reducing cooling loads than a reduced U-value. It can be observed in Figure 5 that a lower U-value does not work for cooling-load reduction comparing with higher U-value cases at a reduced surface absorptivity. The reason of a higher cooling load achieved by a better insulated enclosure is caused by heat-removal difficulties. This situation does not occur in the AT case is that the surface area of the AT case is larger than the AM case, which makes the heat removal possible. For a naturally ventilated apartment at middle level, the better way for energy saving by upgrade the thermal insulation level in enclosure is to increase the surface reflectance, rather than to cut-off the U-value.

Table 6 and Figure 6 show the cooling loads of the AM case under air-conditioned indoor environment, in which the indoor air temperature is set at 25^{o}C with 70% relative humidity. Generally speaking, the cooling load pattern of Figure 6 is different than those under naturally ventilation condition. From Figure 6 one can observe that the lowest cooling load is achieved by the case with the lowest solar absorptivity and U-value. In addition, a decreased U-value achieves more cooling load reduction than a reduced solar absorptivity. For the base case of U-value 3.8 W/m^{2}K with 0.8 solar absorptivity, the cooling load (10430 kWh/yr) of the reduced U-value 2.0 W/m^{2}K (half of the original value) is less than that (10887 kWh/yr) of a reduced solar absorptivity 0.4 (half of the original value) by about 4%. The explanation is that the indoor air temperature of an air-conditioned space is always lower than outdoor air temperature, which makes the heat transfer path constantly from outdoor to indoor. A reduced U-value is therefore equally important as a reduced surface absorptivity for rejecting heat coming in, which is helpful for cooling-load reduction.

Table 5 Cooling load variation at different thermal properties of wall-AM case under natural ventilation condition

solar reflectance	solar absorptivity	U, W/m²K		
		3.8	2	0.5
0.2	0.8	6837	6256	6010
0.4	0.6	5918	5888	5949
0.6	0.4	5245	5429	5827

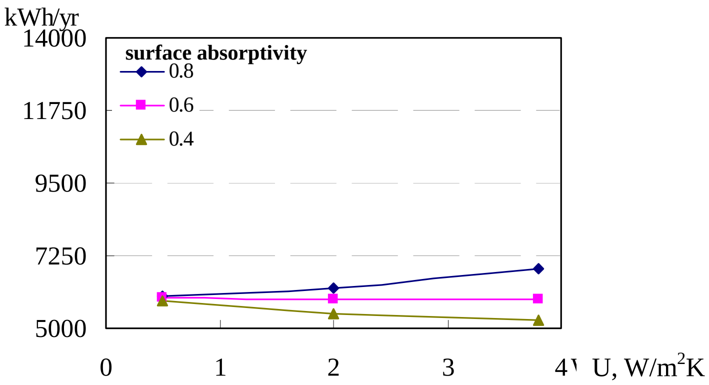

Figure 5 Impacts from wall U-value and surface absorptivity on cooling loads-AM case under natural ventilation condition

Table 6 Cooling load variation at different thermal properties of wall-AM case under air-conditioned condition

solar reflectance	solar absorptivity	U, W/m²K		
		3.8	2	0.5
0.2	0.8	12264	10430	8897
0.4	0.6	11530	10123	8713
0.6	0.4	10887	9846	8621

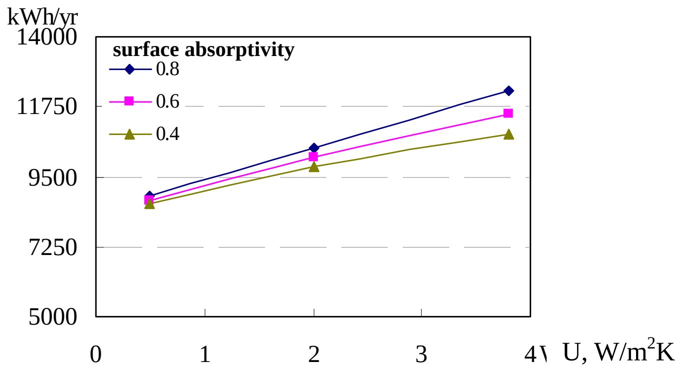

Figure 6. Impacts from wall U-value and surface absorptivity on cooling loads-AM case under air-conditioned condition

CONCLUSION

This study intended to improve the thermal insulation level of the opaque enclosure for both of the new and existing apartments. The goal is to identify the key properties of the enclosure for an effective reduction of cooling load. Two thermal properties of building envelop are examined, U-value and surface absorptivity. To evaluate the influences of thermal properties on energy saving in apartment at top level and at middle level, this study carried out a parametric study by cooling load simulations.

It has been found that to raise the surface reflectance of a natural ventilation space is an effective way in reducing cooling loads. It is also observed that the effective energy saving measure for an apartment at top level is to increase the roof surface reflectance, rather than to improve the surface reflectance of walls. For a naturally ventilated apartment at middle level, the better way for energy saving by upgrade the thermal insulation level in enclosure is to increase the surface reflectance, rather than to cut-off the U-value. For an air-conditioned space, a reduced U-value is equally important as a reduced surface absorptivity for achieving lower cooling loads.

Most of the Taiwanese residence is by natural ventilation, it is therefore beneficial to increase the surface reflectance to achieve energy saving. When workability is concerned, paint may be an effective material to increase the surface reflectance for both of the new and existing residential buildings. To better promote energy conservation in residential buildings, high reflectance paint could be the choice.

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亚热带住宅围护结构节能性能要求

由于缺乏自然资源，台湾 97%的能源消耗是靠进口的。由于地处亚热带，空调系统是不可缺少的，并且在一年中几乎要使用半年的空调。为了有效的降低空调系统的使用，需要提高建筑围护结构（屋顶和墙）的隔热水平。根据以前的研究结果，台湾住宅用于建筑围护结构导热和对流的冷负荷大约占整个建筑冷负荷的 37%，这相当于整个建筑电力消耗的 93%。

在台湾，超过 77%的人口居住在城市，而大多数的城市住宅的建筑形式是公寓。自从 1995 年以后，人们对新建筑的需求已经下降，已建建筑和新建筑之间的建筑面积比在 2001 年上升至 85:1。本文研究的目的是确定住宅围护结构节能性能要求。

本文研究建筑围护结构的两个主要的热工性能——U-值和表面反射系数。为了评价围护结构热工性能对节能的影响，本文通过冷负荷模拟对参数变量进行研究。结果表明，对于隔热较差的围护结构，提高其表面反射系数可以显著地降低冷负荷。本文同时发现，比起自然通风的公寓，降低 U-值对带有空调系统的公寓更有效。

The HVAC System Considerations for Green Building in China

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Abstract This paper reviewed the contemporary movement of Green Building and the HVAC system considerations for green building in China. The future development would probably be focus on energy efficiency and its rationale behind. Varies building components and some critical factors to achieve energy efficient building's requirement were analyzed and discussed with reference to the international research, the current situation and needs in China.

Keywords Green building, building energy, energy efficiency, central chilled system.

Introduction

With the civilization and modernization, human life has been improving in comfort, mobility, communication and so on. In China, the residential building has been rapidly developing since the 80's. Fig. 1 shows the average floor area of new-built per year less than 100 million m^2 in 1980 has been increased more than 5 times by 1999. This also comes with a corresponding increase in demand of air-conditioners; and so is the energy consumption in buildings. In the past 10 years, an export energy of 45.82 MTCE has been turned to 47.06 MTCE net energy import.

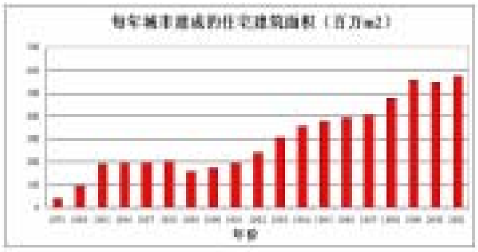


Fig.1 Residential building in cities of Mainland China

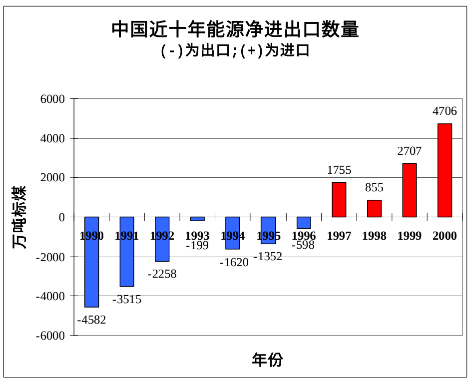


Fig.2 China energy import/export

We all know that clean air and soil, pure water, food reserves, and energy sources are fundamental to life. We also know that our way of life — the buildings we live in, the vehicles we drive, the modern conveniences on which we rely — jeopardizes these finite resources. According to the U.S. statistics, buildings use 1/3 of the total energy, 65.2% of electricity consumption, 30% of greenhouse gas (GHG) emissions, 136 million tons of construction and demolition waste (ie. about 2.8 lb/person/day), 12% of potable water, 40% of raw materials used globally (or 3 billion tons annually), etc. Atmospheric emissions from the use of energy lead to acid rain, ground-level ozone, smog, and global climate change. In 1990, CO_2 emission per person per year is 22 tons in the USA, 2 tons in China and 0.9 tons in India. If nothing is done, China will catch up with the USA by 2020 and India will be 16 tons/person/year. This will require the Earth to absorb 7 times as much carbon dioxide as today! The resulting global warming—one estimate is 2.5°F to 10.4°F (1.4°C to 5.8°C) over the next century—may affect weather patterns, sea levels, agricultural zones, and the quality of life for future generations. The scientists warn that, if the carbon dioxide level were to rise to two times of the pre-industrial level, the global warming will reach 3.6°F (2°C) which is considered to be "dangerous level". Note that it has already bee rise 1°F (0.6°C) in the last 150 years.[1]

"Green Building" Movement

It is only recently that concerns about the environment have taken center stage in the political arena, both internationally and in China. The World Green Building Council (GBC) was officially launched in November 2002 by its 9 founding member countries including Australia, Spain, Brazil, Canada, Japan, Mexico, India, Korea and USA. A so-called "China GBC" is being formed at the moment.

Regardless of the organization, the green building initiative aims at reducing or eliminating negative impact of buildings on environment and occupants. According to Australia GBC[2], buildings consume one third of the world's resources; they use 42% of Australia's energy; 12% of water demand is consumed by buildings; up to 40% of waste going to landfill is from construction and deconstruction activities (predominantly the churn of refurbishments); and 40% of Australia's air emissions are from buildings.

"Green building", "whole building", "sustainable building" or "high-performance building"… no matter how it is called, the fundamental concept attempts to optimize cradle-to-grave performance of the entire building. Economic, environmental, and sociocultral effects receive as much weight as operating costs and initial investment. Performance goals for the building address occupant productivity, comfort, and well being, along with the use of energy, materials and the land. Waste production and transportation need to be considered, as is the adaptability of the building over time. Realizing such ambitious goals requires a very different approach to the building process – one that is collaborative, integrated, and comprehensive rather than fragmented and linear. Professionals from various disciplines as well as the building owner and even end users work together from the pre-design phase. They set the purpose, scope, and performance goals for the building. Subsequent design decisions are based on their effect on the entire building rather than system-by-system or component-by-component. For example, meeting the building goal for energy efficiency requires more than the selection of energy-efficient equipment. It also entails consideration of orientation, envelope, window placement, glazing methods, shading, etc. The results of the whole-building design process are compelling. According to U.S. experience, school districts can save 30 to 40 percent on utility costs each year for new schools and 20 to 30 percent on renovated schools[3]; and green buildings cost about 50 to 60 cents per square foot to operate compared with one to two U.S. dollars for a standard building. The increase in productivity can be out of expectation, which is illustrated by the example of Main Post Office at Reno Nevada, USA.[4]

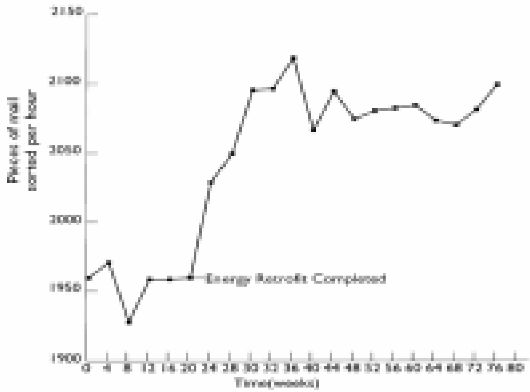


Fig.3 Productivity gain after retrofit, Reno Post Office.

There are many different rating systems available in different countries to define the common metrics for “green building” such as LEED of USA, BREEAM of UK, CASBEE of Japan, GBTool of Canada, Green Star of Australia, LND of Germay, ESCALE of France, Eco-Profile of Norway; and in China Eco-Building rating system was published in 2001 (revised in 2002) for residential buildings. Recently, an “Assessment system for Beijing Olympic Green Buildings” has been published but it is not a statutory document. Although all these rating systems are different in terms of the assessment methodology, priority of environmental issues to be addressed, or local policy and procedures, they share the some common objectives, such as:

- sustainable site planning;
- maximizing energy efficiency or minimizing energy use;
- safeguarding water and water efficiency;
- conservation of materials and resources; and
- protecting both indoor and outdoor environment from pollution or damage.

Recently, a lot of coastal cities and economic zones in China have been suffering from power shortage or brownout. Energy Efficiency is the center of issues today and will be the focus of future development in green building. Chinese government has committed to the Agenda 21 of the UNCED on sustainable development, which included energy efficiency as one of the Priority Programmes. Energy requirements are continuously growing as the economy expands rapidly and the population increases. The per capita sources of energy are limited and energy shortages are increasingly common; therefore, China’s future economic development will inevitably shift from its previous inefficiencies towards efficiency, and focus on energy conservation.[5]

Building energy control may include the following major systems or components:

- building envelope
- air-conditioning and heating equipment
- ventilation and exhaust systems
- systems and building automation
- service hot water supply
- vertical transportation (for high-rise buildings)
- lighting

A comprehensive energy code or standard (e.g. ANSI/ASHRAE/IESNA Standard 90.1) is required to define the minimum performance levels that can be met by the majority or 75 percent of the buildings in the market. However, green buildings must achieve increasing levels of energy performance beyond the minimum requirements, which typically accounts for the top 25 percent in the market. In order to reach the top 25 percent, designers ought to look for innovative alternatives among the building components. For residential building, "Energy Labeling" is one of the effective measures to control energy use of home appliance and it is being adopted in many countries including China. It is a market driven approach to promote energy conservation because products with better energy label (or higher efficiency) will cost less to operate in the future. End-user education will be an important factor to determine its successfulness. For commercial buildings or public buildings, the energy consumption of the HVAC systems accounts for 60 to 70 percent of the total building energy use[6] and majority of them are using central plant. The energy efficient of "big" equipment such as chiller and/or boiler becomes the focus of innovative solution. For chillers, the available technology to improve the efficiency may include selection of the right refrigerant for the right applications, full-load and part-load performance, multi-chiller plant control, etc.

Right Refrigerant for Right Applications

In compliance to Montreal Protocol, CFC refrigerants are being phased out in China. According to U.S. EPA, the most commonly used alternative refrigerants for large building air conditioning applications—HFC-134a and HCFC-123—are allowed, approved, or endorsed for use by Environment Australia; Environment Canada; the Japan Ministry of Economy, Trade and Industry; the Japan Ministry of the Environment; the U.S. Environmental Protection Agency; and most other environment ministries worldwide.[7] In China, the technical requirement of a qualified substitute to an Ozone Depleting Substance (ODS) is that the Ozone Depletion Potential (ODP) cannot be higher than 0.11.[8] HCFC-123 has an ODP value of 0.02 and HFC-134a is zero; therefore, both of them are qualified. However, zero ODP does not necessarily mean NOT depleting the ozone layer. Stratospheric cooling caused by the GHG's has the perverse effect of accelerating the natural depletion of ozone layer, according to William Randel,[9] an atmospheric scientist and a lead author of the United Nations Environment Program's "Scientific Assessment of Ozone Depletion: 2002".[10] Internationally, particularly in Europe, the Global Warming Potential (GWP) is equally or even more important when assessing the environmental impact. Table 1 shows that HFC-134a has significantly higher GWP value than HCFC-123. This implies that the technology to contain the refrigerant within the chiller without leakage is very important. In other words, low-pressure (e.g. R-11, R-123) machine is relatively preferred to high-pressure

Table 1: Refrigerant Environmental Properties

REFRIGERANT	Montreal Protocol ODP	Atmospheric Life, years	100-Year GWP
CFC-11	1.0 (index)	45.0	4680
CFC-12	1.0	100.0	10,720
HCFC-22	0.034	12.0	1780
HCFC-123	0.012	1.3	76
HFC-134a	0	14.0	1320
R-407C (HFC blend)	0	4.9~29.0	1674
R-410A (HFC blend)	0	4.9~29.0	1997

Source: Montreal Protocol Scientific Assessment of Ozone Depletion 2002 (e.g. R-22, R-410A) machine; and hermetic-drive compressor is better than open-drive compressor. The best available chiller today can achieve a "near zero" refrigerant emission, less than 0.5% charge per year. Again, absolute zero emission or even zero GWP does not necessarily mean NOT global warming. An inefficient refrigerant or equipment consumes more energy to operate, which causes the power plant to generate more and therefore more carbon dioxide is released to the atmosphere as a result. This indirect global warming effort has been taken into account by the Total Equivalent Warming Impact (TEWI) which makes use of GWP for refrigerants relative to CO_2 published by the Intergovernmental Panel on Climate Change (IPCC) and is calculated by:

$$\text{TEWI} = \text{GWP} \times L \times N + \text{GWP} \times m \times (1 - \alpha_{\text{rec}}) + N \times E_{\text{ann}} \times \beta$$

where $\boldsymbol{m}$ is the mass of refrigerant in the equipment, kg; $\boldsymbol{\alpha}_{\text{rec}}$ is the fraction of refrigerant charge recovered; $\boldsymbol{L}$ is the annual loss or consumption of refrigerant, kg/year; $\boldsymbol{N}$ is equipment lifetime, years; $\boldsymbol{E}_{\text{ann}}$ is the annual energy use, kWh/year; and $\boldsymbol{\beta}$ is the CO_2 emissions corresponding to every kWh of energy produced, $kgCO_2$/kWh. Fig.4 shows an example in the USA.[11] Obviously, the indirect warming effect outweighed the direct warming effort. For a typical 350-ton chiller over 10-year operation, 100% reduction of the direct effect (i.e. zero emission) means 2 percent improvement in TEWI while 10% increase in COP (coefficient of performance) value can bring along 7 percent better TEWI.

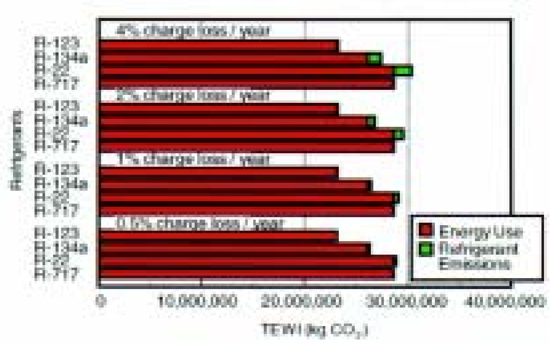


Fig.4 TEWI for chillers in Atlanta

Today, HCFC-123 chiller technology can achieve the highest energy efficiency with the lowest emission and the refrigerant itself has the shortest atmospheric life as showed in Table 1. The 2002 RTOC assessment report prepared under the auspices of the United Nations Environmental Program (UNEP) stated that "HCFC-123 has favorable overall impact on the environment that is attributable to five factors: (1) a low ODP, (2) a very low GWP, (3) a very short atmospheric lifetime, (4) the extremely low emissions of current designs for HCFC-123 chillers, and (5) the highest efficiency of all current options." This international assessment cites studies showing that "continued use of HCFC-123 in chillers would have imperceptible impact on stratospheric ozone while offering significant advantages in efficiency, thereby lowering greenhouse gas emissions from associated energy use."[12]

The next best technology is HFC-134a but the opportunity cost is 5 to 20 percent lower efficiency that could be translated to environmental cost of the annual power plant emission:

· nearly 9,550 billion grams of CO_2

· over 80 billion grams of SO_2

· over 34 billion grams of NO_x

which is equivalent to:

· removing over 2.5 million cars from the road

· planting nearly 600 million trees each year

Full-load and Part-load Performance

The full-load performance of air-conditioning equipment is commonly measured by COP, EER (energy efficiency ratio) or kW per ton. Obviously, most of the equipment is running at full-load during peak demand of electricity. Raising the standard of full-load efficiency reduces the demand for electricity; otherwise, the government ought to pay even higher price for more power plants that may become an obstacle to industry and economic development. In the U.S. for example, this is a mandatory requirement in the energy standard.[13] Table 2 showed the minimum requirement of the current version as compared to an older one.

Table 2: Comparison of Equipment Efficiency Requirements in USA[11]

	Minimum Efficiency[a]		
	Per 90.1-1989	After 29/10/2001	Test Procedure
Rooftop air-conditioner, 15 tons	8.5 EER[b]	9.7 EER[b]	ARI 340/360[c]
Water-source heat pump, 4 tons	9.3 EER (85°F EWT)	Cooling: 12.0 EER (86°F EWT) Heating: 4.6 COP (68°F EWT)	ARI 320[d] (ARI/ISO-13256-1 after 29/10/2001)
Water-cooled screw chiller, 125 tons	3.80 COP	4.45 COP	ARI 550/590[e]
Water-cooled centrifugal chiller, 350 tons	5.20 COP	6.10 COP	ARI 550/590[e]

[a] Coefficient of performance (COP), energy efficiency ratio (EER), entering water temperature (EWT), integrated part-load value (IPLV)

[b] Deduct 0.2 from the required EER if the rooftop air conditioner includes a heating section other than electric resistance heat.

[c] ARI 340/360, *Commercial and Industrial Unitary Air-Conditioning and Heat Pump Equipment*

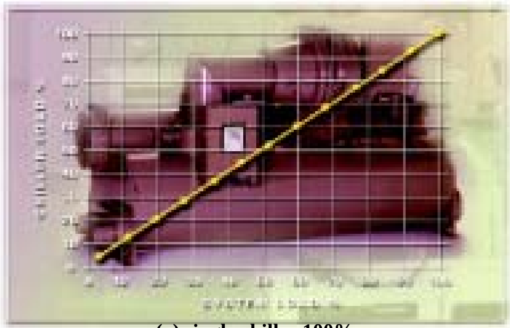
[d] ARI 320, *Water-Source Heat Pumps*

[e] ARI 550/590, *Water Chilling Packages Using the Vapor Compression Cycle*.

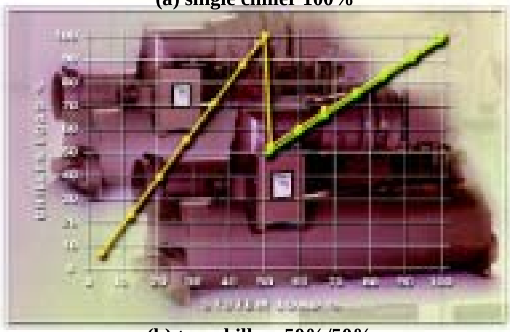
The part-load performance is commonly described by SEER (seasonal energy efficiency ratio) for smaller or unitary equipment while the IPLV (integrated part-load value at standard ARI conditions) and NPLV (non-standard part-load value) are used for larger equipment or chillers by the HVAC industry internationally including China. Unfortunately, many engineers misinterpret this single figure performance indicator or misuse it for calculating annual energy consumption. Note that the number represents the average performance of one single piece of equipment, not a system. For IPLV of a chiller, it is calculated by this formula: [14]

$$0.01A + 0.42B + 0.45C + 0.12D$$

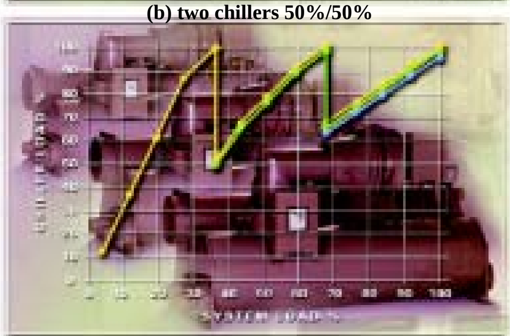
where A, B, C, D are the energy efficiency at the corresponding chiller loading of 100% at 85ºF (29.4ºC) condenser water temperature, 75% at 75ºF (23.9ºC), 50% at 65ºF (18.3ºC) , 25% at 65ºF (18.3ºC) respectively; and the coefficients are weighting factors of the corresponding part-load operation. Particularly pointed out by the Air-conditioning and Refrigeration Institute (ARI), the equation was derived for a single chiller installation and was based on an average part-load operation; therefore, it cannot represent a particular job.[15] In most cases, a high value of IPLV does not imply more energy savings because 80 percent of the chillers (in USA) are installed in multi-chiller plants. Fig.5 showed the chiller load profile of typical multi-chiller plants. It can be seen how the loading of the chillers is affected by the number of chillers in the plant. The individual chiller load profile bears little resemblance to the system load profile. The more chillers there are in a plant, the more operation is near full-load; and chiller unloading or condenser water temperatures will be very different from the ARI standard conditions based on an average single chiller plant. Besides, the IPLV rating is a function of the entering condenser-water temperature (ECWT) relief schedule based on the interpretation of cataloged cooling-tower performance at part load given the average weather data of 29 cities (in USA). However, neither IPLV nor NPLV takes into account different locations that may have very different condenser water temperatures. Once installed, the chilled water plant's energy consumption is determined by the tradeoff between chiller, tower and pump power. At many part-load conditions, the coldest water temperature possible does not result in optimal system operation.[16] Load, ambient conditions and the part-load operating characteristics of the chiller and tower will ultimately determine the optimum ECWT for a given installation. Some chiller manufacturers are able to offer advanced controls such that the chiller and tower operation may be optimized in accordance with the outdoor ambient conditions.[17]



(a) single chiller 100%



(b) two chillers 50%/50%



(c) 3 chillers 33%/33%/33%

Fig.5: Chiller load profile of a typical multi-chiller plant

Therefore, the IPLV is not a good yardstick for evaluating energy performance, and could be misleading if it is being specified in energy standard. Because of the minimal weighting (0.01) of full-load, some chillers with good IPLV have very poor full-load efficiency. For instance, some of these chillers using variable speed devices may degrade the full-load performance indeed (see Table 3 for typical example).

To successfully optimize the performance of a multi-chiller plant and deliver the greatest possible energy cost savings, the designer must account for these facts:

· Variables other than the dry bulb temperature of outdoor air – for example humidity, solar loads and operation schedules – greatly affect cooling loads in commercial and industrial applications.

· System loads and individual chiller loads in multi-chiller plants are distinctly different.

· Changing loads affect cooling-tower operation and entering-condenser water temperatures.

ARI encourages the use of comprehensive analysis tools that reflects the actual weather data, building load profile, number of chillers in use, operational hours, and energy drawn by auxiliaries such as pumps and cooling towers, when calculating the overall chiller plant system efficiency.

Table 3: Typical example of chiller with low NPLV but more energy-consuming

Operating Data				Chiller A (with VSD)[b]			Chiller B (standard starter)		
				NPLV= 0.436			NPLV= 0.448		
Tons	NPLV Weighting[a]	Hours	Ton-Hours	kW/ton	kW	kWh	kW/ton	kW	kWh
500	0.01	30	15000	0.682	341	10,230	0.514	257	7,710
375	0.42	1260	472500	0.52	195	245,700	0.448	168	211,680
250	0.45	1350	337500	0.38	95	128,250	0.428	107	144,450
125	0.12	360	45000	0.416	52	18,720	0.536	67	24,120
Total Hours: 3,000				Total kWh: 402,900			Total kWh: 387,960		

[a] ARI 550/590–1998, *Water Chilling Packages Using the Vapor Compression Cycle*.
[b] VSD = variable speed drive

Energy saving options

Can primary circuit of chilled water system be variable-flow? If you ask this question ten years ago, the answer is most likely "NO". Today, it is not difficult to find successful installation examples with lower first costs and better energy efficiency. A recent research done by ARI confirmed that variable flow, primary-only systems reduced total annual plant energy by 3 to 8-percent, first cost by 4 to 8-percent, and life cycle cost by 3 to 5-percent relative to conventional constant primary flow with variable secondary flow systems. [18] It may cure "low delta-T syndrome" as well.[19]

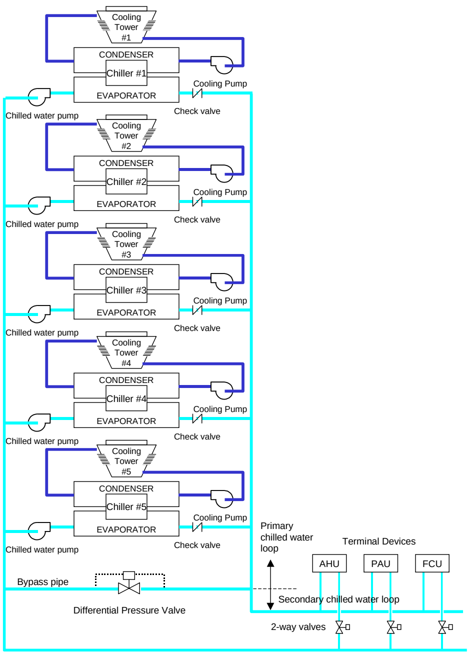


Fig.6 Typical chiller plant schematic diagram

Fig.6 shows a typical "decoupled" chilled water system that consists of a primary circuit (or chilled water production loop), a secondary circuit (or distribution loop) and a decoupler (bypass line). Conventionally, it is advised to maintain a constant flow through the chiller evaporator – that is the primary circuit. The overriding concern has been the risk of nuisance shutdowns or even freezing and rupturing of the chiller evaporator due to water flow reducing faster than the chiller safeties could respond. With the advancement of microelectronic control technology, strategically placed sensors and real-time response allow the modern chillers to perform its primary function of producing cold water even when evaporator water flow varies. The range of many chillers today is 3–12 fps (0.9 – 3.6 m/s)[20] but some of them can accommodate as low as 1.5 fps (0.4 m/s).[21] However, the rate of change of water flow is critical. Table 4 gives example of the allowable flow-rate change for different types of chiller; and Fig.7 shows how a chiller control responds to flow-rate reduction.

Table 4: Variable-flow Tolerance of Chillers

Chiller type	Controller type	Allowable flow change rate (% of design flow per min.)
Absorption	1st Generation	Not recommended
	2nd Generation	30% for comfort cooling 10% for process cooling
Scroll	All	10%
Screw	1st Generation	Not recommended
	2nd Generation and after	30% for comfort cooling 10% process cooling
Centrifugal	1st Generation	Not recommended
	2nd Generation	30% for comfort cooling 10% for process cooling
	Advanced with flow compensation	See Fig.2

Source: Trane Engineers Newsletter Vol.31 No.4, 2002.

Now that the primary circuit can vary water flow, the secondary pumps may be eliminated but the bypass line still remains in order to assure that the rate of chilled water flow through each operating chiller never falls below the allowable limit required by the manufacturer. Here is a list of best practice as the key to success:

- chiller optimization for a minimum evaporator flow limit that is less than 60 percent of the chiller's design flow;
- chilled water pump sizing to accommodate the pressure drop of the system as well the chiller evaporator;
- selection of isolating/check valves with linear relationship between valve position and flow rate;
- series arrangement for 2-chiller system to avoid flow transition;[22]
- air handling units or other

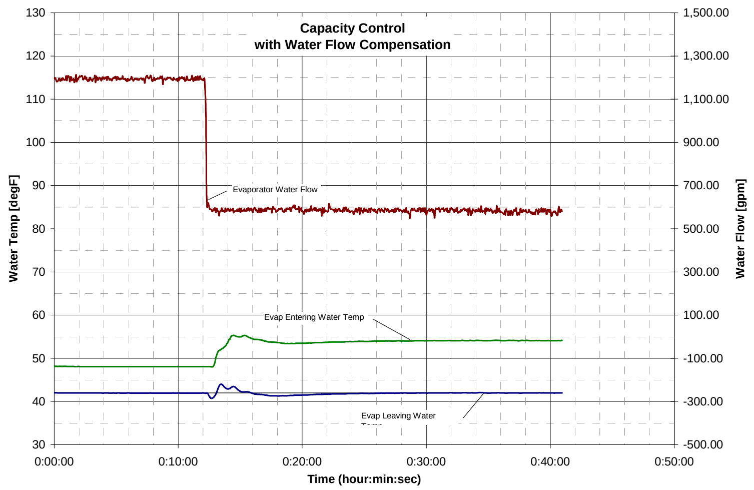


Fig.7 Example of Chiller Controls in response to Flow-rate Reduction

airside terminal devices grouping such that shutdown schedules shall be implemented at 10-minute intervals.

Conclusions

Although green building is a very broad topic and it covers many different disciplines, the future development in China is likely to focus on energy efficiency. A well-constructed building energy standard will be inevitable, especially for public or non-residential buildings. Since the green building is targeting the top 25 percent of the buildings in the market, it is necessary for the designers to search for innovative solutions. For commercial buildings, HVAC system takes 60 to 70 percent of overall building energy consumption and majority of them are using central plant. Chiller technology associated with the selection of right refrigerant is critical to improvement of the building energy efficiency. HCFC-123 chiller technology provides the highest efficiency with the lowest annual emission rate. The refrigerant itself has the shortest atmospheric life, very low GWP, very low ODP and is a qualified alternative refrigerant. As mandatory requirement in building energy standard, equipment full-load performance is considered to be far more important than part-load performance. In particular, the IPLV shall be used carefully. It is an indication of the average par-load performance of a single chiller installation and should not be used for evaluating the energy performance of multi-chiller plants. Instead, ARI encourages the use of comprehensive analysis tools that reflects the actual weather data, building load profile, number of chillers in use, operational hours, and energy drawn by auxiliaries such as pumps and cooling towers, when calculating the overall chiller plant system efficiency. As a powerful energy-saving option, modern chillers allow variable chilled water flow. Recent research showed a savings of total annual plant energy by 3 to 8-percent, first cost by 4 to 8-percent, and life cycle cost by 3 to 5-percent as compared to conventional chilled water system.

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中国绿色建筑中HVAC系统需要考虑的事项

摘 要 本文阐述了当代绿色建筑的发展趋势和中国绿色建筑中 HVAC 系统需要考虑的事项。将来发展趋势可能更关注能效以及其隐含的原理。为实现建筑能效要求，本文分析了不同建筑部分和关键因素对于能效的影响。并且讨论了中国在节能方面可能涉及的情况

Measures towards Sustainable Energy Use in the Residential Sector of Warthe District, Brasov City, Romania

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Abstract In the context of world population explosion and world climate change, the concept of urban sustainable development tends to become a priority nowadays. One way of achieving sustainable development is to reduce energy consumption in the residential sector. When energy is saved, it is possible to fight against other two big environmental problems: the exhaustion of fossil fuels and the emission of harmful combustion gasses. In aiming to reduce the consumption of energy, the European Commission recommends the use of Trias Energetica Strategy in dwellings and urban design. It consists of 3 steps: initially reduce the energy demand, then utilize renewable energy resources and lastly use in an efficient way the energy sources. The three-step strategy for energy saving involves not only the building and urban design, but also spatial planning. Trias Energetica was chosen as central conceptual model and used for developing the conceptual design of this research project.

After it was set free in 1989, Romania has been facing a transitional period and now is trying to reach the requirements in order to join E.U. by 2007. Brasov City is one of the most important attraction points of the country, for both its historical value and tourism opportunities. Therefore it could be an optimal location for the implementation of pilot projects on both energy efficiency and renewable energy use in dwellings. It is a place where a lot of attention is paid to and important investors are interested in. Warthe District represents one of the most beautiful locations within the city boundaries. This paper shows that Warthe District confronts with low energy efficiency and high energy consumption in the residential sector. The objective of the research consists in making recommendations for sustainable energy use of Warthe District's residential sector, by identifying what are the appropriate technical solutions and, where possible, by estimating the energetic gains these measures would bring.

As a result of the case studies and analysis, it will become clear that measures to increase the performance of the building envelope should be applied to both existing and future buildings. Moreover, due to the orientation and topography of the area, the sun, as a renewable energy source, is exploitable at large scale within Warthe District. The last but not the least, by applying measures towards efficient energy use, the energy consumption in the residential sector will decrease. The conclusion of this research shows that Warthe District has, from a technical point of view, the potential to achieve sustainable use of energy in the residential sector. It is expected that the technical measures should be combined with the social, economical and political context in Romania to achieve an optimal sustainable development strategy. This would bring not only socio-economic benefits to the residents, but also considerable environmental benefits.

Outline of the Research Report

Chapter 1 contains a description of the project context, the research objective and the research issue of the research project and a broad outline of the research report. Within this chapter a short introduction of the research topic is given. Then, the research issue is presented with its subchapters: the research tree diagram, the research framework, the central questions and sub-questions.

Chapter 2, the chosen theories and concepts will be elaborated and it will be shown how they have contributed to the specification of the research perspective. Also a method for the determination of the yearly energy need for residential building heating, based on the G values (the Coefficient of Global Thermal Insulation) will be presented. This method will be used for the estimation of possible passive solar gains of the houses to be built.

Chapter 3 provides a justification of the methods used, as becomes clear from the technical research design. It refers specifically to the choice of data sources, the way in which they were accessed and the choice of the research strategy.

Chapter 4 comprises an introduction of current situation in Romania, related with the thesis topic, and a brief presentation of the Romanian National Policies and the legislation related with energy consumption, energy efficiency and renewable energy use. This will be followed by an outline of the old Romanian dwelling typologies. The second part of Chapter 4 represents an introduction of the current situation of Brasov City. Then, after a short introduction of Warthe District, some of the sub-questions will be discussed in detail in separate sections: the climatic characteristics, the energy supply infrastructure and the relevant stipulations of Warthe District's Urban Plan.

Chapter 5 presents the results of the research project in a methodical way, by analyzing the case studies. Moreover, for the assessment of the thermal performance of the existing dwelling stock, 3 houses have been chosen, inspected and analysed in details. Then, the exploitability of renewable energies and the savings their use would bring has been evaluated for a Virtual House, built in accordance with the stipulations of the Urban Plan.

The second section of Chapter 5 provides the answers to the central research question by analysing, presenting applicable measures, towards sustainable energy use, for Warthe District.

In Chapter 6 finally the conclusions based on the research project are formulated. Then it is continued with the general recommendations related to the research context. In addition, a short reflection on how the Romanian social, economical and political context interacts with the theoretical context is provided.

城市环境管理项目

（2002.7-2004.4）

罗马尼亚 Brasov 市 Warthe 地区住宅内的可持续能源利用措施

摘　要　随着世界人口爆炸和全球气候变化，城市可持续发展概念目前变的越来越重要。实现可持续发展的一个途径是降低住宅建筑的能耗。能耗节省了， 就有可能去解决其他两个大的环境问题：石油燃料的消耗和有害的可燃气体的释放。为了降低能耗，欧盟推荐对住宅和城市设计采用三层节能策略，此策略分三个步骤：首先减少能量需求，接着采用再生能源，最后是高效地使用能源。对于节能的三步骤策略不仅针对建筑和城市设计，也包括空间规划。选择三层节能策略作为核心概念模型应用于发展研究项目的概念设计。

1989 年政治变革以后，罗马尼亚正经历一个过渡期，努力在 2007 年以前达到满足加入欧盟的要求。Brasov 市由于它的历史价值和旅游机遇，成为该国最重要的城市。所以，该市可以成为实施住宅内建筑节能和再生能源利用展示项目的最佳地点。这是个受到众多关注的地方，许多重要投资商对它也非常感兴趣。Warthe 地区是改市范围内最美丽的地方之一。本文认为，Warthe 地区面临住宅内低能效，高能耗的现状。本项目研究的目的在于给出 Warthe 地区住宅可持续能源利用的建议；确定合适的技术解决方案；评估实施这些措施节省的能量。

作为案例研究分析的结果，我们清楚的看到提高建筑围护结构性能的措施应该应用于现有建筑和未建建筑。另外，由于该地区的朝向和地形，太阳能作为可再生能源可以在 Warthe 地区大量的开发。通过对有效利用能源措施的实施，可以降低住宅能耗。研究结论表明，从技术观点看，Warthe 地区在住宅内可持续使用能源是很有潜力的。本文希望技术措施可以结合罗马尼亚的社会、经济、政治的情况，实现最佳的可持续发展策略。这一策略将不仅给居民带来社会经济上的益处，同时也带来相当大的环境益处

居室热舒适及其空调参数的节能控制

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摘　要 分析影响居室环境热舒适的主要因素，主要说明有效温度 ET、热舒适指数 TCI 和预测平均投票 PMV-PPD 指标的计算；同时应用计算机技术编程计算其指标的值，给出 PMV-PPD 的计算结果。在认为保证热舒适的前提下，合理确定夏季居室热环境标准、控制空调参数，以达到节能的目的。

关键词　热舒适；评价指标；空气调节；温度；节能

Indoor Thermal Comfort and Air-condition Parameter Control for Energy Efficiency of Residence

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Abstract　Analyses the main influence factors of indoor thermal comfort, and evaluates indoor thermal comfort with effective temperature ET, thermal comfort index TCI and forecasting average ballot PMV-PPD, etc. Takes calculating result in the PMV-PPD index with the computer programmer. Gives out the indoor thermal environment standard in summer, and holds that the indoor design conditions optimized contribute much to energy conservation on conditioning, that a satisfying thermal comfort is guaranteed.

Keywords　thermal comfort; evaluating index; air condition; temperature; energy saving

人体热舒适在 ASHRAE 标准中，定义为人对热环境表示满意的意识状态，实质上反映了人体的主观感受对客观环境的要求。它通过研究人体对热环境的主观热反应，得到人体热舒适的环境参数组合的最佳范围和允许范围以及实现这一条件的控制、调节方法；根据人的热感觉评价新的建筑和建筑设计方案，查明室内气候调节的最佳状况，为空调设计提供依据。

1　影响室内热舒适的主要因素

室内热舒适性主要取决于人体的新陈代谢率、衣着情况等个人因素（主观因素）以及空气干球温度、室内平均辐射温度、空气流动速度、空气湿度等多个室内物理参数（即客观因素）。

1.1　主观因素

（1）个人的新陈代谢率　人体进行一定的活动就会在体内产生热量，因此人体的能量代谢率直接影响人体与周围环境的热交换。人体的能量代谢率受到多种因素的影响，如肌肉活动强度、环境温度高低、进食后时间长短、神经紧张程度、性别和年龄等。饮食的不同，在体内产生的热量也不同，同时代谢率也不同。

（2）衣着情况　在皮肤和人体最外层衣服表面之间的热传递是很复杂的，它包括介于空间内部的对流和辐射过程，以及通过衣服本身的热传递，因此衣服热阻也是影响人体舒适性的重要因素[1]。

主观因素对室内环境的热舒适感产生影响除以上两个重要因素之外，还与各地区的社会文化的差异有关，如：饮食习惯、休息习惯等文化因素与社会因素。

1.2　客观因素

（1）空气温度　指室内环境的干球温度，是影响热舒适的主要因素。它直接影响人体通过对流及辐射的热交换。在水蒸气分压力不变的情况下，空气温度升高使人体皮肤温度升高，排汗量增加，人的主观感觉向着热的方向发展[2]。空气温度下降，则人体皮下微血管收缩，皮肤温度降低。在相同温度下，因为年龄、性别、健康状况等的个体差异,是否感到舒适因人而异。我国《采暖通风与空气调节设计规范》（以下简称规范）规定：夏季室内温度为 24～28℃。

（2）相对湿度　空气湿度的大小不仅会影响人体皮肤表面的水分蒸发，还会影响人体的排汗过程，因此相对湿度直接或间接地影响人体舒适，过高或过低都会引起人体的不良反应。对于人体冷热感来说，通常相对湿度的升高意味着人体热感觉增加。规范规定室内相对湿度应为 40%～80%。

（3）平均辐射温度　环境热辐射是由可能进人室内的太阳辐射及人体与周围环境界面之间的辐射热交换组成，界面温度高于体表面温度时，人体经辐射热交换而得热，反之失热。在炎热的地区，夏季室内过热的原因除了夏季高温以外，还有外围护结构内表面的热辐射、特别是由窗口进入的太阳辐射造成的。

（4）室内空气流速　在夏季，气流能明显地影响人体的对流和蒸发散热。气温低于皮肤表面温度时，增大流速，加强散热效果，使人体凉爽；流速增加 lm/s，会使人感到气温降低 2℃~3℃。当风速小于 0.254m/s 时，人感觉不到风速；当风速为 0.254～0.5m/s 时，人感觉愉快；当风速为 0.508m/s～1.016m/s 时，人有风感，可以接受；当风速为 1.016～1.524m/s 时，人有较强的吹风感，不舒适。规范规定室内空气流速夏季不大于 0.3m/s。

除以上影响因素外，还有色彩、照度等都会使人对居室环境产生不同的热感觉。环境的热舒适是由多方面因素综合作用的结果。随着对热舒适问题认识的加深，人们将会不断总结出更加合理的热舒适评价指标。以下主要说明有效温度ET、热舒适指数TCI和预测平均投票PMV-PPD指标的计算。

2　室内热舒适评价指标

2.1　有效温度 ET

有效温度(effection temperature)是一个提出很早而且广泛流行的热舒适指数，认为人体皮肤表面对空气的感觉温度是干球温度、湿球温度和风速的复杂函数，由此得出的气候生理指数称为有效温度。即

$$T_{ef}= f（T_a，T_s，u） \qquad (1)$$

Huschkc(1959)将其定义为：在研究的实际大气条件下，与在室内静止(平均风速 u≤0.2m/s)、饱和空气条件有同样舒适效应的温度。有效温度试图综合温度、湿度和风速在人体舒适上的效应。它的计算完全是以人体对环境的直接热感应的实验为基础，通常根据实验做出因各地气候特点而异的有效温度线算图，再由线算图计算任意温度、湿度和风速条件下的 T_{ef}。

由于 ET 没有考虑辐射因素，Vornon(1930)曾建议将干球温度表代之以单纯的黑色铜球水银温度表，用这种温度的观测值代替干球温度，就得到改进有效温度(corrected effection temperature)。

以后，Ehis 等人(1972)也研究了改进有效温度的问题，并认为在低风速(u<0.15m/s)情况下，正常的有效温度可近似由下式表示:

$$T_{ef}=(1.21T_a-0.21T_s)/[1+0.029(T_a-T_s)] \quad (2)$$

有效温度在对测量皮肤温度、直肠温度、出汗率和脉率与气候环境的关系方面表现出明显的生理价值，使许多气候生理问题得到合理解释，因而长期以来被医学、工程、建筑业和环境卫生学方面广泛利用。

2.2　热舒适指数 TCI

环境无热负荷（综合热负荷为 0）属于人体热反应的中性区，即冷热适度；人体在此环境条件下仅依靠皮下血管收缩与舒张的调节作用即可维持热平衡，并使体温维持正常、恒定。人体热反应中性区内环境热舒适的 4 个物理量组合一般是：t_a =22～32℃；ф =30%～65%；u=0.2～0.5m/s；$T_r=t_a$。

以上 4 个热物理因素综合形成的热舒适指数 TCI，可用以下回归方程式计算：

$$TCI=11.16 - 0.0556t_a - 0.0538\,T_r - 0.0372P_a + 0.0144[u\,(100 - t_a)]^{1/2} \quad (3)$$

式中 t——室内空气温度(℉)；

T_r——室内界面的平均辐射温度(℉)；

P_a—— 空气中的水蒸气分压力(mmHg)；

u——气流速度(ft/min)。

热舒适指数 TCI 与人体热反应之间的关系如表 1 所示：

表 1　人的热反应等级

热感觉	寒冷	冷	稍冷	舒适	稍热	热	酷热
TCI	7	6	5	4	3	2	1

也有用表 2 所列回归方程计算当壁温=气温、气流速度≤0.14m/s、男女混处、轻微工作时的热舒适指数 TCI 的评价方法。TCI=1 时，寒冷；TCI=4 时，舒适；TCI=7 时，酷热。

表 2　TCI 的回归方程

在室内连续停留时间	TCI 的回归方程
1h	TCI=0.0245t+0.033Pa-2.471
2h	TCI=0. 252t+0.032Pa-2.862
3h	TCI=0. 243t+0.037Pa-2.803

注：Pa 为空气中水蒸汽分压力，(*mmHg*)。

2.3　PMV-PPD 评介指标 [3]

关于热环境的舒适条件，丹麦学者 P.O.Fanger 教授进行了大量研究，提出了 PMV-PPD 指标体系， ISO 7730 标准以 PMV-PPD 指标来描述和评价热环境。该指标综合考虑了人体活动程度、衣服热阻(衣着情况)、空气温度、平均辐射温度、空气流动速度和空气湿度等六个因素，以满足人体热平衡方程为条件，通过主观感觉试验，确定出绝大多数人的冷暖感觉等级。PMV 的分度如表 3 所示。PMV 指标(预期平均评价)代表了对同一环境绝大多数人的冷热感觉，因此可用 PMV 指标预测热环境下人体的热反应。对于即使大多数人表示满意的热环境，由于人们之间的个体差异，仍会

有人不满意；PPD 指标(预期不满意百分率)表示了人们对热环境不满意的百分率。

表 3　PMV 分度与热感觉

热感觉	热	暖	微暖	适中	微凉	凉	冷
PMV	＋3	＋2	＋1	0	－1	－2	－3

(1)PPD 的计算

$PPD = 100 – 95\exp(-0.3353PMV^4 + 0.2179PMV^2)$ (%)　（4）

PPD 值应当小于 10%。

(2) PMV 的计算

$PMV = [0.303\exp(-0.036M) + 0.028]L$　（5）

$L = M-W-\{3.96\times10^{-8}f_{cl}[(T_{cl}+273)^4-(T_r + 273)^4]+f_{cl}h_c(T_d -T_a)+3.05\times10^{-3}[5733-6.99(M-W)-P_a]$

$+0 .42(M-W-58.15)+1.7\times10^{-5}\times M(5867-P_a)+0.0014M(34-T_a)\}$　（6）

式中 M 为人体新陈代谢率（W/m^2），W 为人体所作的机械功(W/m^2)，f_{cl} 为穿衣面积系数，T_a 为人体周围温度（℃），T_{cl} 为衣服外表面温度（℃），T_r 为平均辐射温度（℃），h_c 为衣服与空气之间的对流换热系数(W/m^2・℃)，P_a 为人体周围空气的水蒸气分压力（Pa）。

$W= \eta M$　（7）

f_{cl}、T_{cl}、h_c 由以下方程决定：

当 $I_{cl}>0.078$,　$f_{cl} =1.05 + 0.645I_{cl}$　（8）

当 $I_{cl}<0.078$,　$f_{cl} =1.00 + 1.290I_{cl}$　（9）

$T_{cl} = 35.7-0.028(M-W)-I_{cl}\{3.96\times10^{-8} f_{cl}\times[(T_{cl}+273)^4-(T_r +273)^4]+ f_{cl}h_c(T_{cl} -T_a)\}$　(10)

当 $2.38(T_{cl} –T_a)^{0.25}\geqslant12.1u^{0.5}$,

$h_c= 2.380(T_{cl} –T_a)^{0.25}$　(11)

当 $2.38(T_{cl} –T_a)^{0.25}\leqslant12.1u^{0.5}$,

$h_c =12.1u^{0.5}$　(12)

式中 I_{cl} 为衣眼热阻（m^2・℃/W），u 为空气流速（m/s）。

PMV 的值应当在-0.5～+0.5 之间。以上公式中 M, T_a，T_r，u，η，P_a，I_{cl} 七个参数为已知参数，通过计算机编程计算出 PMV-PPD 值。在空调系统的设计中 M，η，I_{cl} 作为固定量，因此要得到相同的 PMV-PPD 值，可以通过组合 T_a，T_r，u，P_a 四个参数来达到。

3　PMV-PPD 模型的应用分析

以下利用 PMV-PPD 模型进行两项讨论：

1） 优化室内设计参数，确定合理的室内参数组合。

2） 在满足室内热舒适的情况下，通过改变室内参数组合，进行空调节能探讨。

假设人在室内坐着休息，其相应的已知条件为：$M=58W/m^2$，$I_{cl}=0.08\ m^2$・℃/W，u =0.2 m/s，$T_a = T_r$，采用计算机编程计算，将 PMV-PPD 的值列于表 4。

表 4 不同温、湿度下的 PMV 和 PPD 值

室内温度（℃）	指标	相对湿度（%）					
		40	45	50	55	60	65
24	PMV	-0.791	-0.752	-0.713	0.673	-0.634	-0.594
	PPD	18.204	16.909	15.618	14.52	13.426	12.4
25	PMV	-0.414	-0.372	-0.332	-0.288	-0.246	-0.197
	PPD	8.571	7.881	7.266	6.726	6.259	5.807
26	PMV	-0.037	0.008	0.052	0.097	0.141	0.186
	PPD	5.028	5.001	5.056	5.193	5.412	5.714
27	PMV	0.339	0.386	0.433	0.481	0.528	0.575
	PPD	7.391	8.106	8.917	9.823	10.824	11.922
28	PMV	0.715	0.765	0.815	0.865	0.915	0.965
	PPD	15.76	17.333	19.021	20.82	22.685	24.674

ISO 7730 对 PMV-PPD 指标的推荐值为：PPD＜10%，PMV 值在-0.5~+0.5 之间。根据该推荐值，从表中可以看出，人在室内静坐时室内温湿度设计参数为：

室内温度：25~27℃；

相对湿度：当室内温度为 27℃时，取 40~60%。

同时可知，为满足热舒适要求而进行空调参数组合时，存在很大取值空间。例如，温度为 25℃，相对湿度 65%时，PMV 值为-0.197，其平均不满意百分数为 5.807%；温度 27℃，相对湿度为 55%时，PMV 值为 0.481，其平均不满意百分数为 9.823%，都同样能够满足人们对室内热环境的要求。从节能角度考虑，应当取较高的温度值；设计温度提高 1℃，对于一座大城市而言，将节约大量电能。

风速对 PMV- PPD 有较大影响。假设室内空气温度平均值为 30℃，空气相对湿度 50％，平均辐射温度 32℃左右，人在房间着短夏装（0.25clo），静坐或短暂的家务劳动(备餐、洗碗等)，将不同风速时的 PMV-PPD 计算结果列于表 5：

表 5　不同风速时 PMV- PPD 数值表

		u=0.1m/s, T_r=31.24℃	u=0.3m/s， T_r=31.64℃	u=0.5m/s， T_r=31.91℃	u=1.0m/s， T_r=32.41℃
静坐 M=58W / m^2	PMV PPD	1.44 47.64%	1.11 30.79%	0.97 24.87%	0.63 13.33%
家务劳动 M=92.8W/m^2	PMV PPD	1.77 65.46%	1.64 58.52%	1.58 55.26%	1.44 47.65%

表 5 可知，人静坐时，自然通风条件下(v＝0.3m/s)，PMV 为 1.11，PPD 为 30.79%；当辅以机械通风，使 V＝0.3～0.5m/s,PMV 可降至 0.97，相应的 PPD 值为 24.8％。若使 V＝1.0m/s，PMV 值降至 0.63、PPD 为 13.33％。由此看出，加强通风，可明显降低 PMV-PPD 的值，较好的改善室内热环境。

4　居室热环境标准讨论及空调参数节能控制

空调参数的确定与节能控制是以居室热环境标准为依据的，以下分别讨论不同标准所给出的空调参数范围：

（1）由文献[4]可知，有效温度 ET 给出的空调参数范围一般是：t_a =25～29℃，Φ=40%～80%，u=0.1～1.2m/s；

（2）利用热舒适指数 TCI，得出人体热反应中性区内环境热舒适的 4 个物理量取值一般是：t_a =22～32℃，Φ=30%～65%，u=0.2～0.5m/s，T_r =t_a；

（3）利用预测平均投票 PMV-PPD 指标，当 PMV=-0.5~+0.5，PPD≤10%，空调参数范围是：t_a =25~27℃；Φ=40~70%；u=0～0.2m/s，T_r =t_a。

此外，文献[5]针对自然通风条件还提出：当室内气温为 29.1℃～3l.0℃．黑球温度 29.7℃～32.0℃，相对湿度 76％～80％、室内风速 0.1～0.2m／s，人体温度 36.2℃～36.4℃，此时人体感觉稍热，主观评价尚可。文献[6]指出：长江流域进行的大量调查研究表明，夏季当室温为 28～30℃时，室内约 30％的人感到热，但绝大多数人都还能在住房内正常生活。

综上所述，最大限度地考虑到节能，夏季室内热环境指标可定为：气温值 25～30℃；相对湿度 40～75%；气流速度 0.1～0.5m/s，最大不超出 1.0m/s；平均辐射温度 25℃～33℃。因此，空调参数的极限值分别为：t=30℃；Φ=75%；u=1m/s。

对于居室，充分利用自然风，调控居住热环境；适当将夏季空调舒适温度标准从 25～26℃提高到 27～30℃，并不影响大多数居民的舒适性要求，而且可提高人对环境的适应能力，减少因室内外温差过大引起的热伤风等空调病，还可减少空调开机时间，减少空调能耗。同时，在空调系统末端设置手动及自动调节装置，对居室热环境进行适时控制，对环境条件的变化迅速做出反应，充分实现空调节能。

5　结论

（1）室内热舒适性主要由人体的活动程度、衣服的热阻、空气干球温度、室内平均辐射温度、空气流动速度、空气湿度等多个因素共同决定，这些因素的不同组合，所需消耗的能源不同。合理组合各因素，可在保证热环境质量的前提下，降低能耗。

（2）在对室内热舒适的指标的研究根据不同的要求可以给出不同的指标。如：有效温度、热舒适指数 TCI 可以用于评价除主观因素外的室内热环境，PMV-PPD 则可以综合主客观因素来评价室内热环境。

（3）夏季室内热环境指标可定为：室内气温值 25～30℃；室内空气相对湿度 40～75%；室内气流速度 0.1～0.5m/s，最大不超出 1.0m/s；室内平均辐射温度 25℃～33℃。

（4）实现空调系统对居室热环境的适时控制，同时重视以‘非空调’方式实现居住热环境的‘空调’节能；因人而异、因地制宜地确定居室热环境参数标准，是实现建筑节能的有效途径。此外，夏季加强通风，可明显改善居室热环境；在人们可接受的风速范围内，尽可能提高风速，从而提高夏季室内设计温度，实现空调节能。

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生态建筑太阳能空调及地板采暖复合能量系统的设计

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摘　要　生态建筑作为建筑节能的一个全新设计理念，已逐渐为世界各国重视，并已成为业内一项重要的研究课题。最大限度地利用风能、太阳能等自然能源，削减不可再生能源的耗费是生态建筑能源技术的最终归宿。针对上海市建筑科学研究院环境实验楼，本文介绍了一种基于太阳能热利用的生态建筑空调与地板采暖复合能量系统，详细阐述了系统的设计方案、运行方式以及控制策略。夏季，利用太阳能热水驱动两台吸附式制冷机组，担负生态技术展示厅的显热冷负荷。冬季，太阳能热水作为低温地板辐射采暖系统的热源。
关键词　生态建筑；太阳能；吸附式制冷；地板采暖; 系统设计

Design of hybrid energy system of solar-powered air-conditioning and floor heating in ecological building

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Abstract　As a new design concept, ecological buildings have been emphasized all over the world, and it has become an important subject in the building vocation. It is the end-result of ecological buildings' energy systems to sufficiently use natural energy such as solar energy and wind energy and therefore, reduce dissipation of fossil energy. In this paper, a hybrid system of heating and air conditioning based on solar energy, which is designed for the ecological building of Shanghai institute of architecture science, was introduced in detail. The design scheme, operation modes as well as control strategies are discussed. In summer, two solar-powered adsorption air-conditioning units are used to take on the sensible cooling load of the exhibition hall. In winter, a solar-powered floor heating system is utilized to supply heat for the exhibition hall.
Keywords　Ecological building; Solar energy; Adsorption air conditioning; Floor heating; Design of the system

0　引言

生态建筑观是人类对自然界生态平衡的重视在建筑领域的延伸，它反映了人与自然环境之间水乳交融的相互依赖关系。所谓生态建筑，是用生态学原理和方法，以人、建筑、自然和社会协调发展为目标，有节制地利用和改造自然，寻求最适合人类生存和发展的生态建筑环境，将建筑环境作为一个有机的、具有结构和功能的整体系统来看待。因此，人、建筑、自然环境和社会环境所组成的人工生态系统成为生态建筑的研究对象[1]。生态建筑是一种比喻，它是指具备了“ 生态 ”性质，即适应自然生态良性循环基本规律的一类建筑。生态建筑的内涵可归结为：以人为本、节省资源、

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节约能源、保护环境。它以整体有序性、循环再生性、反馈平衡性、层次阶跃性和绿色技术等特征保证了人类生存环境的可持续发展，从而达到了人与自然的真正和谐[2]。随着经济和住宅建设的发展、人们生活水平的提高，建筑物的能耗在我国总能耗中所占的比重越来越大，目前，我国建筑物的单位能耗甚高，必须重视建筑节能，倡导生态建筑理念，最大限度地利用风能、太阳能等自然能源，实现建筑、能源与环境的可持续发展。

生态建筑在能源消耗上，尽可能地利用可再生的自然能源，如太阳能、风能、地热能等，而少消耗煤、石油等矿物燃料。太阳能是一种取之不尽、用之不竭的洁净能源，用太阳能替代常规能源对于建筑节能和环保都具有十分重要的意义。未来的发展趋势是实现太阳能与建筑一体化，其基本思路是利用太阳能这种最丰富、最便捷、无污染的能源来进行采暖制冷以及供应热水，以满足人们生活的需要，同时达到减少和不用矿物燃料的目的。近年来，太阳能热水器的应用发展很快，这种以获取生活热水为主要目的应用方式其实与大自然的规律并不完全一致，冬季通过适当扩大太阳能集热器的面积，便可形成太阳能热水与采暖复合能量系统，而对于太阳辐射强、气温高的夏季，人们更需要的是空调降温而不是热水，这种情况在我国南方地区尤为突出。随着经济的发展和人民生活水平的提高，空调的使用越来越普及，由此给能源、电力和环境带来很大的压力。因此，利用太阳能空调是一个理想的方案，它不仅可使太阳能得到更充分、更合理的利用，可以把低品位的能源（太阳能）转变为高品位的舒适性空调制冷，而且对节省常规能源、减少环境污染、提高人们生活水平具有重要意义，符合可持续发展战略的要求。

实现太阳能空调有两条途径：1）太阳能光电转换，利用电力制冷；2）太阳能光热转换，以热能制冷。前一种方法成本高，以目前太阳电池的价格来算，在相同制冷功率情况下，造价约为后者的 4～5 倍。国际上太阳能空调的应用主要是后一种方法[3]。利用光热转换技术的太阳能空调一般通过太阳能集热器与除湿装置、热泵、吸收式或吸附式制冷机组相结合来实现。在太阳能空调系统中，太阳能集热器用于向再生器、蒸发器、发生器或吸附床提供所需要的热源，因而，为了使制冷机达到较大的性能系数（COP）,应当有较高的集热器运行温度，这对太阳能集热器的要求比较高，通常选用在较高运行温度下仍具有较高热效率的真空管集热器。针对上海市建筑科学研究院环境实验楼，本文介绍了一种基于太阳能热利用的生态建筑空调与地板采暖复合能量系统，详细阐述了系统的设计方案、运行方式以及控制策略。

1　系统概述

上海市建筑科学研究院环境实验楼位于上海市建筑科学研究院莘庄基地内，总建筑面积为 1984 m^2，建筑占地面积 904 m^2，建筑层数：地上 3 层。作为一个生态建筑示范工程，该建筑包容了多种绿色能源技术，包括太阳能采暖、空调、光伏发电、自然通风、自然采光等。上海交通大学承担了太阳能空调以及地板采暖系统的研究设计，具体内容包括：(1）夏季利用太阳能吸附式空调与建科院设计的溶液除湿空调耦合，分别负担一层生态建筑展示厅的显热冷负荷以及潜热冷负荷；(2）冬季利用太阳能地板采暖系统负担一层生态建筑展示厅以及二层大空间办公室的热负荷。(3）在过渡季节，利用太阳能热水强化自然通风。

鉴于该环境实验楼以办公为主，热水需求量较少，因此，在系统设计中，以满足采暖、空调工

况为主。太阳能空调及地板采暖复合能量系统包括真空管太阳能集热器、吸附式制冷机组、冷却塔、风机盘管、地板采暖盘管、蓄热水箱以及循环水泵等主要部件。其中，太阳能集热器作为吸附式制冷机组的驱动热源以及地板采暖的热源，是该复合能量系统的核心部件。太阳能空调系统所涉及的一层生态建筑展示厅面积为 265 m^2，空调设计工况下的显热冷负荷为 15 kW，由太阳能吸附式空调负担；空调设计工况下的潜热冷负荷为 45 kW，由溶液除湿系统负担。太阳能地板采暖系统负担的总采暖面积为 390 m^2，包括一层生态建筑展示厅以及二层大空间办公室，采暖设计热负荷 25 kW。

2 系统设计

2.1 采暖空调室内、外设计参数

采暖空调室外计算参数

空调室外计算干球温度	空调室外计算湿球温度	空调室外计算相对湿度	采暖室外计算干球温度
34 ºC	28.2 ºC	83%	-2 ºC

采暖空调室内设计参数

空调室内设计温度	空调室内设计相对湿度	新风标准	采暖室内设计温度
26 ºC	55%	30 m^3/h·P	17 ºC

2.2 夏季空调系统设计

一层生态建筑展示厅夏季空调采用风机盘管+新风系统，太阳能吸附式制冷机组为风机盘管提供 15 ºC 的冷冻水；溶液除湿系统处理新风，其设计送风温度为 23 ºC，相对湿度为 40%。设计选用两台吸附式制冷机组并联运行，单台的额定制冷量为 10 kW，其吸附工质对采用硅胶/水，无污染，符合环保要求，该机组由上海交通大学自行开发研制，具有体积小，性能稳定，操作灵活等优点。

2.3 冬季地板采暖系统设计

冬季地板采暖系统共有 19 个回路，其中一层 13 个回路，二层 6 个回路，地板采暖盘管间距 200 mm，水泥质面层，每个回路的盘管长度约为 100～140 m，负担采暖面积约为 25～30 m^2。地板采暖采用德国 Wieland 公司生产的 cuprotherm 地暖系统，其导热管由优质纯铜材料制成，外面包一层橙色保护膜，可以抵御化学侵蚀以及机械损害，此外，该系统具有导热性好、耐老化、不渗漏等优点。

2.4 太阳能采暖空调系统流程及主要运行工况

图 1 示出了太阳能采暖空调复合能量系统的流程图。系统的主要运行工况包括：

（1）夏季热水直通模式下空调快速启动工况：

吸附式制冷机组运行之前，关闭电磁阀 E2、开启电磁阀 E3，利用太阳能集热器加热管网中蓄存的水，使之成为驱动吸附式制冷机组的初始动力。

（2）夏季热水直通模式下吸附式制冷空调工况：

根据太阳辐射强度以及室内冷负荷的变化，通过控制电磁阀 E4、E5，可分别实现驱动单台制

冷机组的夏季空调工况以及同时驱动两台制冷机组的夏季空调工况，使系统处于高效节能的运行状态。

（3）夏季全水箱模式下吸附式制冷空调工况：

以蓄热水箱为中介，通过太阳能集热循环加热蓄热水箱中的水，同时利用另一台水泵将水箱中的热水输送到吸附式制冷机组，形成两个循环系统。根据太阳辐射强度以及室内冷负荷的变化，通过控制电磁阀 E4、E5，可分别实现驱动单台制冷机组的夏季空调工况以及同时驱动两台制冷机组的夏季空调工况。

（4）冬季地板采暖工况：

关闭电磁阀 E3、开启电磁阀 E2，将蓄热水箱中的热水送入地板采暖盘管，地板采暖的供回水管之间设置电动调节阀 E1，用来调节供水温度，防止地板过热。

（4）过渡季节太阳能强化自然通风工况：

在地板采暖供回水管上设置切换阀门，即可在过渡季节实现太阳能强化自然通风工况，建筑屋面的自然通风风道内设置 7 组加热器，用来加热流道内的空气，产生热压，提供自然通风所必需的动力。

（5）过渡季节热水工况：

系统流程图中，在集水器 J1 与集水器 J3 之间增设一个板式换热器，即可实现过渡季节的热水供应。本工程为环境实验楼，热水用量相对较少，因此，系统设计中仅对热水工况作了预留，未作详细设计。

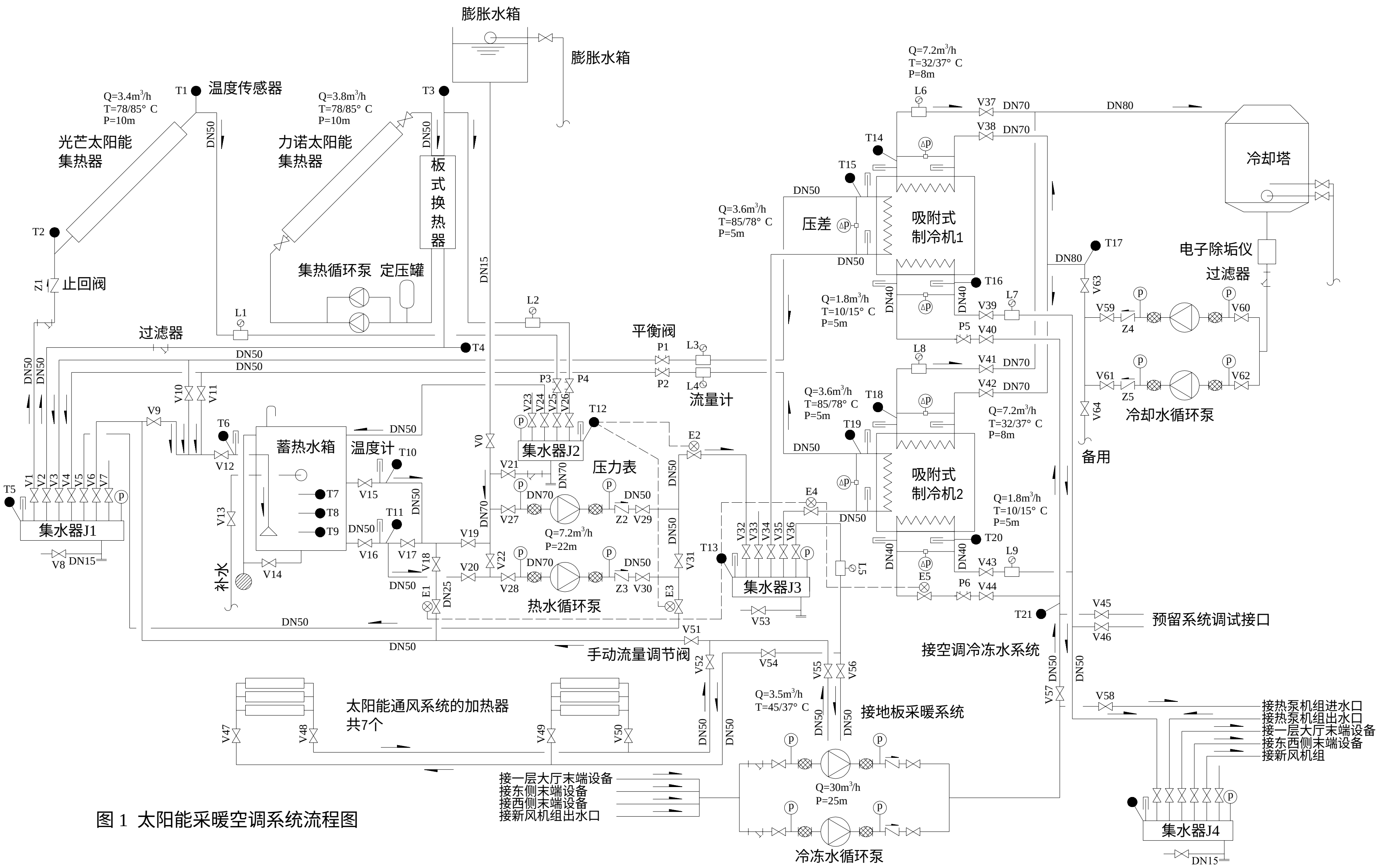

图 1 太阳能采暖空调系统流程图

2.5　太阳能集热器及其与建筑的结合

本系统采用了热管式真空管太阳能集热器，总面积为 170 m^2，热管式真空管太阳能集热器具有热效率高、耐冰冻、启动快、保温好、承压高、耐热冲击、运行可靠、维修方便等诸多优点，是组成高性能太阳能采暖空调系统的重要部件。在建筑设计中，充分考虑了太阳能集热器与建筑坡屋面的一体化设计，南向坡屋面倾角为 40 °，共布置三排太阳能集热器，具体布置见图 2。新颖的设计不仅保证了建筑的造型美观，而且充分体现了太阳能在生态建筑能量系统中的核心地位。

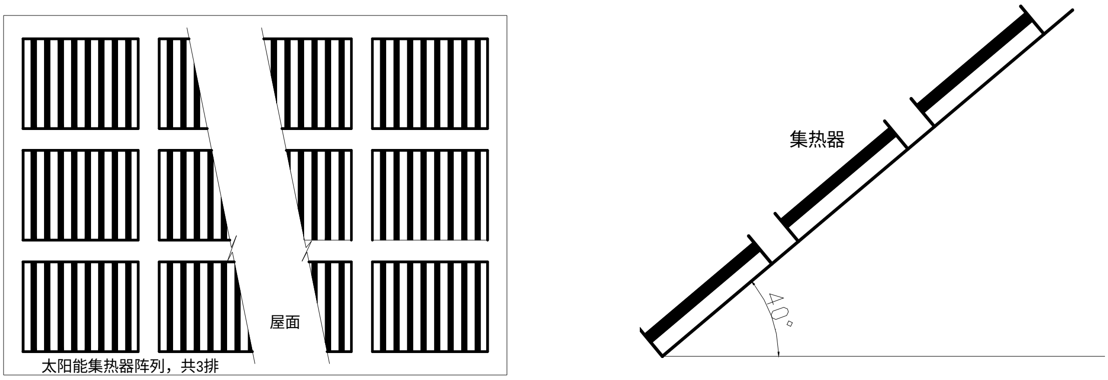

图 2　屋面太阳能集热器阵列布置示意图

2.6　自动控制系统

根据以上介绍的不同运行模式，选用一台工业控制计算机对系统进行实时监控、数据采集以及自动控制，所有信号均可上传到建筑总的控制中心。

3　结论

本文介绍了一种基于太阳能热利用的生态建筑复合能量系统，对系统设计思想总结如下：

（1）太阳能热利用与生态建筑一体化的基本思路就是利用太阳能这种最丰富、最便捷、无污染的能源来进行采暖制冷以及供应热水，以满足人们生活的需要，同时达到减少和不用矿物燃料的目的。这就要求在建筑设计中，要同时考虑两个方面的问题，一是考虑太阳能在建筑上的应用对建筑物的影响，包括建筑物的使用功能，围护结构的特性，建筑体形和立面的改变；二是考虑太阳能利用的系统选择，太阳能产品与建筑形体的有机结合。本工程中所涉及的太阳能热水以及地板采暖系统在技术上已基本成熟；然而，作为生态建筑能源技术中最重要的太阳能空调制冷尚未在产业化突破，这主要是因为现有的制冷技术与市场上普遍使用的太阳能集热器不能很好地 “ 接轨”。

（2）本工程将真空管太阳能集热器与吸附式空调系统相结合，实践了新型的太阳能空调系统。与常规压缩式空调相比，太阳能空调具有以下几个基本优点：（一）太阳能空调的季节适应性好，系统制冷能力随着太阳辐射强度的增加而增大，而这正好与夏季人们对空调的迫切要求相匹配；（二）同一套太阳能空调可以将夏季制冷、冬季采暖以及其它季节提供热水结合起来，显著提高太阳能系统的利用率和经济性；（三）传统的压缩式制冷机常用的

含氯氟烃制冷剂对大气臭氧层有破坏作用，而本工程中所采用的吸附式制冷机以无毒无害的硅胶－水为工质对，对保护环境有利。

总之，全天候、集热水、采暖、空调等于一体的复合能量系统是基于太阳能热利用的生态建筑能源技术的最终发展方向，它是生态建筑能源技术的核心内容，同时也是现代生态技术体系的重要组成部分。

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置换通风在建筑节能领域的应用及进展

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摘　要　置换通风在建筑节能中的应用主要体现在改善室内空气品质，而不是用于提供室内冷热负荷。探讨了置换通风能耗分析的研究方法：基于热平衡的能量模拟法。从送风量、送风温度、新风量三个方面分析了置换通风的节能优势。能耗模拟及节能分析表明：合理应用置换通风具有节能优势。

关键词　置换通风； 建筑；节能；能耗分析

The Application and Development of Displacement Ventilation in Building Energy Conservation Fields

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Abstract The current situation of displacement ventilation application in the building energy conservation fields is introduced,in which suppling indoor superior air quality rather than cooling or heating loads is the major aim. Discusses research approaches of energy consumption analysis such as Energy Simulation based on heat balance. Energy conservation advantages of this system caused by air flow rate and fresh air flow rate and supply air temperature are also analyzed.It is concluded that appropriate application of displacement ventilation is of energy conservation.

Key words displacement ventilation，building ，energy conservation，energy consumption analysis

0　引言

随着建筑业的发展和生活水平的提高，节能和室内空气品质日益成为我们关注的话题。暖通空调用能在建筑总能耗中占很大比例。合理地使用置换通风，既能保证室内热舒适，又能降低 HVAC 系统能耗，已成为建筑节能领域的一个重要问题。置换通风因独特的气流组织形式，是否节能与许多因素有关，因而准确地对置换通风进行能耗分析对建筑节能来说意义重大。本文从工程应用、能耗分析方法、节能优势分析等方面论述了置换通风在建筑节能领域的应用和进展。

1　置换通风的原理

置换通风（Displacement Ventilation）是将稍低于室温的新鲜空气经送风装置以低速直接送入工作区,送风速度一般为 0.25m/ｓ左右,送风温度通常低于工作区温度 2～4℃，较凉的新鲜空气扩散到整个室内地面。室内的热源(人员及设备)产生向上的对流气流，如图 1 所示。新鲜空气随对流气流向室内上部流动形成热羽流。整个流场分为两个区域：上区空气污浊，温度高；下区空气清新，温度低。它是以空气的密度差和小量的机械力为动力。

置换通风因较高的通风效率和换气效率以及潜在的节能优势，在欧洲、北美的工业建筑、商业及办公室建筑中应用十分广泛。对其耗能情况也进行了大量的研究。

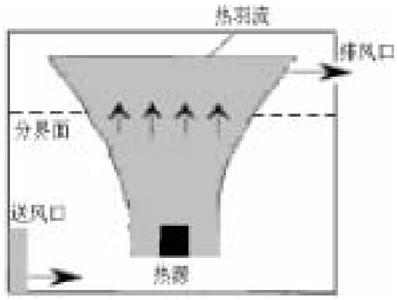

图 1　置换通风流场示意图

2　置换通风（DV）在建筑中的应用

置换通风与温度控制系统的结合是欧洲办公、商业建筑节能应用中的主流。工程中，置换通风系统提供 100%的室外新风用于改善室内空气品质，送风量减少，风机和制冷、加热能耗都降低；室内的冷热负荷用辐射顶板来处理。温度为 15℃-18℃的水送入混凝土板中的管网内，由于单位质量的水携带的能量是空气的 3000 多倍，辐射制冷、加热系统降低了能耗。对于回风采用效率高达 80%以上的热回收装置。该系统在欧洲的应用表明：其能耗是传统 HVAC 系统能耗的 60%—70%，甚至更少[1]。

置换通风在我国主要应用于影剧院、体育馆、工厂等高大空间。在工程应用中，置换通风不仅用来改善室内空气品质，而且用于消除室内负荷。对于负荷较小(35W/m^2以下)的空间，置换通风系统中用于排除室内污染物的通风量同时可以消除室内负荷，可起到节能的目的；对于40W/m^2以上负荷较大的空间单独采用置换通风节能效果并不明显。

国家大剧院观众厅处于圆形钛合金外壳之中，空间高大,属于空调内区，无围护结构负荷，需全年送冷，因而置换通风适合于观众厅冬夏季的空调系统。该系统采用全空气一次回风, 使用再热器使房间维持恒温恒湿。利用阶梯形看台的底部作为送风静压箱，座椅下设置送风口，上部灯光密集处布置回风及排风口，为下送上回方式。设计参数如表1[2]所示。

表1　观众厅的空调设计参数

夏季室内计算参数		新风量m^3/(人h)	送风温差℃	工作区风速m/s
温度℃	相对湿度%			
24±1	50±10	30	≤4	0.15-0.20

在置换通风系统的负荷计算中，由于缺乏计算资料，根据实测数据,将观众厅空调区负荷简化为人员的全热散热量、新风负荷、再热负荷三部分之和,上部负荷则为灯具对流散热量。采用相同的原始数据和设计参数，对观众厅采用不同空调系统进行能耗比较，如表3[2]所示。

表2　夏季空调方式比较

空调方式 参数	混合通风 (控制湿度)	置换通风 (不控制湿度)	置换通风 (控制湿度)
送风温差℃	9.5	3.4	3.4
总风量m^3/h	49,000	54,100	54，100
室内相对湿度%	50	73	50
制冷量kW	572	381	630
加热量kW	0	0	118
能耗总计kW	572	381	784

从表3可以看出：置换通风在观众厅的应用中，不考虑房间湿度要求时，与混合通风相比，其制冷量降低，不需加热量，具有节能效果。然而，对于温湿度要求严格的高标准的剧院观众厅来说，控制湿度的置换通风系统需要将空气处理到机器露点，存在冷热抵消的能耗，比混合通风需要更多的制冷量和加热量，无节能效果。尽管置换通风负荷为混合通风负荷的一部分，置换通风所需总风量仍高于混合通风，因而并不能节约由风机运行及空气输送引起的能耗。如果在观众厅空调系统设计中，置换通风只用于提供新风，空调区的人员负荷由其它方式来处理，那么该空调系统会有可持续的节能优势。

3　置换通风能耗模拟方法

基于热平衡法的能量模拟（Energy Simulation）是一种动态能耗模拟方法，它首先对建筑构造热过程进行模拟，针对逐时室外气象条件和室内温湿度要求计算全年或更长时间的冷热负荷，根据设备模型及逐时计算的冷热负荷确定建筑物 HVAC 系统能耗。

3.1　能量模拟原理

能量模拟（ES）的基本方程是室内空气的能量平衡方程，计算如下：

$$\sum_{i=1}^{N} q_{i.c} A_i + Q_{other} - Q_{heat\_extraction} = \frac{\rho V_{room} C_P \Delta T}{\Delta t} \tag{1}$$

式中：$\sum_{i=1}^{N} q_{i.c} A_i$ 是维护结构表面到室内空气的对流热传递；$q_{i.c}$、A_i、N 分别为表面 i 的对流热流通量、表面 i 的面积、维护结构表面的个数；Q_{other}、$Q_{heat\_extraction}$ 分别为照明、人员、设备及渗透等的得热量，房间的除热量；$\frac{\rho V_{room} C_p \Delta T}{\Delta t}$ 是室内空气的能量变化量；ρ、V_{room}、C_p 分别是空气的密度、房间的容积、空气的比热；△T、△t 为室内空气的温度变化和采样的时间间隔。

3.2　实例研究

1999 年 Shiping Hu 等人对办公室、教室和工厂的置换通风与混合通风（Mixing Ventilation）进行能量模拟。三种建筑的外墙传热系数 U=0.72W/(m^2．K)，窗户传热系数 U_{window}=4.6 W/(m^2．K)；面南遮阳系数为 0.5，面北为 0.8。建筑特性与热力条件如表 3[3]所示。

表 3　建筑特性及室内负荷与温度条件

空间类型	办公室	教室	工厂
空间尺寸	5.2×3.7×2.4(m)	11.7×9.0×3.3(m)	26.2×21×4.5(m)
外墙面积	52%外墙面积	44%外墙面积	61%外墙面积
内部负荷	2 人：260W， 2 电脑:250W 灯:204W	25 人：3250W 灯:1264w	112 人：14560W， 设备:3362W，灯:5502w
房间温度	供冷 t=25℃ 加热 t=23℃	供冷 t=25℃ 加热 t=23℃	供冷 t=25℃ 加热 t=23℃

研究结果图 2[3]、图 3[3]表明：与混合通风(MV)相比，置换通风风机能耗更多，制冷与锅炉能

耗较少，总能耗比混合通风系统小。

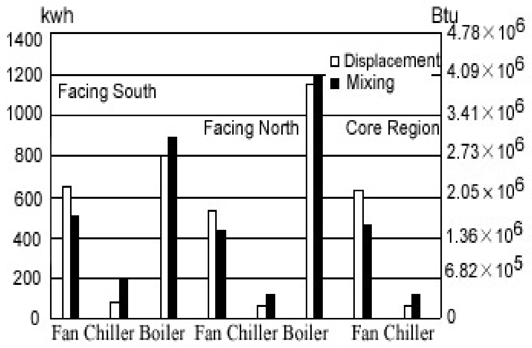

图 2　不同位置办公室 DV 与 MV 每年能耗比较

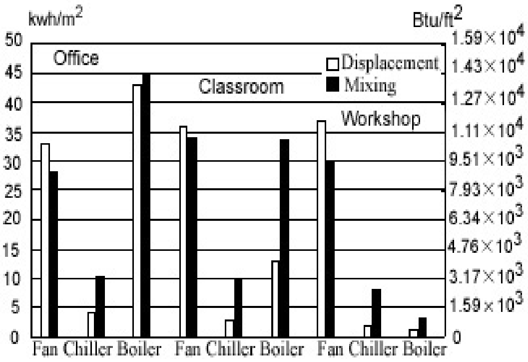

图 3　各类房间 DV 与 MV 单位面积年能耗比较

图 2 表明建筑方位对能耗的影响：因供热季较少的太阳得热，较高的热负荷，北面区的锅炉能耗最高；南面区制冷能耗较高；核心区，无外窗和外墙，无须加热。

图 3 比较了不同类型建筑物中置换通风与混合通风的能耗。教室中，散热设备少，人是主要的热源，人员密度大于办公室，因而新风量较办公室大，新风提供了更多的冷热负荷，因而，在冬天教室与办公室相比，置换通风系统节能优势更明显。工厂的人员密度与教室类似，但有更多的散热设备，提供了一定热负荷，降低了锅炉能耗。

4　置换通风的节能分析

从三个方面分析置换通风的节能优势：

4.1　置换通风的送风量引起的节能

HVAC 系统中，风机能耗占有很大比例，风机能耗与送风量和风压成正比，因而置换通风中送风量的大小决定了是否节约风机能耗。

4.1.1　单独置换通风系统室内送风量计算如下：

$$V = \frac{3600Q_1}{\Delta t_{hf}\rho c_P} \tag{2}$$

式中：V、ρ、c_p 分别为送风量 m^3/h，空气密度，kg/m^3，空气比热，J/(kg . K)；Δt_{hf} 是头脚温差，$\Delta t_{hf} \leq 3$℃；Q_1 是工作区负荷，w。

混合通风送风量 L 的计算与公式(2)相同，只是其中负荷为室内总负荷 Q，送风温度与室内温度差为 Δt_n。从(2)式可见，置换通风要消除的是工作区负荷，混合通风为全室负荷。ASHRAE 提出的适用于办公室建筑的置换通风系统工作区负荷计算如下：

$$Q_1 = a_{oc}Q_{oc} + a_l Q_l + a_{ex}Q_{ex} \tag{3}$$

$$a_{oc} = 0.295, a_l = 0.132, a_{ex} = 0.185 \tag{4}$$

$$Q = Q_{oc} + Q_l + Q_{ex} \tag{5}$$

式中：Q_{oc}、Q_l、Q_{ex} 分别为室内人员、台灯及设备的负荷，顶灯的负荷，维护结构及太阳

辐射的负荷，w；a_{oc}、a_l、a_{ex} 表示坐姿人体头脚范围内的各种冷负荷占室内总冷负荷的比例。

在我国，空调区夏季分层空调冷负荷计算，在进行规划设计估算时，可采用经验系数法，即为室内冷负荷乘以经验系数 α，$\alpha = \dfrac{\text{工作区冷负荷}}{\text{室内总负荷}}$，$\alpha$ 是根据高大建筑物性质经实测与计算得出，通常 α =0.5-0.85,当缺乏数据时，可取 α =0.7[4]。

混合通风送风温差一般在 6-10℃范围内，置换通风送风温差小于 4℃。为确定两种通风方式下送风量的大小，引入系数

$$\beta = \frac{V}{L} = \frac{\Delta t_n Q_1}{\Delta t_{hf} Q} \tag{6}$$

因而，与混合通风相比，置换通风是否有较小的送风量由系数 β 确定。是否节约由送风量引起的风机能耗要根据落入空调区不同负荷的大小来定。如对于办公室建筑，工作区人体负荷较小，维护结构和照明负荷占室内总负荷的80%以上。工作区上部散热大部分被排出，所需送风量小，而餐厅，呼吸区负荷较大，送风量也较大，风机节能优势不明显。

4.1.2　置换通风与温度控制系统结合时送风量计算如下：

（1）按室内人员来确定送风量:$V_p = nq$　　(7)

式中：n，q分别为室内人数和每人单位时间所需的改善空气品质的通风量，m^3/h。

（2）依据室内有害物发生量确定该送风量

$$V_p = \frac{\rho M}{C_y - C_j} \tag{8}$$

式中：M、C_y、C_j 分别为室内污染物散发量mg/h，室内污染物的最高允许浓度，进入室内污染物浓度，mg/m^3。

无论以哪种方法确定送风量 V_p 都将远小于 V，送风量减小，又由于送风速度低，风机压头低，用于风机和风管的初投资及系统的运行费用减少，风机能耗明显减少。

4.2　送风温度引起的节能

置换通风送风温度较高，一般在18℃以上，室内温度分层，而且温度随房间高度而上升，室内平均气温高于混合通风，上区热空气减少了通过屋顶、墙体与室内的传热，降低了室内负荷，一定程度上降低了能耗；由于置换通风送风温度高，空调设备中制冷剂的蒸发温度高，单位制冷量提高，单位压缩功减小，增加了制冷循环COP；由于送风温度较高，置换通风制冷量小，在过度季节，能有效利用室外天然能源而节省人工制冷。

4.3　新风量产生的节能优势

置换通风的通风效率高，当保证同样的室内空气品质时，置换通风所需新风量比混合通风少。由于新风负荷在总负荷中占有较大比例，因而置换通风在处理新风这一项上要比混合通风节能。置换通风新风所节约能量计算如下[5]：

$$w = \frac{1}{3.6}\alpha\rho l_n\left(i_w - i_n\right) \tag{9}$$

式中：α 为置换通风的新风比混合通风的新风少的百分比；w 为新风节约的能量，W； ρ 是空气密度，kg/m^3 ；l_n 是混合通风的新风量，m^3/h ；i_w、 i_n 分别为夏季室外计算参数时的焓值和室内空气焓值，kJ/kg。

6 结语

置换通风在我国高大建筑空间如影剧院、体育馆、工厂等有所应用，合理应用，可达到节能的效果；置换通风制冷能耗较低，如果结合单独的温度控制系统，风机能耗也可降低，整个空调系统有可持续的节能优势。置换通风的节能与许多因素有关，精度高、灵活、易于扩展的能耗分析方法是准确评价其系统能耗的前提，采用基于热平衡的能量模拟法研究表明：建筑类型、功能等都会影响其能耗，与混合通风相比，置换通风系统风机能耗并没有减少，制冷、加热能耗降低，总能耗降低。从置换通风送风量、送风温度、新风量三个方面分析表明：置换通风具有节能优势。

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生态建筑太阳能除湿热泵系统

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摘　要　生态建筑追求节能、清洁、健康和可持续发展。针对生态建筑的这些要求，本文提出一种将太阳能热泵系统、水蓄能、液体除湿系统进行集成的方案，可以合理地利用并节约能源进行冬季采暖、夏季空调以及全年供应热水。
关键词　生态建筑，太阳能，热泵，液体除湿，节能

Abstract　Energy saving, clean, health and sustainable development are all necessary in ecological building. To meet these requirements, a rational version is proposed in this paper. It is suggested that solar-assisted heat pump (SAHP), water energy storage and liquid desiccant system (LDS) could be integrated in this version. So, energy can be saved and used rationally when the heat pump system run in heating condition in winter , cooling condition in summer and hot water supplying condition yearly.
Key words　ecological building, solar energy, heat pump, liquid desiccant, energy saving

0　引言

长期以来，人类使用的能源一直是以石油、天然气和煤等化石燃料为主，这些能源是地球经过千百万年储存在地层中的，属于不可再生能源。自上个世纪 70 年代出现能源危机以来，人们越来越重视可持续性的发展，开始了对可再生能源的开发和利用。

太阳能是一种丰富的可再生清洁能源，近年来越来越受重视。我国幅员辽阔，有着十分丰富的太阳能资源。据估算，我国陆地表面每年接受的太阳辐射能约为 $50\times10^{18}\,kJ$ （相当于 24000 亿吨标准煤），全国各地太阳年辐射总量达 335～837 $kJ\cdot cm^{-2}\cdot a^{-1}$，中值为 586 $kJ\cdot cm^{-2}\cdot a^{-1}$[1]。因此，我国具有良好的利用太阳能的条件，应大力开发太阳能资源。

建筑能耗在人类总能耗中占有很大比重，达到 30～50%[2]。所以，建筑节能对于可持续发展意义重大。近年来出现的“生态建筑”，给拯救、保护人类自身健康和周围环境带来了厚望。生态建筑追求节能、清洁、健康和可持续发展，在建筑中大力推广应用太阳能与生态建筑自身所追求的理念是相一致的。

太阳能在建筑中的应用包含两大方面。其一是太阳能热应用：用太阳辐射加热水，以供给建筑生活热水、取暖或制冷；另一方面太阳能光伏发电（PV）系统：将太阳辐射直接转化为电能，为建筑提供环保的能源。由于目前太阳能电池价格较高，光伏发电技术在建筑物中还难以普遍推广。根据中国的实际情况，在国内建筑物中推广太阳能热利用技术，是能够大力促进建筑节能的。

我国太阳能热利用近年来发展迅速，太阳热水器已经走向千家万户，全国已经形成了近 100 亿元左右的年销售额。然而目前在热利用方面尚有不少局限，体现在[3]：

1) 尚无真正的太阳能采暖空调和热水供应集成系统；
2) 太阳能空调制冷尚未在产业化突破；
3) 太阳能热水及水源热泵综合集成系统尚未发展。

本文在介绍现有太阳能热泵空调及热水系统的基础上，提出了进一步集成液体除湿系统的构想，构成适于在气候湿热地区的生态建筑使用的太阳能除湿热泵系统，为生态建筑节能提供一种新的思路。

2 太阳能热泵空调及热水系统

上海交通大学太阳能发电及制冷教育部工程研究中心设计和建造了一套直膨式太阳能热泵空调及热水系统（所谓"直膨式"，是指制冷剂的蒸发过程与太阳能的集热过程在同一系统内——太阳能集热器——进行）。

该系统基于蒸汽压缩式制冷/热泵循环原理，直接利用周围环境中的冷/热源（太阳辐射能为主，空气源为辅），通过制冷/热泵循环保证建筑物的冬季采暖、夏季空调和全年生活热水供应。

在阴雨天或太阳辐射相对不足的情况下，可通过与太阳能集热器并联的室外风机盘管换热器与室外空气换热、利用空气作为热泵热源，保证了冬季采暖的连续性和稳定性；在夏季蓄冷工况下，太阳能集热/蒸发器又作为夜间辐射散热/冷凝器使用，热泵系统利用深夜"谷电"制取冷水并进行蓄冷运行，以满足次日空调负荷的需要，不仅提高了设备利用率、满足了建筑多种用能需求，而且有利于城市电力使用的"移峰填谷"，促进合理用电。

下文将该系统分为两部分介绍：

1.1 太阳能热泵

太阳能热泵将太阳能热利用技术与热泵技术有机地结合了起来，可同时提高太阳能集热器和热泵机组的热力性能，它主要由太阳能集热/蒸发器、压缩机、冷凝器、热力膨胀阀、储热水箱等部件组成，如图 1"太阳能热泵部分"所示。

用该系统制取热水的具体工作过程如下：

晴天，经热力膨胀阀节流后的低温低压制冷剂首先流入太阳能集热/蒸发器中，通过吸收太阳能热量而蒸发，蒸发后的制冷剂被压缩机吸入并压缩成高温高压的气体，然后被排入冷凝器中，制冷剂蒸汽与通过冷凝器的冷却水进行换热而得到冷凝，同时，水得热升温，流入热水箱或蓄热水箱，冷凝后的制冷剂经热力膨胀阀又重新流入太阳能集热/蒸发器中，由此完成一次循环；阴天或夜间，太阳能集热/蒸发器也可以通过吸收大气中的显热和潜热来维持正常的热泵循环，从而可以全天候地生产热水。

直膨式太阳能热泵系统，使得集热器的工作温度与制冷剂的蒸发温度始终保持一致，并接近环境温度，实验研究和理论分析均表明，太阳能热利用技术与热泵技术的结合，不仅可以提高太阳能集热器的集热效率，而且可以有效提高热泵机组的 COP。例如，据文献[4]报道，在新加坡的气候条件下，一种太阳能热泵热水器的集热效率达到 40%～75%，热泵 COP 达到 4～9，热水温度从 30℃升到 55℃。经实验验证，本系统的集热器效率一般可达 60%～80%，热泵 COP 一般可超过 3。

该系统的太阳能集热器采用易于与建筑结构实现一体化集成的、廉价的平板型太阳能集热/蒸发器。吸热体可采用铜铝复合焊接板或全铝热压吹胀板，顶部无盖板，底部及四周加以适当保温，表面喷涂光谱吸收性材料，管路承压要求在 15～20 kgf/cm^2 以上。由于该太阳能集热/蒸发器结构简单、质轻体薄，所以易于倾斜安装在屋顶之上或垂直挂装在南向外墙壁上，特别适合于多层或高层

建筑。

该系统并联安装了太阳能集热/蒸发器和室外风机盘管换热器，在晴天可以利用太阳能生产热水，而在阴雨天或夜间又可利用大气中的显热和潜热作为热泵的低温热源，从而实现全天候运行。例如，澳大利亚的 Morrison 等人对一种太阳能热泵热水器进行了 24 小时运行测试，结果表明，热泵 COP 在 2.4～3 之间变化[5]。

因此，太阳能热利用技术与热泵技术有机结合的太阳能热泵系统，可以节约大量用于生产低温热水的优质能源（如电能），实现能源的合理利用和可持续发展，同时缓解由于化石燃料的消耗而造成的环境污染问题。这种系统将是为生态建筑提供冬季采暖、夏季空调和全年生活热水的有效模式。

1.2 水蓄能

该系统采用闭式承压蓄能水箱进行蓄冷/热，水箱内布置高效的铜管换热器，管内为制冷剂通路，通过自然对流和导热与水进行换热。热泵系统通过水箱的蓄能，夏季实现空调蓄冷，冬季实现采暖蓄热。

夏季空调工况下，热泵机组在夜间制备冷水,并将其储存到蓄冷水箱中，白天供空调系统使用。升温后的水返回水箱，第二天晚间再被制冷而循环使用。采用这种蓄冷方式有以下特点：

1) 蓄冷系统简单，能直接与常规空调系统相匹配，系统设计简单；

2) 运行温度比冰蓄冷高，制冷机性能系数高，电耗小；

3) 制冷机在夜间运行时，以太阳能集热器或者室外风机盘管换热器作为冷凝器，其散热效果都好，运行效率高，节能省电；

4) 蓄能水箱要注意保温和合理设计，防止槽内供水和回水短路、混合，造成能量损失。

冬季采暖工况下，热泵机组利用太阳能或者空气作为热源，在较高蒸发温度下高效制取热水并将之储存在水箱中，供给地板辐射盘管或者风机盘管等室内采暖末端设备。

这种水蓄能式热泵系统具有蓄冷/热、移峰填谷、比常规空调系统适应性好的特点，是一种较经济的空调方式。

2 液体除湿

除湿技术作为有效的建筑节能手段之一，日渐引起了重视和研究[6,7,8]。

空气中的水分能被具有强烈吸湿性的除湿剂吸收，再将干燥后的空气进行蒸发冷却即可实现降温。除湿系统主要由除湿部分和再生部分组成。

除湿技术与传统制冷机相结合，可以组成“热、湿分担”型空调，即将空气的湿负荷和热负荷分开处理，通过除湿器对空气的湿度进行完全处理和控制，制冷机产生的冷量仅用于降低空气的温度而不再负责除湿，因此可以大幅度的提高制冷机蒸发器的温度，进而使制冷机的性能系数得到显著提高，同时也消除了传统空调方式中因“先冷后热”过程造成的能源浪费。另外，采用热湿分担的处理方式，空调过程无凝水出现，这就从根本上解决了传统空调箱中时常存在的霉菌污染空调空气的难题[9]。由此可见，在空调过程中应用除湿技术，既节能，又提高了空气品质。

按照所用除湿剂的种类不同，除湿可分为固体除湿和液体除湿。液体除湿系统（LDS）与固体

除湿系统(SDS)相比，有许多独到的优点[10]：

1) 系统尺寸相对较小，设计灵活多样；

2) 为保证连续运行，蓄能对于太阳能除湿空调系统至关重要，对于 LDS，能量在除湿溶液中以化学能的形式而不是以热能的形式存在，其蓄能潜力很大（可以达到 1000MJ/m^3），而且在一般存储条件下不会发生耗散，蓄能稳定，这是 SDS 无法比拟的；

3) LDS 和 SDS 都适用于以太阳能为主要供能的空调系统，不过除湿溶液的再生温度比固体除湿剂的更低，能够在低于 80℃的温度条件下再生，因此在目前普通太阳能集热器的技术水平下（热水温度在 80℃～90℃左右），LDS 能更好的发挥其效能；

4) 作为除湿剂的盐水溶液具有一定杀菌作用，利于提高室内空气品质。

太阳能液体除湿具有节能、清洁、易操作、处理空气量大和除湿溶液再生温度低等优点，因此它在建筑节能和提高空调空气品质方面的应用方面具有很好的发展前景。

2.1 除湿溶液

已经被学者们研究并达到实用程度的除湿溶液有三甘醇以及溴化锂（LiBr）、氯化钙（$CaCl_2$）和氯化锂（LiCl）等卤素金属盐溶液[11]。它们的特点是具有强烈的吸湿性，能在50 ℃～80 ℃的较低温度下有效再生，适合于利用太阳能、余热等低品质热源驱动。

溴化锂溶液是性能优良的除湿溶液，但是价格较高。氯化钙溶液价格低廉，而且再生温度低，是一种比较经济的除湿溶液。另外，通过两种或多种除湿溶液相混合，还可以配制出满足系统要求的高性价比除湿溶液。

2.2 除湿器

目前所应用的除湿器的结构型式多种多样，但根据其在除湿过程中冷却与否可以将其分为两类。一类是绝热型；一类是内冷型。

早期的研究主要集中在填料喷淋塔式除湿器（绝热型）上，因为它具有结构简单和比表面积大等优点；但由于除湿溶液的绝热吸湿升温，使其除湿效率不能令人满意。20世纪90年代以来，内冷型除湿器受到了人们的普遍关注。内冷型除湿器采用冷水盘管或冷却空气(都不与除湿溶液直接接触) 将除湿过程释放出的潜热带出。由于抑制了除湿溶液的温升，使溶液始终能保持较低的水蒸气压，有利于吸收空气中的水蒸气。

内冷型除湿器比绝热型除湿器性能优越，但是内冷型除湿器需要增加额外的冷却水循环系统，会增加系统的复杂性和投资，鉴于此，可采用空气（一般可采用室内排风）作为除湿器的冷却介质。除湿过程采用空气冷却方式，可以带走部分潜热，有助于提高除湿器的除湿效率。相关研究表明，内冷型除湿器更适合于太阳能液体除湿热泵系统[12]。

2.3 再生

由于太阳能液体除湿系统采用太阳能等低温热源作为其主要供能，而且除湿溶液可以循环反复使用，因此它的运行成本是低廉的。就再生而言，为了能最大限度的发挥系统的效能，用溶液直接接受太阳能辐照应该是首选，但是，这样的话，系统的一次投资是比较大的。

为降低建造成本，可以考虑把除湿系统和现有的太阳能集热设备结合起来。这样对于用户来说，

既能把现有的技术成熟、已经商品化的太阳能集热器作为日常的热水设备，又可以很方便的用它来驱动太阳能液体除湿空调系统。一种最简单的结合方式就是用热交换器来实现把太阳能集热器热水的热量传递给液体除湿空调系统。

3　系统集成的构想

基于上文所述液体除湿的特点，作者考虑，可将液体除湿和现有的太阳能热泵空调及热水系统进行集成，实现建筑节能的优化组合。

集成后的太阳能除湿热泵系统主要由太阳能热泵部分、蓄能部分、液体除湿部分和室内空调末端部分组成，其流程示意图如图 1：

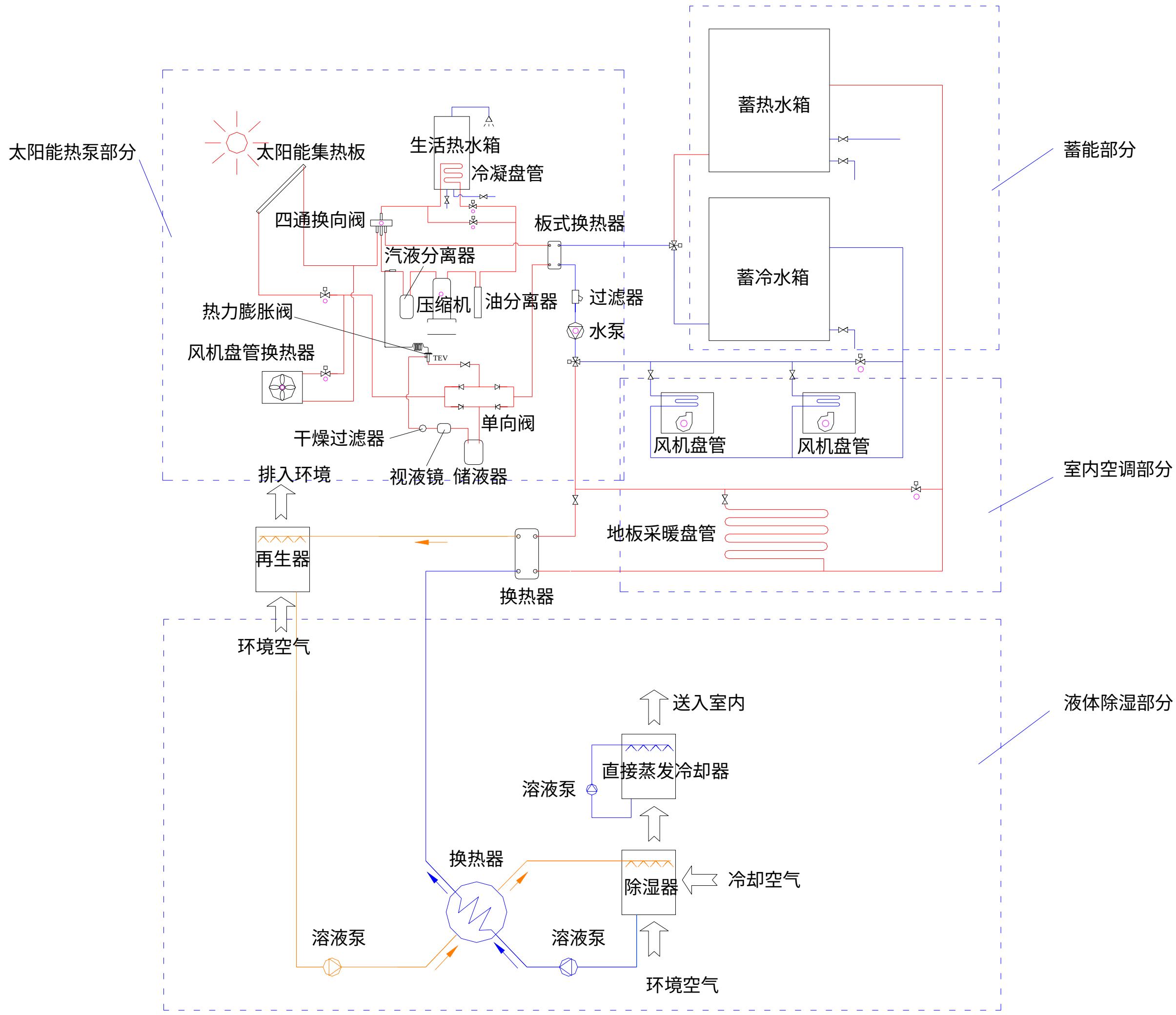

图 1　太阳能除湿热泵系统流程示意

3.1　太阳能热泵部分

本部分由太阳能集热/蒸发器、四通换向阀、气液分离器、变频压缩机、冷凝盘管、生活热水箱、板式换热器、储液器、干燥过滤器、膨胀阀、室外风机盘管换热器以及制冷管路和阀件等组成。

太阳能集热/蒸发器的出口经四通换向阀、气液分离器与变频压缩机的吸气口相连，变频压缩机的排气口与冷凝盘管的进气口连接，冷凝盘管的出口经四通换向阀与板式换热器的进口连接，板式换热器的出液口与储液器相连，然后分别经干燥过滤器、膨胀阀与集热/蒸发器的进液口相连，

从而形成制冷剂的闭合循环通道。其中，冷凝盘管布置在生活热水箱中，用于生产生活热水(40~60℃)，冷凝盘管设有旁通管路，管路上采用电磁阀进行通断控制，从而选择是否使用生活热水箱。而板式换热器则通过与循环水换热制取冷水或热水，供给蓄冷或蓄热水箱，并且蓄冷/蓄热水箱的上、下部分别设置接管与室内空调末端装置的供、回水管路加以连接。

室外风机盘管换热器作为太阳能集热/蒸发器的辅助设备，其进、出口分别通过一个电磁三通阀与太阳能集热/蒸发器并联。

3.2　蓄能部分

系统采用水进行蓄能，用于蓄能的蓄热、蓄冷两个水箱通过电磁三通阀并联，采暖和除湿工况下使用蓄热水箱，空调工况下使用蓄冷水箱。在循环水泵驱动下，水与板式换热器换热，从而制取热水或冷水。

3.3　液体除湿部分

液体除湿部分主要由再生器、换热器、除湿器、直接蒸发冷却器组成，以蓄热水箱内蓄存的热水作为其主要供能。如图1“液体除湿部分”所示，环境空气或室内回风进入除湿器与除湿溶液接触，其中部分水份被除去；对干燥后的空气绝热加湿降低显热，从而达到空气调节的目的；吸湿后被稀释的除湿溶液送到再生器再生。

由前文的讨论知，可以采用价格低廉的氯化钙溶液作为液体除湿剂；为提高除湿效率，采用空气冷却的内冷型除湿器；用换热器把蓄热水箱内热水的热量传递给再生器对除湿溶液进行再生。

3.4　室内空调末端部分

本系统夏季采用风机盘管送冷风，冬季采用地板采暖盘管辐射供热。

3.5　系统的各个运行工况

1) 冬季采暖工况：热泵系统在采暖工况下运行的时候，利用太阳能作为热泵的热源，以热泵系统的冷凝器加热循环水，制取的热水送入蓄热水箱，用于冬季采暖，直接送至空调末端系统。

此时，系统循环工作过程为：白天，制冷剂经膨胀阀节流后流入太阳能集热/蒸发器中，通过吸收太阳能热量而蒸发，随后经气液分离器的分离作用使制冷剂蒸汽被压缩机吸入，产生的高温高压蒸汽首先被排入冷凝盘管与生活热水箱中的水进行换热，一部分蒸汽得到冷凝，此后湿蒸汽又流入板式换热器继续冷凝，一部分热量用于房间采暖，另一部分则被蓄存起来，冷凝后的液态制冷剂经单向阀、储液器、干燥过滤器和膨胀阀流回太阳能集热/蒸发器重新吸收太阳能，从而完成一次循环。夜间，如果蓄热水箱中的水温足够高，则通过空调末端循环直接从蓄热水箱中取热，不必启动热泵机组。但是，如果白天蓄存的热量不足以满足夜间（或阴雨天）连续采暖的需要，则电磁三通阀开启旁通管路，利用室外风机盘管换热器作为系统的辅助热源装置，以满足房间采暖的舒适性要求。

2) 夏季空调工况：四通阀门换向，将热泵系统的采暖工况转为制冷工况，以太阳能集热板作为冷凝器（此时可节约常规室外风机盘管换热器的风机耗电），利用系统的蒸发器冷冻循环水，制取的冷水送入蓄冷水箱，储存的冷量可在次日用于空调。这样，就有效地利用了夜间的低价谷电，利于城市电力的移峰填谷。

通过四通换向阀的换向，将太阳能集热/蒸发器用作夜间辐射散热/冷凝器，辐射散热/冷凝器的进口经四通换向阀与冷凝盘管的出口相连，与此同时将蓄热水箱切换为蓄冷水箱，而板式换热器的出口则经四通换向阀与气液分离器的进气口连接起来，其余部件之间的连接关系保持不变。

此时，系统循环工作过程为：夜间，从压缩机出来的制冷剂蒸汽首先流入冷凝盘管，通过加热生活热水而部分冷凝，然后湿蒸汽经四通换向阀流入夜间辐射散热/冷凝器，通过对流和辐射散热继续冷凝，得到的液态制冷剂经单向阀、储液器、干燥过滤器及膨胀阀流入板式换热器内，通过吸收蓄冷水箱循环水的热量而蒸发，使得水温的不断下降，制得的冷水一部分供夜间空调使用，另一部分蓄存在水箱中供白天空调使用，蒸发后的制冷剂经气液分离器又重新被压缩机吸入、压缩，从而完成一次循环。如果夜间蓄存的冷量足以满足白天空调的需要，则可以利用空调末端循环直接从蓄冷水箱中提取冷量，不必启动热泵机组。如果夜间蓄冷量不足，则启动热泵机组，开启电磁三通阀的旁通管路，采用室外风机盘管换热器作为系统的辅助冷凝器，以保证白天房间空调的需要。

3) 过渡季热水工况，可通过降低压缩机的频率来减少制冷剂的循环量，同时开启电磁阀，使得制冷剂蒸气在冷凝盘管中全部冷凝用于生产热水，而冷凝后的制冷剂液体经换热盘管的旁通管直接流入储液器中。

4) 除湿工况：需要进行除湿的时候，系统按冬季采暖工况运行，将蓄热水箱内的热水作为再生热源提供给液体除湿系统的再热器。根据文献[7]的报道，采用价格低廉的氯化钙为除湿溶液时，太阳能液体除湿系统再生器的除湿溶液进口温度（即再生温度）为 50～75℃。以目前普通太阳能集热器的技术水平，能够制取的热水温度在 80℃～90℃左右[10]。所以，利用太阳能热水对除湿溶液进行再生，只要保证热水的供应量，是能够满足要求的。

本系统各个工况下，每当太阳能不能满足要求时，启动辅助冷/热源——室外风机盘管换热器，以保证采暖或制冷工况运行的连续性和稳定性。

4　结论

1) 将太阳能热利用技术与热泵技术有机地结合起来，可同时提高太阳能集热器和热泵机组的热力性能；

2) 水蓄能（尤其是夏季蓄冷）能够起到“移峰填谷”、平衡用电的作用，系统简单，性能系数高，值得推广；

3) 除湿技术与热泵系统相结合，进行热湿分担的空气处理过程，既可提高的机组的性能系数、节约用能，又可解决常见的空调箱内冷凝水导致霉菌滋生的问题。

综上所述，本文提出了适用于生态建筑合理地利用并节约能源进行冬季采暖、夏季空调和全年供应热水的太阳能除湿热泵系统，该系统集成了太阳能热泵、水蓄能和液体除湿技术，是这几种节能技术的优化组合。

这一系统，适用于冬季不太冷、夏季湿热的国内南方地区。广大南方地区经济发展迅速，生态建筑近年来有望在这些地区得到推广和普及。目前，上海市建筑科学研究院正在上海闵行地区建造生态建筑办公样板楼，其需要集成的关键技术达十项之多（自然通风、天然采光、超低能耗、健康空调、再生能源、绿色建材、智能控制、生态绿化、资源回用、舒适环境），这些关键技术的研究

和集成，即是为推广生态建筑作必要的理论和实践准备。本文提出太阳能除湿热泵系统，希望为生态建筑的空调系统集成提供一种新的思路。

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基于 BLOCK 模型的大空间建筑分层空调的设计方法

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摘　要　本文探讨并应用了一种基于多区热质平衡模型的分层空调设计方法。多区热质平衡模型包括多股射流速度重合与流量、垂直壁面换热与流动、表面热平衡、区域热质平衡等子模型。该方法从研究多股平行非等温射流的特性以及大空间垂直温度分布特点入手，其计算条件为相应的室外计算参数、空间几何尺寸、围护结构传热特性以及内部已知散热源，计算过程包含了传导、对流和辐射的三传耦合。通过模型的求解，可以得出相应的设计参数，如空调负荷、空调送风量、喷口的尺寸与数量等。在稳态条件假设下，与原有的分层空调设计方法进行了比较，指出了原有方法的不足之处。

关键词　热质平衡模型；分层空调；设计；稳态假设

1　分层空调技术背景

1.1　技术发展

近年来，大空间建筑在工业和民用场合出现越来越多，分层空调技术在各类大空间建筑中应用也更加广泛。分层空调作为一种特殊的气流方式，于 20 世纪 60 年代最早出现在美国，后又在日本、中国等开始大量应用[1]。分层空调一般可以定义为：在大空间两侧或单侧腰部设置送风喷口，下部同侧均匀设置回风口，运用多股平行非等温射流将空间隔断为上下两部分，仅对下部空调，形成“ 空调区 ”，对上部通风形成 “ 非空调区 ”。

国外学者曾对分层空调气流进行了模型试验，并试图对分层空调进行理论解析，但其结论很难应用于实际工程[2]。20 世纪 80 年代，中国建筑科学研究院对分层空调进行了大量的模型试验，提出了 “ 分层空调气流组织计算方法 ”、“ 分层空调热转移负荷计算方法 ” 等[2, 3]，成为目前国内大空间建筑分层空调设计的主要参考依据。此后，又有人采用 CFD 技术、简易能量平衡模型等手段对分层空调横向隔断气流以及室内温度分布进行了研究，特别是对垂直温度分布特点的研究已成为进一步解决大空间建筑节能和良好热舒适环境的重要途径，文献[4]结合国内外研究现状，综述了近些年 CFD 模型、能量平衡法、实验手段等方面的重要进展。

1.2　存在问题

就目前来看，关于多股平行非等温射流的理论已较为成熟，从实验、解析到数值模拟都有一些研究成果[2, 5, 6]。然而，对于分层空调气流下负荷的解析计算以及能耗的分析还有待进一步的深入研究。文献[2,3]虽然系统给出了分层空调的设计方法和过程，但仍然缺乏理论依据，有不少地方是值得商榷的，比如，在确定非空调区温度时，采用以下方法：

$$t_2 = \frac{1}{2}(t_1 + t_{2d}) \qquad (1)$$

式中，t_1为空调区计算温度，由工艺确定；t_2为非空调区计算温度；t_{2d}为屋盖下空气温度或排风温度，取室外计算温度附加 2~3 ºC。实际上，非空调区的温度是随室内外条件而变化的，并不是定值，其取值范围只能适用于某些情况，再者让工程人员在设计过程中凭经验人为取值也是不合理的。

另外，为了计算非空调区对空调区的辐射热转移负荷，文献[3]采用下式确定围护结构内表面温度：

$$\tau = t_n + K\Delta t_{zh} / \alpha_N \qquad (2)$$

式中，τ为围护结构内表面温度；t_n为室内计算温度，即t_1或t_2；Δt_{zh}为综合温差；K围护结构传热系数；α_N为内表面换热系数，可取 8.72 W· m^{-2}· K^{-1}。可以看出，在确定某一个围护结构内表面温度时，该方法将对流和辐射换热概括到一个表面换热系数中，从理论上看，把与所有其它围护结构辐射换热简化为与室内空气的当量热交换，且只考虑非空调区对空调区表面的辐射热交换，将整个非空调区高度范围内的表面温度看成一个单值，都是不合理的。

总体来说，该设计方法完全来自于模型试验，缺乏相应的理论解析，其适用性应该是有限制的，且计算过程也比较麻烦。因此，建立一个完整的基于区域与表面能量平衡的理论模型，并借助于计算机程序，抛弃对未知条件的假设、保留试验结果的合理性因素，对于分层空调技术应用是大有裨益的。

2 多区热质平衡模型

为了研究大空间热环境，国外学者相继提出了一室二温、三温、多温等模型[4]，并逐渐考虑了空气流动交换、送风射流作用等因素，通过垂直分布来求解模型并进行分析。其中最为完善的是日本学者户河里敏的 BLOCK 模型[7]。这一模型核心就是多区热量/质量的平衡，它已经得到大量检验，以于 1993 年正式被日本空气调和卫生工学会空气调和设备委员会热负荷法小委员会推荐，作为大空间建筑室内垂直温度分布和热负荷计算方法[4]。

BLOCK 多区热质平衡模型中已经考虑了送风射流的影响，但是，其射流模型只包含冬、夏季的单股射流、没有考虑相互重合下的多股平行射流。此外，模型中对流换热系数取为定值，不能体现空气温度与表面温度的关联性；辐射热交换因素没有被引入到表面热平衡；围护结构导热不考虑，需要测出表面温度的分布才能计算。

本文在 BLOCK 模型基础上，建立了一个多区热质平衡模型，包括多股射流速度重合与流量、表面热平衡、垂直壁面换热与流动、区域热质平衡等子模型，计算过程包含了传导、对流和辐射的三传耦合。

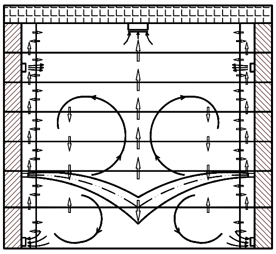


图 1 分层空调大空间的
多区热质平衡模型

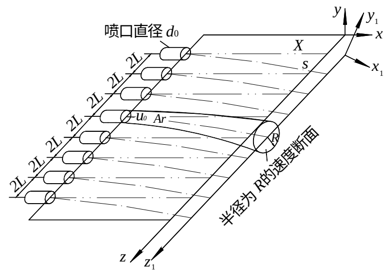


图 2 多股平行非等温射
流的卷吸流量模型

图 1 给出了采用分层空调大空间的多区热质平衡模型的示意图，下部是由多股平行非等温射流以及均匀回风作用下的空调区，上部为进风与排风作用产生的非空调区。区域划分的方法是，将工作区作为一个区域，射流体所在高度空间作为一个区域，非空调区按 BLOCK 数划分为若干区域，同时围护结构除了地面和屋顶以外，其它均按照空间区域范围划分成相应的区域。可见，只要解决了多股平行非等温射流的卷吸流量计算、含辐射的封闭系统多表面热平衡方程求解以及区域间由于射流卷吸引起的空气流动问题就可以将模型应用于分层空调大空间的垂直温度分布预测。

对于多股平行非等温射流的卷吸流量，首先需要研究多股射流的重合特性。笔者根据动量原理以及射流断面几何交叉关系（如图 2），推导了射流重合的平均速度修正系数 K_{vm}[5]。

$$K_{vm}=\sum_{i=1}^{5}e_i(s/L)^{i-1} \tag{3}$$

式中，e_i 为系数，分别地 e_1=7.690×10^{-1}，e_2=5.310×10^{-2}，e_3=-5.347×10^{-4}，e_4=2.514×10^{-5}，e_5=-0.454×10^{-9}；s 是指多股射流的射程，通过多股射流的轨迹方程积分得到；L 是指相邻两股射流的轴心间距的一半，即相邻两个射流喷口的半间距。然后，推导出了多股射流的流量计算公式（减去送风量就是卷吸流量）[5]：

$$V_z=4u_mK_{vm}[F_{\text{int}}+Cs^2(\frac{\pi}{2}-\arccos\frac{L}{0.22s})+\frac{\sqrt{0.0484s^2-L^2}L}{2}]\text{，}R>L \tag{4}$$

$$V_z=0.006\pi u_0d_0s^2/(as+0.145)\text{，}R\le L \tag{5}$$

式中，R 射流半径；u_0 为送风速度；d_0 为送风口直径；a 为送风口紊流系数；u_m 为单股射流轴心速度；F_{int} 为中间变量，见公式（6）；常数 C = 6.223×10^{-3}。

$$F_{\text{int}}=\sum_{i=0}^{3}g_i(s/L)^i \tag{6}$$

式中，g_0=1.966×10^{-2}，g_1=-4.388×10^{-2}，g_2=2.910×10^{-4}，g_3=7.305×10^{-7}。

对于围护结构内表面，建立如下的热平衡方程：

$$K_i(t_{zh,i}-\tau_i)+\alpha_{n,i}(\tau_i-t_i)+\sum_p\alpha_{r,ip}(\tau_p-\tau_i)=0 \tag{7}$$

式中，K 是围护结构传热系数；t_{zh} 是外表面综合温度；τ 为内表面温度；t 为空气区温度；α_n 为内表面对流换热系数；$\alpha_{r,ip}$ 是表面 p 对 i 的辐射热换热系数，用下式计算：

$$\alpha_{r,ip} = 5.67\times10^{-8}\frac{(273+\tau_p)^4-(273+\tau_i)^4}{\left(\frac{1-\varepsilon_i}{\varepsilon_i A_{w,i}}+\frac{1}{\varphi_{i.p}A_{w,i}}+\frac{1-\varepsilon_p}{\varepsilon_p A_{w,p}}\right)(\tau_p-\tau_i)} \tag{8}$$

式中，ε 为表面辐射发射率；A_w 表面的面积积；φ 为表面间辐射角系数，由代数法或 Montcarlor 法计算[8]。

此外，垂直壁面换热与流动规律与 BLOCK 模型介绍的壁面流子模型[7]方法相同，认为由自然对流驱动壁面附近空气流动，并通过相应判断方法确定垂直流动以及回流空气量。最后，通过对各个区域进出空气量以及热量建立平衡方程使得整个模型封闭。

3 基于多区热质平衡模型的分层空调设计方法

在已知工作区温度以及室外温度条件下，设计计算过程与垂直温度分布的预测是统一的，通过多区热质平衡模型求解垂直温度分布，同时计算空调区得热，最后便可确定满足工作区温度的分层空调方式及喷口尺寸、数量、出风速度等设计参数。另外，对于上部非空调区机械通风系统，考虑到最大限度利用自然风、减小对空调区的热转移以及经济性等的多重要求，其合理设计属于多参数优化问题，目前有还待进一步研究。图 3 描述了含机械通风系统优化的基于多区热平衡模型的分层空调设计流程。流程图中，垂直温度分布预测需要一个叠代求解过程，分层空调气流组织设计与大空间垂直温度分布预测是交叉的。这种交叉就是要保证满足空调区设计温度，并同过多股射流流量的计算得以实现。最终，当垂直温度分布前后两次叠代值满足计算精度时，整个过程才结束。

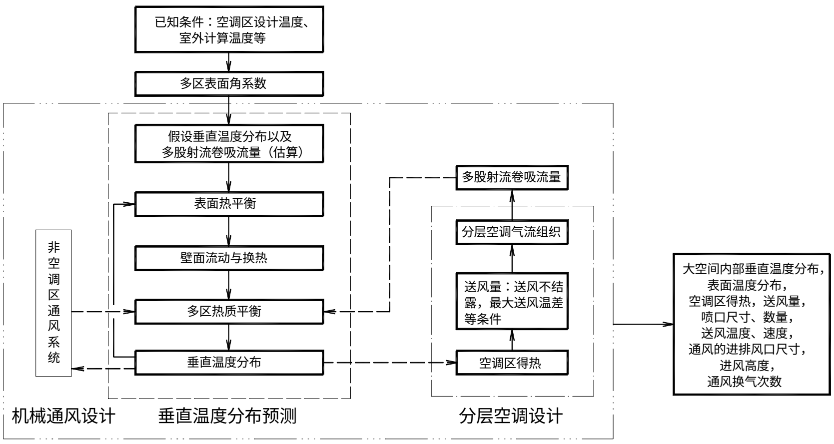


图 3 基于多区热质平衡模型的分层空调设计流程（含非空调区机械通风）

4 分层空调设计方法的应用及比较

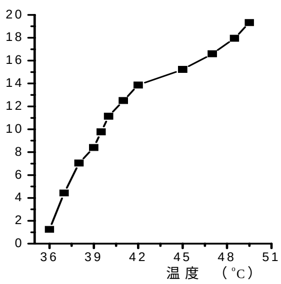


图4 围护结构外表面综合温度分布

在程序计算过程中，本文构造了一系列局部叠代和全局叠代，引入了变欠松弛技术，叠代初期取用大的松弛因子，后期不断减小。为考察叠代的收敛性，分别判别了区域温度、区间质量流叠代误差两个指标。

计算对象取一 45 m×30 m×20 m 大空间建筑。工作区高为 2.5 m。考虑到工作区人员设备等热源，取内热 12 W· m^{-3}。空调区湿量 20

kg· h^{-1}（需判断送风结露与否）。气流计算中取射流垂直落差为水平射程的 1/4。工作区平均风速 0.25 m/s。将建筑空间垂直划分为 12 个区域（先根据工作区高度以及射流特性确定下面两个区高度，再均分上部空间为 10 个区）。

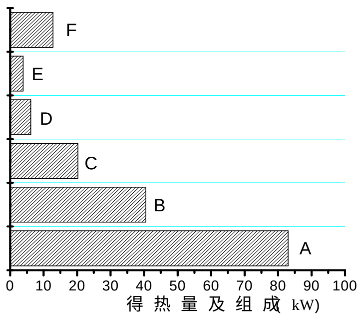
上部不设通风。空调系统回风比为 100%。喷口紊流系数取 0.066。墙体、屋顶的热传导系数分别为 1.27 和 0.49 W· m^{-2}· K^{-1}，地面绝热。各个内表面的发射率均取 0.91。空调区设计温度 26 °C，相对湿度 50%。室外空气温度 30.4 °C（四个外表面综合温度取相同分布，见图 4；屋顶综合温度 51°C），相对湿度 70%。用 I 壁面表示不设送风口的壁面，用 J 壁面表示设置送风口的壁面。关于分层空调设计计算结果如表 1。

表 1 本文方法计算结果

喷口直径	送风速度	送风温度	送风量	空调得热	风口高度	风口数量
200 mm	6.70 m/s	16.0 °C	24860 m^3/h	84.0 kW	6.1 m	28

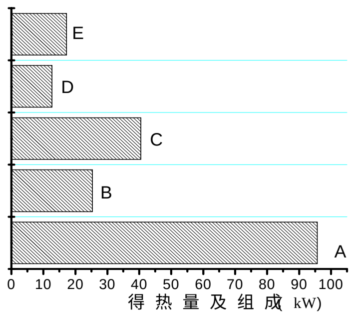
下面将本文方法与前述的中国建筑科学研究院的试验基础上得出的方法进行对比。简便起见，两者计算都在稳态假设下进行。对于原来方法，围护结构外表面综合温度取设定分布（见图 4）的平均值。计算条件都不变。

图 5 和图 6 给出了两种方法计算所得的空调区的得热及其各组成部分。原来方法中空调区得热由空调区内热源、空调区外围护结构传热、对流热转移以及辐射热转移组成[3]；本文方法中空调区得热则包括空调区内热源、地面吸收辐射放热、非空调区对空调区对流热转移、非空调区对空调区温差热转移、边界层对空调区对流热转移。本文方法和原来方法计算的空调区的得热量分别为 84.0 kW 和 95.6 kW，原来方法相对偏大 13.8%；两者的组成不同，但实际上图 5 中 C、D、E、F 四项总和与图 6 中 B、D、E 三项总和是相当的。



A－空调区的总得热
B－空调区内热
C－地面吸收辐射放热
D－非空调区对空调区对流热转移
E－非空调区对空调区温差热转移
F－边界层对空调区对流热转移

图 5 本文方法计算的空调区的得热及其组成



A－空调区的总得热
B－非空调区对空调区辐射热转移
C－空调区内热
D－空调区外围护结构传热
E－非空调区对空调区对流热转移

图 6 原来方法计算的空调区的得热及其组成

图 7~9 显示按两种方法计算得出的空间以及墙内表面温度分布比较情况。另外按本文方法计算得出的地面和屋顶内表面温度分别为 27.7 °C 和 33.5 °C；而按原来方法分别为

26 ℃和 30.7 ℃。分析可知，原来方法的非空调区温度的确定和内表面温度的计算是欠妥的，公式（1）缺乏任意条件下应用的依据，公式（2）没有辐射换热对热平衡的作用。这就造成了图 7~9 中，原来方法计算的各个温度值明显低于本文的方法。由此，再结合图 5 和图 6，非空调区对空调区的总辐射转移量应该是本文方法较大，而总的空调区得热又是原来方法较大，可见原来方法的非空调区对空调区的总对流热转移量要大于本文方法。

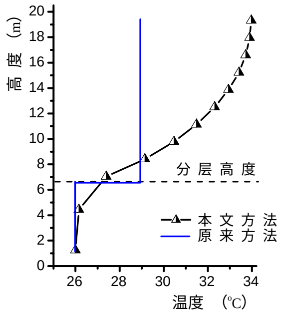


图 7 两方法空间温度比较

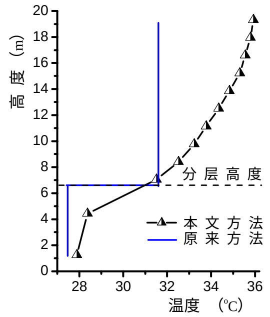


图 8 两方法 I 壁面温度比较

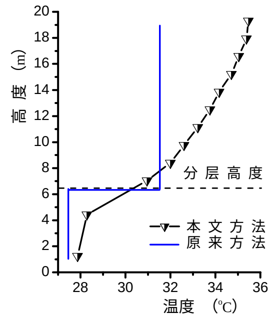


图 9 两方法 J 壁面温度比较

最后，需要指出的是，本文在稳态条件假设下计算的得热，实际上与空调区实际的负荷的概念是不同的。关于“得热”、“负荷”、“瞬时得热”等概念，我们将在动态模型的研究中严格界定，关于实际的分层空调设计也需要在动态负荷计算基础上进行。

5 新方法与 CFD 比较

6 结语

首先，本文探讨了大空间建筑分层空调技术研究以及应用的背景，分析了原方法在非空调区温度确定、表面温度计算等方面缺乏理论可靠性。

随后，本文又介绍了 BLOCK 模型在大空间建筑垂直温度分布研究中的应用，结合了建研院空调所关于多股平行非等温射流试验的结论以及相关的射流卷吸研究，建立了一种基于多区热质平衡模型的分层空调设计计算方法。

为了实现基于多区热质平衡模型的分层空调设计，本文给出了分层空调设计过程、通风系统优化以及垂直温度预测相交叉的计算流程。

最后，基于稳态过程的假定，本文将这一新的分层空调设计方法应用于一实例，比较了本文方法和原来方法的结果。结果显示，本文方法更具合理性、理论性。

本文为分层空调设计提供一种方法与思路，也为分层空调理论的进一步完善提供了理论依据。

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大空间建筑室内空调流场数值模拟与分析

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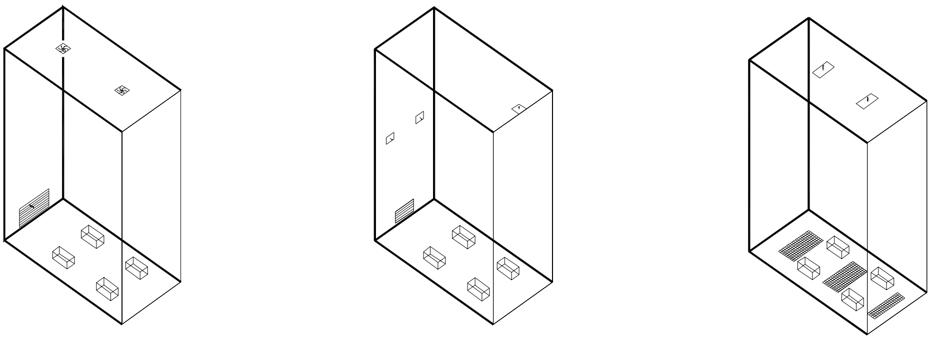
摘　要　大空间建筑室内舒适度与节能的研究很大程度上依赖于空调送风方式。本文通过 CFD 数值模拟，研究了三种典型送风方式下大空间的气流与温度分布特性，进而讨论了不同送风方式的节能效果，为大空间建筑空调设计提供了依据。
关键词　大空间建筑； CFD； 数值模拟；节能
Abstract The thermal comfort and energy saving in large spaces mainly lie on the air supply of air conditioning system. This paper studies the temperature and velocity distributions in a large space under three representative air supply methods with the numerical simulation by CFD technique and discusses the results of energy saving. The results of this paper will provide a foundation for the air conditioning design in large spaces.
Key words large space; CFD; numerical simulation; energy saving

1 引言

大空间建筑由于空间高大，影响因素多且复杂，一般空调负荷较大[1]。大空间空调设计成功与否的主要参考指标为负荷较小与热舒适良好，因此研究大空间建筑室内空调流场就非常重要。相对于实验和现场实测，利用 CFD 技术进行全场的模拟是一种即可靠又最为经济的手段。本文将从 CFD 模拟入手，分析几种大空间空调方式下的室内速度场和温度场，以此研究送风方式对大空间建筑空调负荷和舒适度的影响。

2 大空间空调方式

典型的大空间空调方式包括顶送全室空调、侧送分层空调和下送置换空调三种。顶送全室空调采用顶棚喷设置喷口或旋流风口和空间下部布置回风口实现；侧送分层空调以在侧墙中部以下设置喷口、同侧墙下部近地面处设置回风口并辅以上部空间的通风（机械通风或自然通风）实现；下送置换空调则以地面或近地面侧墙处设置风口（一般为置换送风口）和空间上部设置回风（排风）口实现。从送风气流特性看，前两者都是高速送风，送风温差大，且诱导大量周围空气，能达到较远的区域；而置换空调一般以不大于 0.3m/s 的速度送风，送风温差小，不需要卷吸周围空气，送出空气先在地面上蔓延形成“冷空气湖”，当遇到热源便会沿热源攀升，温度逐渐升高。下图 1（a）、1（b）、1（c）分别为一含热源大空间对称单元在三种空调方式下的风口布置情况，也是模拟计算的几何模型。



（a）顶送全室空调　　（b）侧送分层空调　　（c）下送置换空调

图 1　含热源大空间对称单元风口布置示意图

3　数值模拟与分析

3.1　数学模型

如上图计算对象，本文采用的大空间建筑单元高度为 13m，半宽度 8m，长度 4m。地面上均匀放置四个相同的尺寸为 1m×0.5m×0.5m 的热源。模拟采用的数学模型通用表达式如下[2]：

$$\frac{\partial}{\partial t}(\rho\phi)+div(\rho\vec{u}\phi)=div(\Gamma_{\phi}grad\phi)+S_{\phi} \tag{1}$$

上述通用控制方程包含了连续性方程、三个方向动量方程和能量方程。其中，ϕ 为通用变量，S_{ϕ} 为广义源项，Γ_{ϕ} 为广义扩散系数。本文采用的紊流模型为 Q. chen 等人研究的室内流动零方程模型，其紊流粘度采用下式定义[3]：

$$\mu_t = 0.03874\rho vL \tag{2}$$

其中，μ_t 为紊流粘度，ρ 为局部空气密度，v 为局部空气流速。L 为距离最近壁面的距离，0.03874 为经验系数。本文采用通用 CFD 软件进行模拟，用控制容积法离散偏微分方程组；采用 SIMPLE 算法求解速度压力耦合方程；采用 Boussinesq 假设，即除动量方程中的浮力项外密度按常数处理；考虑表面间辐射换热，用半球面模型计算计算辐射角系数，当遇见遮挡时用 Monte Carlo 法[4]。

边界条件除了送回风条件以外，其余取用相同的值。为了使三种空调方式下工作区都达到平均 25 ^{o}C 左右的设计条件，本文进行了大量的试算确定了送回风边界条件。各边界条件列表如下：

表 1　边界条件

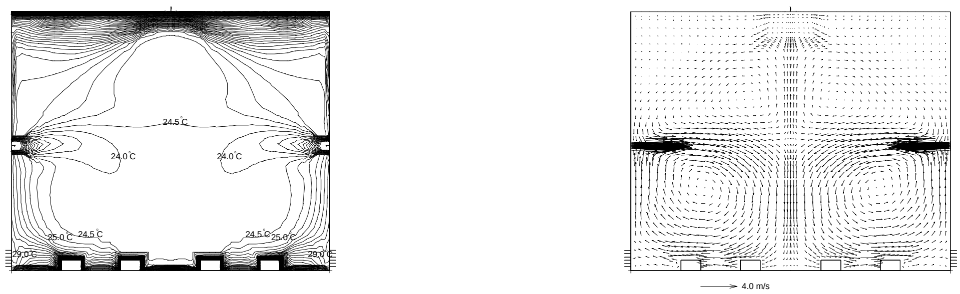
共同边界条件	热源	外墙	屋顶	地面
	2500 w/个	30 w/m^2	350 w/m^2	120w/m^2
各空调方式的边界条件	边界	全室空调	分层空调	置换空调
	送风	0.5m×0.5m 10.0m/s　19.0^{o}C	0.5m×0.5m 4.0m/s　19.5^{o}C	2m×1m 2m×0.5m 0.3m/s　22.0^{o}C
	回风	2m×1.2m	1m×0.5m 回风比 85%	
	排风		0.5m×0.5m 排风比 15%	1m×0.5m

3.2　结果与分析

取送风口中心所处的纵断面来考察不同空调方式的速度和温度分布特点，其中全室空调为对称单元长向中心处，分层空调和置换空调都为距离长向一侧对称面 1m 处。将数值模拟结果给出如下（按宽向对称面镜像）：

（a）送风口中心断面温度分布　　　　　　　　　　（b）送风口中心断面速度分布

图 2　顶送全室空调的流场图



（a）送风口中心断面温度分布　　　　　　　　　　（b）送风口中心断面速度分布

图 3 侧送分层空调的流场图

（a）送风口中心断面温度分布　　　　　　　　　　（b）送风口中心断面速度分布

图 4 下送置换空调的流场图

从上述结果看，全室空调方式下，整个大空间室内温度分布较为均匀；上下垂直温度梯度小；需要很大的送风量及送风速度才能保证工作区良好的温度条件。分层空调方式下，工作区温度相对均匀；垂直温度明显；送风速度大；工作区大部分在回流区；适当提高排风比可以减少上下热转移和降低工作区温度。置换空调方式下，下部热源高度范围内温度垂直梯度较大，中部温度变化变缓，上部梯度又增大；全排风运行较为经济；送风在下部形成了“ 冷空气湖 ”，遇热源上升，并使得热源上方形成明显羽流。

从回风利用性来看，全室空调回风温度较低，提高回风比是经济的；分层空调在减少上下区域热转移量基础下，提高回风比也较经济；置换空调的上部空气温度很高且污浊，利用回风是不合适的。反过来，一般而言置换空调新风比最大，分层空调次之，全室空调最小。

从舒适度和室内空气品质来分析，置换空调新风比大或多为全新风，且未经混合室内空气直接供给下部人员，新风利用情况最好，但容易造成脚部过凉；分层空调能创造较好的回流区，避免脑后风，但新风利用不如置换空调；全室空调的新风到达工作区时已经历较远距离，由于完全参混了室内空气，其新风利用情况最差。

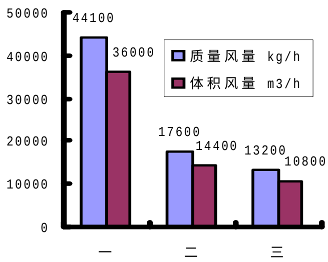


图 5 三种空调方式送风量

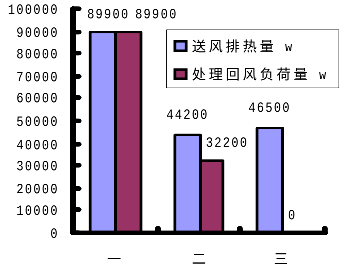


图 6 三种空调方式排热与处理回风冷量

从模拟的结果中，我们可以得到三种空调各自的送风量、送风排热量以及处理回风的冷量。这几个量是分析大空间建筑空调节能性的重要指标。图 5 给出了三种空调方式的质量和体积送风量；图 6 给出了三种空调方式的送风排热量和处理回风冷量（分层空调回风比按 85%，置换空调全新风、全室空调全回风）。横坐标 “ 一 ” 代表全室空调方式，“ 二 ” 代表分层空调方式，“ 三 ” 代表置换空调方式。数值为镜像后的值，是实际计算值 2 倍。

根据图 5，为了达到工作区相同的温度条件（平均约 25 ºC），三种空调方式的送风量差别很大，其中置换空调和分层空调两者相差不多，按体积风量分别只为全室空调的 30%和 40%。同时送风温度也是置换空调最高，为 22 ºC；分层空调为 19.5 ºC，全室空调为 19.0 ºC。可见，置换空调需要的空气处理设备容量最小，分层空调略大些，而全室空调最大。如图 6 所示，全室空调由于送风量绝对最大，因此送风排热量是最大的，但其结果是全室降温，无效排热占很大比例。如果都以相同回风比，那么可以看出置换空调和分层空调相对于全室空调，其冷负荷节约率将分别达到 51.7%和 49.2%。此外，置换空调虽然送风量小于分层空调，但其排热量反而稍大于分层空调。全室空调取用全部回风，则其处理回风的冷量恰好等于送风排热总量，可见能耗巨大。

4 结语

通过本文的研究，我们可以得出以下结论：

① 大空间建筑中，置换空调能保证最佳的舒适度和室内空气品质；分层空调能保证良好的室内条件；而全室空调不易达到前两者的室内条件。

② 达到相同的工作区温度，全室空调需要很大的送风量和送风速度；分层空调需要较小的送风量和较大送风速度；置换空调则只要很小送风量和极低的送风速度。

③ 相同条件下，置换空调的设备容量最小，分层空调的略大，全室空调最大。

④ 按照本文计算条件，即使都按相同回风比运行，置换空调和分层空调的节能率也能达到 50％左右。

本文采用数值模拟技术，从室内条件和节能角度分析和比较了三种典型空调方式在大空间建筑中应用的合理性，为大空间建筑空调设计提供了依据。本文的研究也显示了 CFD 将是现代化工程设计中不可或缺的工具。

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国内太阳能热水器建筑一体化研究概况

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摘　要　介绍了我国太阳能热水器建筑一体化发展的背景及历史沿革；论述了国内在太阳能热水器与建筑一体化方面的研究现状，并分析了国内太阳能热水器与建筑一体化的发展动向及其市场前景。

关键词　太阳能；热水器；建筑一体化

The development of building integration of solar water heater

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Abstract　The history of building integration of solar water heater is introduced. After that, the development of building integration of solar water heater in China is discussed, the development trend and market potential of building integration of solar water heater are analyzed.

Keywords　Solar energy; Water heater; Integration of building

0　引言

在能源危机和环境污染的双重压力下，太阳能作为一种取之不尽且无污染的能源，已成为当前国际能源开发利用领域中的新热点。太阳能热水器在太阳能热利用领域中，技术最成熟，应用最广泛，产业化进程最迅速[1]。但由于国内太阳能热水器生产厂商与建筑师在如何实现太阳能热水系统与建筑物有机结合方面的研究力度不够，既影响了太阳能热水器的进一步普及，又影响了城市的景观。本文将重点介绍国内在太阳能建筑一体化方面的研究现状，分析太阳能热水器建筑一体化的发展动向及市场前景。

1　我国太阳能热水器建筑一体化发展的背景与历史沿革

我国地处北纬 18o－54o之间，幅员广阔，年日照时间大于 2000 小时的地区约占全国总面积的三分之二，有着十分丰富的太阳能资源。在能源危机和环境污染的双重压力下，我国的太阳能热水器产业迅速发展。进入上世纪 90 年代，我国已建立了全玻璃真空集热管和平板集热器工业。但随着城市建筑密度的增加及建筑的高层化，如何在建筑物上有限的空间充分利用太阳能资源，并使太阳能热水系统能够与建筑物有机结合，显得尤为迫切。

为促进太阳能热水器产业的可持续发展，1998 年 10 月国家经贸委和建设部在昆明召开了“ 太阳能技术与建筑技术研讨会 ”，提出了我国太阳能系统建筑一体化问题，分析了太阳能系统建筑一体化的必要性及紧迫性。2001 年 12 月建设部在南京再次研讨了如何实现太阳能热水器与建筑有机结合这一设计理念[2]。在这种设计理念的指导下，国内太阳能热利用领域的科研机构和企业都在努力寻求实现太阳热水器与建筑结合的最佳方式。

2　太阳能热水器建筑一体化的研究现状

随着社会的发展，一方面城市住宅建筑日益高度化，传统太阳能热水器将面对安装空间不够这一严峻现实。另一方面，人们对城市景观日益看重。人们希望太阳能热水器既能提供生活热水，同时又不影响城市景观。为实现热水器产业的可持续发展，国内一些相关科研机构与企业正致力于太阳能热水器与建筑一体化方面的研究。这方面的研究主要包括新型集热器的研制、太阳能热水器建筑一体化工程实践及与建筑有机结合的分体式太阳能热泵热水器的研究。

2.1　新型太阳能集热器的研制

太阳热水器建筑一体化的要点在于把太阳热水器视为建筑的一部分，在工程设计、设备安装、设备色彩、工程尺度等方面与建筑的功能、造型、色彩、风格、质感等和谐一致。目前普遍采用的平板型集热器及真空管集热器，难以满足太阳能热水器建筑一体化的要求。为实现太阳能集热器于与建筑的和谐统一，昆明新元太阳能设备厂研制了一种新型太阳能集热器—新元热板（如图 1 所示）。该集热板可安装在坡屋面上，作为屋面构件，除集热功能外，还具有建材的围护、保温、隔热、防水等功能，并能在形态和色彩上与建筑融合。

同其它集热器相比，新元热板具有模块化和建材化等特点。新元热板具有固定的厚度和宽度，其长度可在 9 米范围内任意调节，并可根据建筑设计要求适量弯曲、起翘、透光、截角。此外，由于具有集热、防水、保温、隔热等功能，该热板既具有太阳集热器功能, 又能独立构成建筑物的太阳能屋面或墙面。

图 1　新元热板（昆明新元太阳能设备厂生产）

2.2　太阳能热水器建筑一体化工程实践

由新元热板和相关部件组成的太阳热水系统与建筑结合，构成了一种特别的坡屋顶太阳热水器一体化建筑。在由云南红塔屋业发展公司开发,云南省设计院设计的昆明红塔金典园住宅区(如图 2 所示)及由昆明市官度区土地房屋开发经营总公司开发,昆明官房建筑设计有限公司设计的云南蒙自红竺园住宅区成功地安装了由新元热板和相关部件组成的太阳能热水系统。该种太阳热水系统按建筑单元设计，集热板安装在建筑坡屋面上，外观、色彩、尺度与建筑协调，热水箱和相关设备放置在建筑楼梯间顶部的设备间中，避免了以往太阳能热水系统对城市景观所造成的破坏。

此外，此种太阳热水系统要求与住宅建筑统一设计，同步施工。热水系统水管布置于建筑墙体内，既减少了系统的热损，又避免了以往安装太阳能热水器水管时穿墙打洞所造成的不安全因素。

图 2　太阳能热水器与建筑一体化示范小区—昆明红塔金典园住宅区

2.3　与建筑结合的分体式太阳能热泵的研究

传统的太阳能热水器，一方面受气候的影响，不能全天候有效运行，年热水提供率低。另一方面，由于住宅建筑的日益高层化，传统太阳能热水器将面对安装空间不够这一严峻现实。所有这些，极大地阻碍了太阳能热水器的进一步普及。

在此种背景下，研制能与建筑有机结合的、全天候的太阳能热水器将具有广阔的市场前景。太阳能热泵热水器能很好地满足这一要求。上海交通大学教育部太阳能发电与制冷工程研究中心研制了一种直膨式太阳能热泵热水器（如图 3 所示）。该热泵热水器考虑到对于高层或多层建筑非顶层用户普遍存在的集热器安装问题，将太阳能热泵热水器样机设计成分体式结构，即将太阳能集热器/蒸发器作为一个单独部件，根据实际情况，可倾斜安装在南向屋顶之上，也可挂装在建筑物南向外墙或阳台之上。压缩机、冷凝器、储热水箱等作为另一个整体放置在室内，既便于系统的控制和维修，又可减少水箱的散热损失；室内外部件之间采用制冷剂管路连接。同传统的太阳能热水器相比，分体式太阳能热泵热水器不仅大大简化了系统的安装过程，降低了安装费用，而且易与建筑实现一体化集成，尤其适合于高层或多层建筑。

图 3　直膨式太阳能热泵热水器

3　太阳能热水器建筑一体化进程中的研究动向及市场前景

3.1　研究动向

由于能源危机的影响，建筑节能已引起世界各国的普遍重视。传统的压缩式空调系统，不仅消耗常规能源，而且污染环境。因此，研究新型清洁、节能的采暖及制冷装置，势在必行。现行的太

阳能热水系统，尚不能满足建筑采暖、空调的双重功能。另一方面，研究表明太阳能制冷在技术上是完全可行的[3,4]。为进一步扩大太阳能热水系统的市场份额，一些研究机构及太阳能设备生产厂家正致力于以下方面的研究:

（1）与热泵结合，冬季室内地板采暖，全年供生活热水的住宅太阳能复合热水系统的研究

与常规的空调机组、电加热器相比，太阳能地板采暖复合热水系统（如图 4 所示）不仅可以节约高品位的电能，而且，由于地板采暖温度波动较少，可有效提高人体舒适度。此外，我国有着十分丰富的太阳能资源，年日照时间大于 2000 小时的地区约占全国总面积的三分之二；另一方面，我国绝大部份地区冬季较寒冷。随着人们生活水平的提高，冬季采暖的能耗将逐步增加。因此，顺应建筑节能的潮流，研制太阳能地板采暖复合热水系统，将进一步扩大太阳能热水器的市场份额。

图 4　太阳能地板采暖复合热水系统

（2）基于建筑一体化的太阳能冷暖空调与热水复合系统的研究

太阳辐射能与制冷用能需求在时间和地域上的分布规律高度匹配。因此，开发太阳能热驱动的冷暖空调与热水复合系统，部分替代夏季白昼电网电力空调峰值负荷及冬季供暖，对人居环境保护和缓解城市电网峰负荷具有重要意义。随着太阳能吸收式制冷及吸附式制冷研究的进一步深入[5, 6]，太阳能热水器与吸收式或吸附式制冷装置有机结合的太阳能冷暖空调与热水复合系统，将逐渐成为太阳能热水器的另一发展方向。上海交通大学教育部太阳能发电与制冷工程研究中心在该方面进行了深入的研究，目前已成功研制出了太阳能冰箱热水器复合机[7]。该复合机在提供生活热水的同时，还可有效制冷。

此外，在太阳能热水器建筑一体化进程中，传统的太阳热水器的角色发生了根本变化，由相对独立、与建筑开发商毫无关联、可任意安装的一个装置，变换为与建筑密不可分的建筑构件。因此，太阳能热水系统的设计、营销、安装验收、售后服务等环节需要太阳能设备生产及安装厂家、建筑规划设计部门、建筑开发商等共同参与、共同探索及共同完善。住宅建设管理等职能部门将对太阳热水器的安装制定相关的法规，以引导太阳能热水器行业的健康发展。

3.2　市场前景

随着人们生活水平的提高，建筑能耗已接近发达国家水平。为减少建筑能耗，建设部制定了«建筑节能技术政策 1996－2010»，将太阳能热利用纳入国家建筑节能的范畴，为太阳能产业的发展奠定了政策基础。据统计，1995－2000 年间，全国新建住宅 55 亿平方米，到 2010 年新建住宅将增至 150 亿平方米[1]。按 20%的新建住宅安装这种基于建筑一体化的太阳能热水系统计算，其市场前景十分广阔。

4 结语

随着社会的发展，一方面城市建筑密度日益增加，楼宇日益高层化，有限的建筑空间难以安装足够多的传统的太阳能热水器。另一方面，传统的太阳能热水器在一定程度上影响城市景观。太阳能热水器建筑一体化是绿色能源和新建筑理念的有机结合。在国家政策的引导下，太阳能热水系统与建筑的有机结合，将成为未来太阳能热水系统的发展趋势。

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太阳能集热影响因素及采暖应用分析

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摘　要　对一天中任意倾斜角度，任意朝向的太阳能集热面所能获得的太阳辐射量进行计算，研究不同集热器形式、地理位置、摆放形式等对一天中收集的可用热量的影响及水箱内温度变化，并举例计算太阳能在采暖应用中的节能效果。
关键词　太阳能；影响因素；采暖；太阳能保证率

Analysis of solar heat collection factors and application of heating

By Chen Peng★, Yu Guo Qing

Abstract　On the basis of computing the total solar irradiation of a terrestrial surface of any orientation and tlit with any incident angle., we analysis the collector form,specific location and others affect on availiable solar energy and temperature variable in the storage tank. In the end , we evaluate the economy effects on engineering applying.
Keywoeds　solar energy, collection factors, heating , solar energy assurance
★University of Shanghai for Science and Tecnology, China

0　引言

太阳能作为一种取之不尽，用之不竭，清洁安全的能源，越来越受到人们的关注，各种利用太阳能的技术措施不断推出。如太阳辐射能可通过光—电转化为电能；可通过光—化学转化为化学能，例如制氢等；可通过光—热转化为热能，这是目前技术较为成熟，成本低廉，因而应用最为广泛的形式。

光—热转化成的热能主要以水为传输介质，可用于采暖、制冷、提供家用热水、产生动力、蒸馏及工艺用热。这些场合需要提供不同的热水温度，如淋浴用热水水温为 40℃，采暖所需水温最低 35～40℃，单效吸收式制冷所需温度为 70℃~110℃。

集热器所能提供的热水温度受很多因素的影响，如集热器形式、摆放位置、蓄热水箱的容积等，这些因素相互影响，对太阳能在实际的选择应用带来不便，下文中将通过模拟计算，对这些影响因素分别进行讨论分析。

1　太阳能集热的影响因素

1.1　集热器形式的影响

目前市场上常见的太阳能集热器主要有平板型集热器，真空管集热器及热管集热器，其中前两者多在实际工程中应用。与聚焦型集热器相比，平板集热器具有结构简单、可固定安装（不需跟踪太阳）、可同时利用直射辐射和散射辐射以及成本低等优点。但因它不具备聚光功能，热流密度较低，所以工作温度限于 100℃以下。真空管集热器采用高真空双层玻璃管结构，减少了吸热面与透

明盖层之间的对流换热损失，所以它可以在更高温度下运行。同时。真空管集热器不必跟踪太阳，在太阳光入射角较低时仍具有较高的效率，因此，更适合于应用于吸收式空调系统。图 1 显示了在 1 月 1 日，在上海地区（东经 121.43°,北纬 31.2°）水箱容积 50 升，集热器倾角 30°，朝向正南条件下，应用高效平板型和真空管型集热器所能获得的水温变化及效率曲线。由图中可以看出，在相同的条件下，真空管型比平板型可以获得较高的热水温度，同时，集热效率也较高。普通平板集热器的集热温度和效率更低。

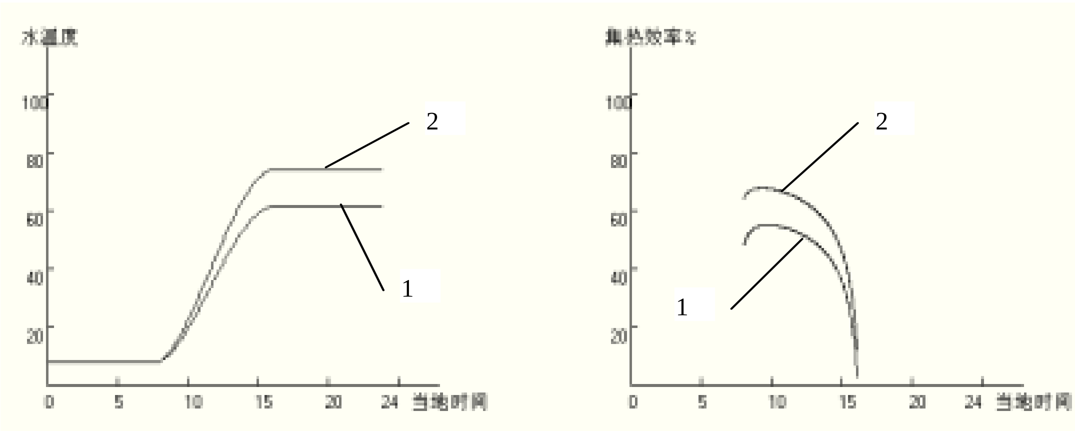


图 1　1、平板型 2、 真空管型

1.2　集热器朝向

为了得到最大的年日射量，集热器应面朝赤道方向，图 2 显示了（上海地区、水箱容积 50 升、集热器倾角 30°）平板集热器朝正南方、偏东 10°、偏西 10°情况下对集热温度的影响。由图中曲线可以看出，无论在冬季(下面一簇曲线),还是夏季(上面一簇曲线),集热器朝向偏西可以比朝向正南或偏东获得较多的集热量。

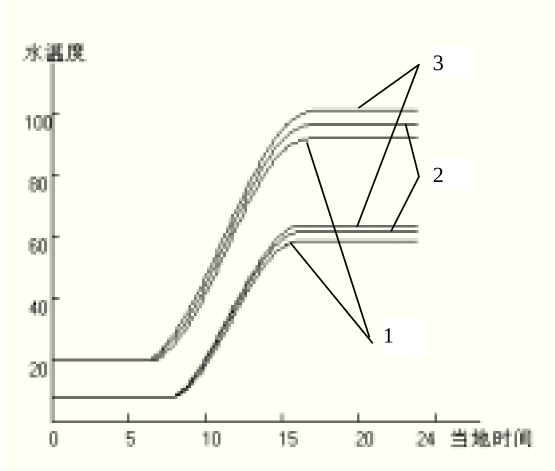


图 2 1、偏东 10 2、正南 3、偏西 10

1.3　集热器倾角　图 3 显示了上海地区，水箱容积 50 升，朝向正南条件下，应用平板型集热器冬季（1 月 1 日），夏季（8 月 1 日）倾角分别为 20°，30°，40°条件下，水箱内随温度的变化情况。由图中可以看出，为了获得更多的太阳能，对于全年供热的集热器，倾角应取当地纬度φ；对于主要用于冬季（下面一簇曲线）的集热器，其倾角应增大至φ+10°；应用于夏季（上面一簇曲线）的集热器则倾角应为φ-10°。

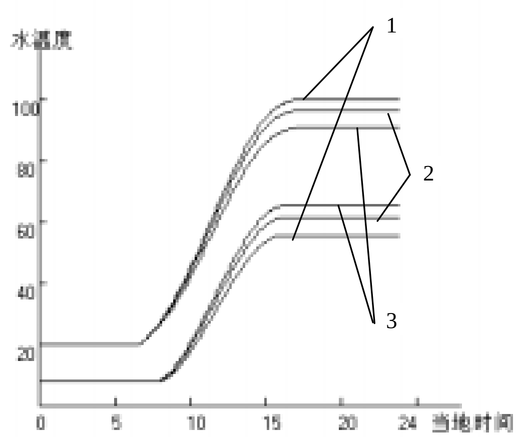


图3 1、倾角20 2、倾角30 3、倾角40

1.4　集热温度的影响　集热温度是根据用户要求设

定的，当水温高于此温度后，开始向用户提供热量。集热温度高将带来下列一些缺点：

a、 将使的大量的太阳能用于提高初始水温；

b、 水箱中的水温高将增加水箱及管道的热损失，额外增加保温材料成本；

c、 较高的集热温度将导致集热效率的下降，使得集热量减少。

因此在选择时应尽可能降低集热温度的设定值。下表是在水箱容积为 50 升，8 月 1 日，倾角 30°，单位真空管集热面积在集热温度不同时所收集的热量（水箱内水的初温为 12℃）：

集热温度（℃）	30	50	90
一天中收集的可用热量（高于集热温度后）（MJ）	17.2152	11.448	9.72

2 太阳能采暖应用

太阳能供暖系统，目前尚处于试验阶段，技术累积得还不够，经济性也有问题，所以还没有标准的设计方法。在多数情况下，是在常规的系统上增添集热器等设备，依靠利用太阳能所节约的能源来回收设备投资。因此，需要估算年供暖、供热水负荷以及计算太阳能利用量[3]。下面就以一个例子作相应的计算。

上海地区一幢四层办公大楼[4] ，总建筑面积 1859m^2,工作时间 8：00~18：00，冬季采暖温度为 20℃，夜间值班温度 5℃，如采用太阳能供暖方式，确定其集热面积及太阳能保证率。

由文献[4]，从 6℃开始计算，工作时间供暖小时数为 718 小时，供暖总负荷为 42.7kWh/m^2,平均负荷为：

$$L=\frac{42.7\times1000}{718}=59.47W/m^2$$

值班时间供暖小时数为 1339 小时，供暖总负荷为 11.6kWh/m^2,平均负荷为：

$$L=\frac{11.6\times1000}{1339}=8.66W/m^2$$

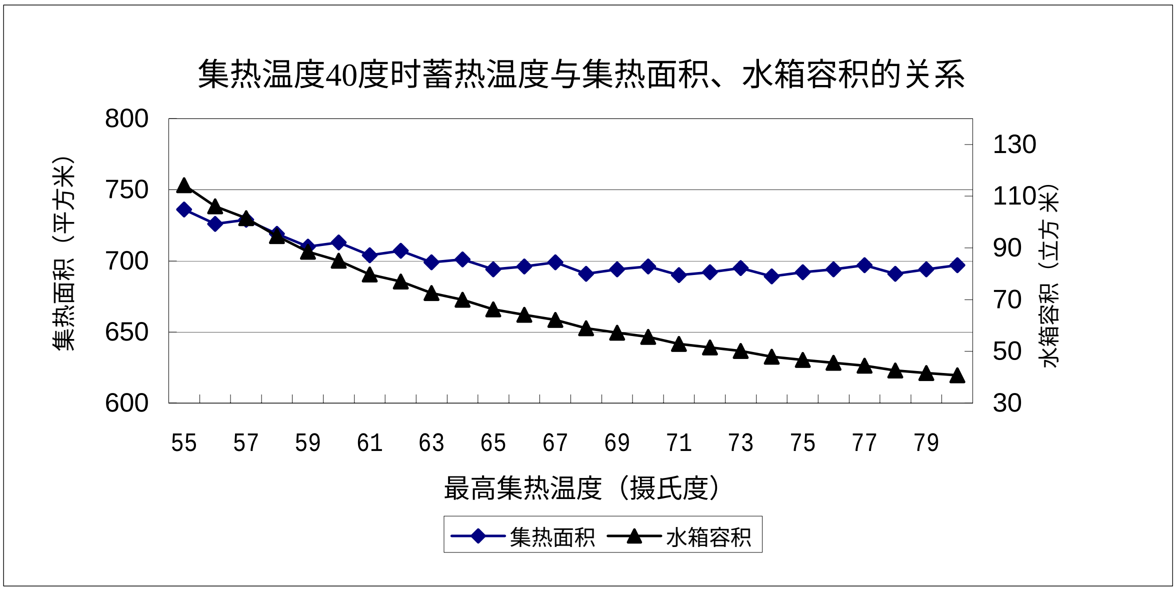
假定采暖集中在 12、1、2 三个月内，则 12 月的负荷为：

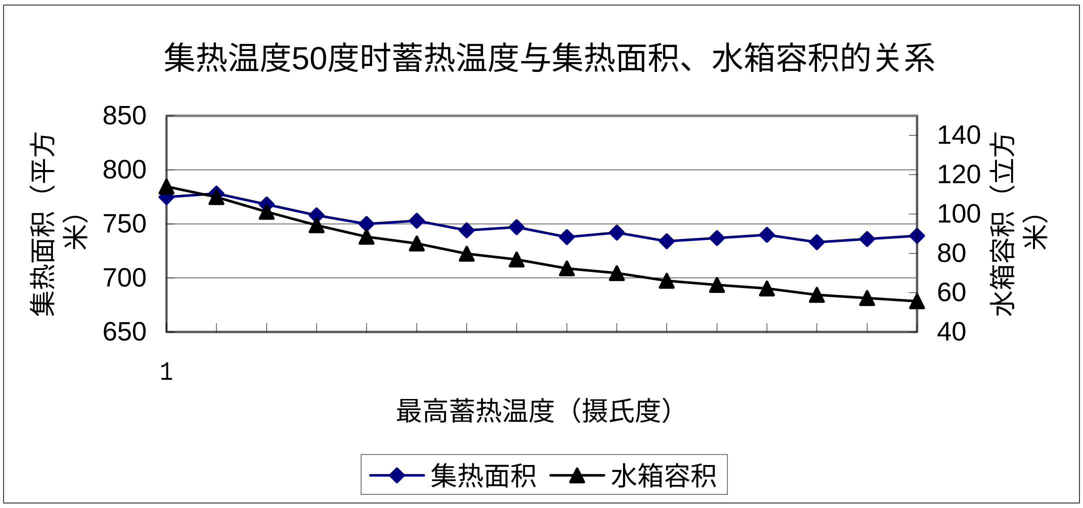
$$L_{12}=(59.47\times10+8.66\times14)\times1859\times3600\times31=1.485\times10^5\,MJ$$

同理，一月份负荷为 $L_1=1.485\times10^5\,MJ$，二月份为 $L_2=1.342\times10^5\,MJ$。

根据上述影响因素的分析，选定集热器形式及布置如下：采用真空管集热器，集热器朝向正南偏西 10°，倾角 40°。在计算中以冬至日（12 月 21 日）为基准，假定当日为晴天，该日收集的太阳辐射能除可供当日负荷要求外，还可以蓄存第二日负荷所需热量。因为供暖连续运行，因此水箱中的温度始终维持在集热温度以上，采暖开始时，可通过提前运行集热系统，将水箱内的水温由初始水温提高到一定温度，接近设定的集热温度。本例计算中，假定正式开始采暖时初始水温比集热温度低五度。

下面两张图表是在不同集热温度情况下，当最高蓄热温度不同时，为满足负荷要求所计算出的集热面积及相对应的水箱容积。





从上面的图中可以看出，在相同的蓄热温差下，为满足负荷要求，集热温度为 50°C时所需集热面积大于集热温度 40°C时的需要。太阳能采暖系统设置在采暖房间的散热部件主要有以下几种：

1) 常见的暖气片 供暖系统工作水温为 75°C左右；

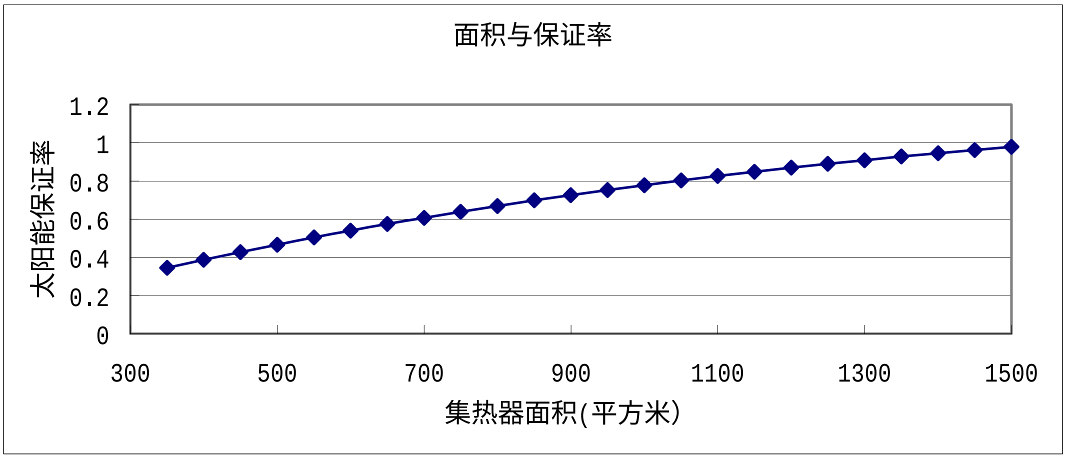
2) 顶棚辐射板 按照热舒适要求顶棚温度不得超过 32°C，因而水流温度在 35°C左右；

3) 风机盘管 工作水温为 40~60°C；

4) 地面辐射板 地板表面温度 25°C左右，所以 28°C~30°C左右的水便可以加以利用。

因此，冬季太阳能供暖系统的集热温度定在 40°C左右是比较合理的，若提高集热温度将使得集热面积增大。选择蓄热温差 25°C，此时所需集热面积为 694m^2,水箱容积为 66.3m^3。

下图是根据文献[2]中推荐的公式，计算并得出的集热面积与太阳能保证率之间的关系。



根据上图，可以得出集热面积为 694 m^2 时，整个供暖季平均太阳能保证率为 61.45%，可节省的热量为：

$$(1.485+1.485+1.342)\times10^{11}\times61.45\%=73604\text{kWh}$$

如果上述热量全部采用电采暖，按上海市电价每千瓦时 0.61 元计算，一个供暖季可节约电费 44898 元。

如果该建筑位于北京地区，由文献[5]中的窗墙比供暖指标计算，工作时间单位面积负荷为：

$$q=\frac{(7\alpha+1.7)W}{F}(t_n-t_w)=\frac{(7\times\frac{370}{1315.5}+1.7)\times1315.5}{1859}\times(20+9)=75.29\text{W}/\text{m}^2$$

其中，α ——1 外窗面积与外墙面积（包括窗）之比；

W——外墙总面积（包括窗），m^2；

F——总建筑面积，m^2；

t_n、t_w——室内、外供暖设计温度，℃。

值班时间单位面积负荷为：

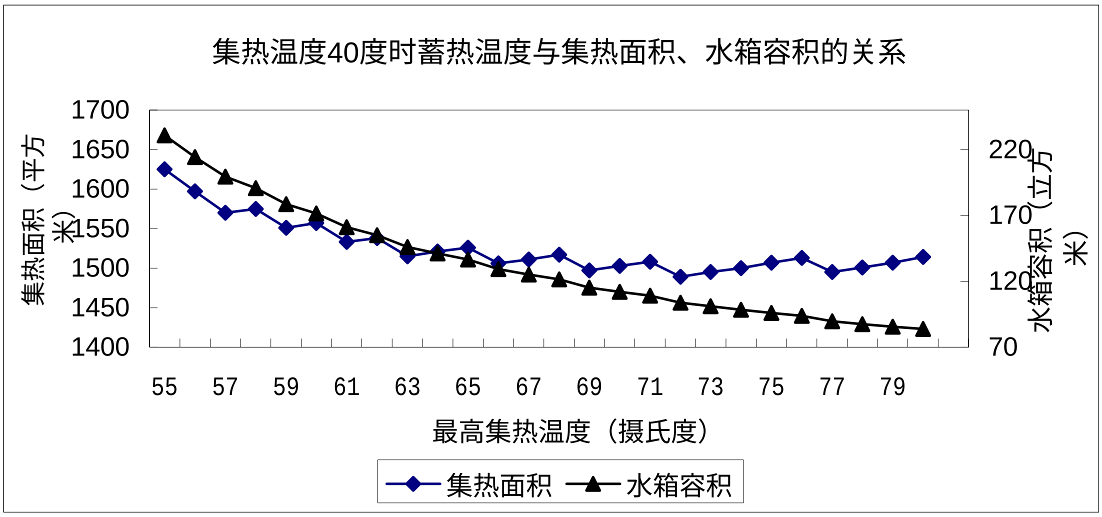
$$q=\frac{(7\times\frac{370}{1315.5}+1.7)\times1315.5}{1859}\times(5+9)=36.35\text{W}/\text{m}^2$$

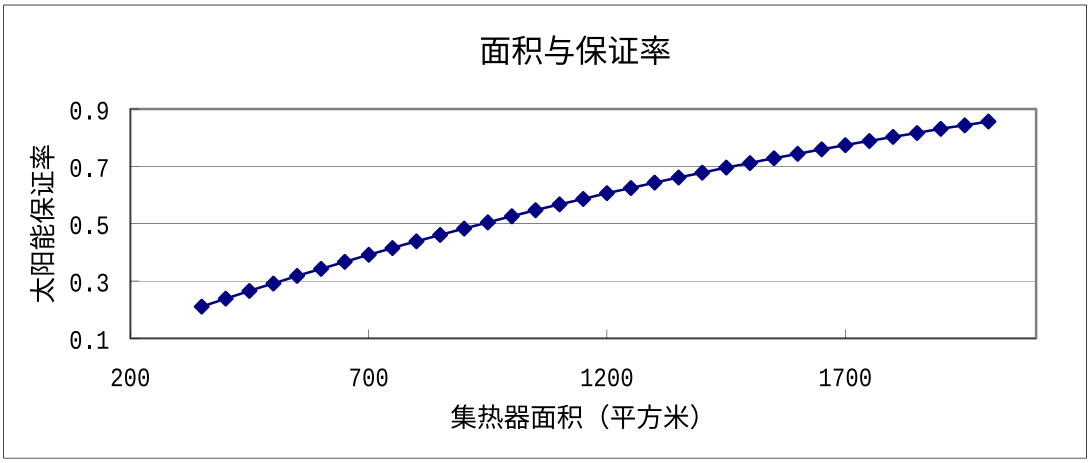
北京地区供暖期共 126 天，从 11 月 12 日至第二年的 3 月 17 日，为方便计算，假定 11 月，12 月，1 月，2 月为供暖期。同上，每个月负荷为：

$$L_{11}=2.533\times10^5\text{MJ}，\ L_{12}=2.618\times10^5\text{MJ}$$

$$L_1=2.618\times10^5\text{MJ}，\ L_2=2.364\times10^5\text{MJ}$$

集热器形式及计算依据与前面计算相同，下图是在集热温度 40℃情况下，当最高蓄热温度不同时，为满足负荷要求所计算出的集热面积及相对应的水箱容积：





根据以上两图，选择蓄热温差 25°C，此时所需集热面积为 1526m^2,水箱容积为 136.5m^3，整个供暖季平均太阳能保证率为 72.02%，可节省的热量为：

$$(2.533+2.618+2.618+2.364)\times10^{12}\times0.7202=202716\text{kWh}$$

如果上述热量全部采用电采暖，按北京市电价每千瓦时 0.44 元计算，一个供暖季可节约电费 89195 元。

另外，北京地区月平均辐射量 11 月为 227.87MJ，3 月为 424.32MJ，因此，本例计算中将采暖月按照 11 月、12 月、1 月、2 月四个月计算所得出的集热面积，比按照 12 月、1 月、2 月、3 月四个月计算所得出的集热面积偏大，因此实际可节省的热量比计算得出的更多。

由上述计算可以看出，这两个地区在冬季运用太阳能采暖都能够达到一定的采暖要求，具有很好的经济效益，同时可减少常规能源的消耗，因而必将带来可观的环境效益。

3 结论

1）在设置太阳能集热器时，为获得更多的太阳能，以下是一些有力措施：

- 采用真空管型集热器比采用平板型可以获得更多的能量；
- 集热朝向正南偏西 10°左右；

- 集热器倾角应根据太阳能集热器的使用时间而定，全年使用时集热器倾角应近似等于当地纬度φ。如果要在冬季获得最佳的日射量，倾角应增大至φ+10°；如果要在夏季获得最佳日射量，则倾角应为φ-10°。
- 在可能的情况下，增大水箱容积，可以相对降低水温，提高集热效率，有利于增加集热量；
- 采取尽可能低的集热温度。

2）太阳能保证率与集热面积成正比，保证率的提高将节约更多的能量，但将使得集热面积和水箱容积的增大，增加设备的投资，因此集热面积的确定还需要进行进一步的技术经济比较。

3）增加辅助热源将有利于减少集热面积和水箱容积，使得供热系统可靠率增加，同时合理分配使用辅助热源与太阳能将获得更好的经济效益。

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基于热气机分布式冷热电三联供效益分析*

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摘　要　以上海地区一幢典型五层住宅建筑热、电、冷负荷需求为计算基础，分别计算了基于热气机的冷热电三联供系统和传统冷热电分供系统的一次能耗率、全年净收益以及投资回收期，验证了三联供系统的节能性和经济性。分析表明热气机余热利用率和能源价格是影响该三联供系统节能效益和经济效益的主要因素。
关键词　热气机；冷热电三联供；天然气；节能；经济效益

The Benefit Analysis of Combined Cooling, Heating and Power System Based on Stirling Engine

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Abstract　Based on cooling load, heating load and power load of one typical five-storied house buildings in Shanghai, the investigation calculates and compares the primary energy rate, annual net revenue and payback period of a small scale trigeneration system for combined cooling, heating and power generation (CCHP) with Stirling engine against contemporary conventional separate production, showing that a CCHP system saves fuel resources and has the assurance of economic benefits. The result of analysis states that waste heat utilization ratio and energy price are the main factors that influence energy-saving benefit and economic benefit of the CCHP system.
Keywords　Stirling engine, Combined cooling, heating and power, Natural gas, Energy saving, Economic benefit

1　引言

冷热电三联供是一种建立在能的梯级利用概念基础上，将制冷、供热及发电过程一体化的多联产总能系统。它是在热电联供的基础上发展起来的。文献[1-5]论述了三联供系统的节能、经济性好、缓解电力紧张、环保等优点。分布式区域冷热电三联供系统的功能与传统冷热电联供相同，均可向周边区域提供冷、热和电力，但由于其相对比较独立，因此又称为“ 能源岛系统 ”(简称“ 能源岛 ”)。在能源岛中，发电系统以小规模(数千瓦至数兆瓦)、分散布置的方式建在用户附近，独立地输出冷、热或电。它不仅满足了区域内用户的用能需求，还节省大量的城市供热管网的建设和运行费用，因此该技术在工业化国家迅速发展。近年来，随着先进微型热电转换装置的问世，出现了楼宇冷热电联供系统。它由多个小型能源岛相连，在向本楼宇供应冷、热和电力的同时，依靠因特网的指挥调度，可实现临近系统的互连互靠，形成自下而上的 “ 能源互联网 ”。这种供能方式适应了信息时代

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以效益定规模的生产方式要求，弥补了由大型电厂、多层电网及供热锅炉组成的传统城市能源体系的不足[6,7]。

2　基于热气机的分布式冷热电三联供系统

热气机又称斯特林热机（Stirling Engine），是一种外燃的闭式循环往复活塞式热力发动机。该机运行时，燃料在气缸外的燃烧室内连续燃烧，独立于燃气的工质通过加热器吸热，并按斯特林循环对外做功[8,9]。燃料燃烧发电后的余热包括排烟和冷腔冷却水中含有的热量，可以用来供热和提供生活热水。

图 1 和图 2 分别为基于热气机的分布式冷热电三联供和传统冷热电分供系统示意图。如图 1 所示，基于热气机的三联供系统采用热气机和直燃溴化锂吸收式冷热水机组联合循环的工艺。该工艺首先由热气机利用天然气发电，烟气由于温度较低而经过处理直接排掉，将缸套冷却水中的余热通过容积式换热器吸收利用，全年提供建筑物生活热水，冬季还用来提供建筑物采暖热负荷。夏季冷负荷直接由吸收式冷热水机组提供。冬季不足采暖热负荷由溴化锂吸收式冷热水机组补充，不足电力从电网补充。图 2 所示的传统冷热电分供系统采用购电、锅炉和空调联合工艺，建筑物夏季冷负荷由电制冷空调机组承担，全年供热负荷（包括生活热水负荷和采暖负荷）由燃气锅炉燃烧天然气提供，用电负荷（包括空调机组用电和照明等其它设备用电）从公用电网购得。

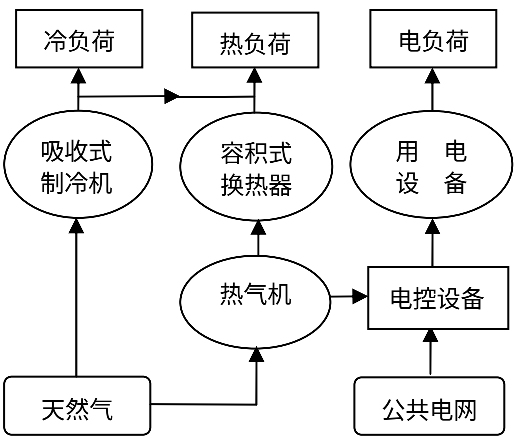

图 1 基于热气机的冷热电三联供系统示意图

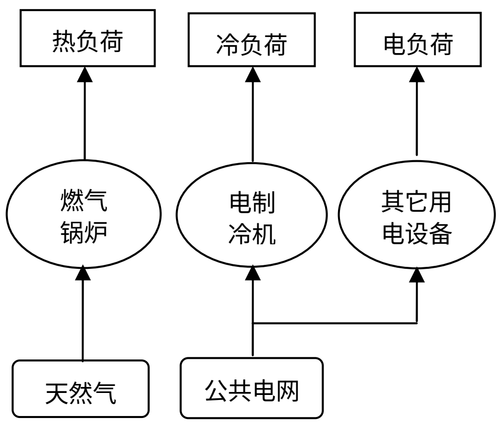

图 2 传统冷热电分供供系统示意图

3　住宅楼冷、热、电负荷

由于冷热电三联供系统节能与经济性均和建筑物负荷密切相关，本文选择了上海市某一典型五层住宅楼作为计算对象。表 1 为此住宅楼具体构成情况。

表 1　住宅楼的组成情况

居室规格	建筑面积（m^2）	人数（人）	面盆（个）	厨房水槽（个）	户数（户）
1 室 1 厅 1 卫	40	2	1	1	5
2 室 1 厅 1 卫	60	3	1	1	5
3 室 2 厅 2 卫	100	5	2	1	5
住宅楼总计	1000	50	20	15	15

表 2 为住宅楼空调负荷室内外计算参数[10]。住宅楼生活热水需求情况如表 3 所示。

表 2　上海地区住宅楼空调负荷室内外计算参数

计算参数	夏季	冬季
室外计算干球温度（℃）	34	-4
室外计算相对湿度（%）	83	73
室内计算温度（℃）	26	18
室内计算相对湿度（%）	60	55

表 3　住宅楼生活热水消耗量

卫生用具	供应时间	单位热水用量	每日热水用量（kg）
洗浴缸	每人每日一次	每人次 250kg	12500
面盆	全日供应	平均每小时 4.4kg／只	2112
厨房水槽	全日供应	平均每小时 17.5kg／只	6300
住宅楼总计			20912

住宅楼冷负荷采用空调用冷负荷系数法进行计算，夏季典型日冷负荷变化情况如图 3 所示。经分析，可以认为一天中有 5h 冷负荷为 70kw，12h 冷负荷为 65kw，另有 7h 冷负荷为 58kw。利用供暖通风设计手册中通用空调热负荷计算方法，计算住宅楼冬季热负荷为 52.3kw。由表 3 可得住宅楼每小时生活热水需求量为 872kg/h，如果热水需从 5℃加热到 50℃，大约需要 46kw 的加热量。

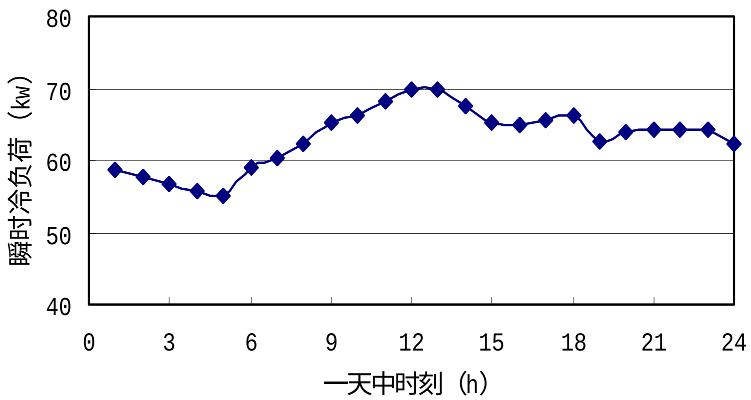

图 3　夏季一天中建筑物室内冷负荷随时间变化曲线

由文献[11,12]，本文取住宅区的用电指标为 45W/m^2，并取住宅楼用电需要系数值为 0.76，于是整个住宅楼的用电负荷大约为 35kW。

4　效益分析

4.1 系统配置

依据住宅楼冷热电负荷实际情况，三联供系统选择一台中国船舶重工集团 711 研究所研制生产的容量 50 KW 的热气机和一台远大公司生产的制冷供热量均为 70kW 的 BCT70 双效直燃式溴化锂吸收式冷热水机组。考虑到热气机发电剩余部分可供应住宅楼附近的其它建筑物使用，本文在进行效益分析时认为热气机全年全负荷运行，并将热气机总发电量作为系统收益的一部分。热气机和吸收式冷热水机组性能分别如表 4 和表 5 所示。

表 4　热气机基本参数

输入天然气热能	204kW（20.9Nm^3/h）
输出电功率	50kW
发电效率	24.5%
外燃散热	3.5kW
排气散热	15.5kW（排气 178℃）
机械摩擦耗功	20kW
机身冷却水带走热量	110kW
机身进水温度	50℃
机身出水温度	57℃

表 5　溴化锂制冷机（ Broad BCT70）基本参数

最大制冷量	70kW
最大制热量	70kW
制冷消耗天然气量	6.7m^3/h
制热消耗天然气量	7.8m^3/h
排烟温度	170℃
制冷出、回水温度	7℃/14℃
供热出、回水温度	57℃/50℃

（注：表中天然气热值取 10kWh/m^3）

传统冷热电分供系统选用上海新业锅炉厂生产的 WHS 系列 100kW 燃气热水锅炉，其天然气燃烧效率为 85%。电制冷空调机组选用约克公司的制冷量为 81kW 的压缩式制冷机组，其 COP 值约为 3.5。

系统在全年全天 24h 内有效运行。夏季制冷期自 5 月 15 日至 10 月 15 日，共 3672h；冬季供热期自 11 月 20 日至 3 月 10 日，共 2640h，过渡期为 2448h。

4.2　节能效益

组成冷热电联供系统的各种设备所消耗能量品位和来源都有不同，为进行能耗的分析比较，本文将它们全都折算为一次能源消耗量，其中电量按全国发电能耗折算，取发电效率为 30%。一次能耗率（PER）是一次能耗量与需要输出能量的比值[13-15]。文献[16]给出相对一次能耗率的概念，它反映了相同的需要输出能量值时，冷热电三联供系统相对传统分供系统节约一次能耗量的程度。相对一次能耗率可由式（1）计算得出：

$$\Delta q_p = \frac{Q_{ps} - Q_p}{Q_{ps}} = 1 - \frac{PER_{CCHP}}{PER_{SG}} \qquad (1)$$

式中 Δq_p 为相对一次能耗率，Q_{ps}、Q_p 分别为传统冷热电分供系统和三联供系统的一次能耗量，PER_{CCHP}、PER_{SG} 分别为传统冷热电分供系统和三联供系统的一次能耗率。具体计算结果如表 6 所示。

表 6　两种能源供应方式一次能耗率（PER）比较

系统	制冷期	供热期	过渡期	全年
热气机三联供	1.658	1.376	2.125	1.657
购电锅炉空调分供	1.761	1.904	2.300	1.911
相对一次能耗率（%）	5.85	27.73	7.61	13.30

由表 6 可知，基于热气机的三联供系统的一次能耗率在各个时期均低于传统的冷热电分供系统，全年的相对一次能耗率为 13.3%，具有明显的节能效果。并且还可以看出，三联供系统供热期的相对一次能耗率远高于制冷期和过渡期，这主要是由于供热期内三联供系统更加充分地利用了热气机产生的余热。

4.3　经济效益

目前上海市住宅楼普遍使用小型分体式热泵型电空调器进行房间夏季制冷和冬季供暖，生活热水由城市煤气驱动的燃气锅炉提供。本文取家用热泵型电空调机组的制冷 COP 值为 2.8，制热 COP 值为 3.5；电价按照上海市供电局提供的数据取统一电价为 0.62 元/kWh；城市煤气燃料价格取值为 1.05 元/m^3。依据上述取值，可以计算出上海市住宅楼使用的冷热量成本：冷价为 0.222 元/kWh，热价为 0.178 元/kWh，生活热水价格取值为 19 元/t。表 7 和表 8 分别为冷热电三联供和传统分供系统的初投资。两系统的经济性计算结果列于表 9。计算中天然气价格取值为 1.9 元/Nm^3。

表 7　热气机冷热电三联供系统初投资

项目	热气机	溴化锂直燃机组	其它设备	机房、安装费	总计
投资（元）	350,000	120,000	5,000	45,000	520,000

表 8　购电锅炉空调分供系统初投资

项目	燃气锅炉	制冷机组	其它设备	机房、安装费	总计
投资（元）	20,000	190,000	20,000	60,000	290,000

表 9 两种能源供应方式经济性比较

项目	单位	热气机冷热电	购电锅炉空调
年供电量	kWh	438,000	438,000
年供电收益	元/a	271,560	271,560
年采暖供热量	kWh	138,072	138,072
年采暖供热收益	元/a	24,577	24,577
年制冷量	kWh	235,008	235,008
年制冷收益	元/a	52,172	52,172
年生活热水量	t	7,639	7,639
年生活热水收益	元/a	145,141	145,141
年天然气总耗量	Nm^3	205,578	65,098
年燃料成本	元/a	390,598	123,686
年购电支出	元/a	0	313,190
单位千瓦时运行维护费用	元/ kWh	0.05	
年运行维护费用	元/a	21,900	13,450
系统年总支出	元/a	412,498	450,326
系统年总收益	元/a	493,450	493,450
系统年净收益	元/a	80,952	43,124
系统初投资	元	520,000	290,000
系统投资回收期	a	6.42	6.73
十年总投资全利润差	元	148,280	0

由表 9 可以看出，基于热气机的冷热电三联供系统的年净收益几乎是传统分供系统的两倍，而其投资回收期（6.42 年）高于传统分供系统（6.73 年）。十年总投资全利润是指系统十年运行总净收益扣除系统初投资和大修费用后的实际获得利润，本文认为两系统大修费用基本相同，由计算结果可知，三联供系统十年总投资全利润比分供系统多 148,280 元。值得注意的是，随着热气机冷热电三联供系统的推广应用，热气机价格会有较大幅度的降低，系统初投资随之降低，从而系统投资回收期相应有较大幅度的缩短。

进一步分析发现，热气机的余热利用率对三联供系统的节能效益和经济效益有较大的影响，如图 4 所示。热气机的余热利用率是指系统全年实际利用余热量与热气机实际产出余热量之比。本文分析时假定热气机满负荷运行，提供的冬季住宅楼采暖负荷不变，即 52.3kW。热气机其他余热用来提供生活热水，通过改变生活热水量来调节系统余热利用率。由图 4 可以得出，系统余热利用率越高，其投资回收期越短，一次能耗率越低。并且可以看出，投资回收期变化曲线随着余热利用率的升高而逐渐平缓，这就是说，余热利用率越低，其变化对系统投资回收期影响越大。当系统余热全部得以利用时，系统投资回收期仅为 2.23 年，一次能耗率为 1.23。

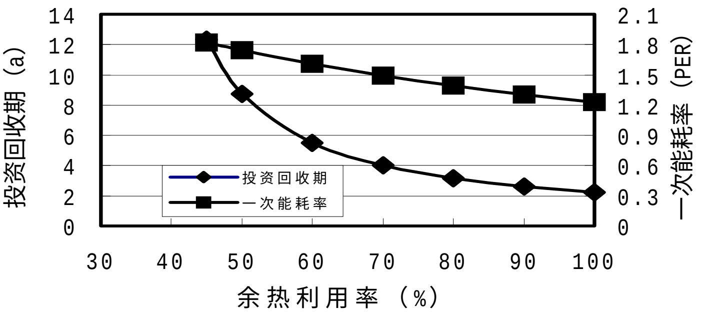

图 4　投资回收期和一次能耗率随余热利用率的变化情况

分析时还发现，能源价格也是影响三联供系统的经济效益的一个重要因素[17]。图 5 显示了天然气价格对系统全年净收益和投资回收期的影响。可以看出，天然气价格越低，三联供系统全年净收益越高，投资回收期越短。并且还可以看出，投资回收期变化曲线随着天然气价格的升高而逐渐变陡，这就是说，天然气价格越高，其变化对系统投资回收期影响越大。当天然气价格为 1.4 元/Nm^3，例如北京地区，系统的全年净收益约为 184,000 元，投资回收期仅为 2.83 年。

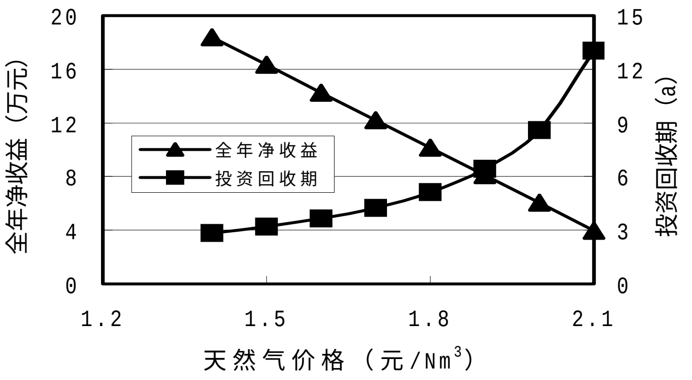

图 5　天然气价格对系统经济性影响

5 结论

采用热气机和吸收式制冷机的能源岛系统，是一条我国现阶段发展城市天然气能源岛产业的有效技术途径。基于热气机的冷热电三联供系统将天然气利用、发电、采暖和制冷技术整合在一起，提高了资源利用率，节能效果显著，经济效益明显。热气机余热利用率和能源价格是影响该三联供系统节能效益和经济效益的主要因素。余热利用率越高，系统投资回收期越短，一次能耗率越低；天然气价格越低，系统投资回收期越短，全年净收益越高。而且余热利用率越低，天然气价格越高，两者的变化对系统投资回收期的影响越大。在现有条件的基础上，提高设备运行效率并尽可能充分利用热气机产生的余热是提高整个系统节能效益和经济效益的努力方向。

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高层建筑节能评估方法研究

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摘 要 针对 DeST 软件在高层建筑节能评估工程中计算时间长的缺点，本文结合实际建筑围护结构的热工参数，以传热学理论为基础，对实际高层建筑进行了简化。计算结果表明，在评估过程中，对高层建筑进行合理简化不但可以保证计算结果的正确性，也可大大缩短评估时间，从而大大提高 DeST 软件在高层建筑评估工作中的生命力。
关键词 节能评估；简化方法；DeST 软件；高层建筑

1 问题提出

建筑能耗一直占据国家总能耗的第一位。我国的建筑能耗约占总能耗的 25%，在一些发达国家可高达 30%～40%[1]，但由于我国建筑的保温隔热性能很差，再加上供能系统的低效率，致使建筑物达到规定热舒适程度单位建筑面积所需的建筑能耗比同纬度发达国家高出 3~5 倍。随着中国城市化的发展、人口的增长以及现代化程度的加大，高层建筑得到了迅猛发展。高层建筑在美化了城市的同时，也加大了常规能源的消耗。据统计，在我国建筑能耗中，高层建筑能耗约占 8%左右。因此对高层建筑进行节能具有重要意义。

建筑物的能耗可通过现场实测与软件计算评估两种方法得到。与现场实测相比，软件计算评估方法可在建筑物设计阶段对其建筑能耗进行预测，从而确保建筑物建成后能够满足国家相应的建筑节能标准。目前，中国市场上可用于建筑节能评估的软件有 DOE-2 和 DeST。据作者所知，DOE-2 软件能够计算的房间数有一定限制，对高层建筑只有进行简化后才能进行相应的节能评估，但不合理的简化可能导致较大的计算偏差而使其对建筑的节能效果得到错误的评价。相比之下，DeST 软件没有房间数的限制，因此可对高层建筑进行建筑节能评估而不需要简化。但随着建筑层数与房间数的增加，DeST 软件评估所需的时间也大幅增加，这限制了 DeST 软件的工程应用。

本文从基本理论出发，结合上海某一实际高层建筑，通过模拟计算，研究 DeST 软件在评估高层建筑能耗过程中简化的可能性，从而在不影响评估结果的情况下尽可能地缩短评估所需的计算时间。

2 理论分析

根据传热学原理，对建筑的某一楼层，其能耗可用下式计算：

$$Q_i = (Q_{wall} + Q_{window} + Q_{floor} + Q_{ceiling} + Q_{air-leak} + Q_{sun} + Q_h) / F_i \tag{1}$$

$$\begin{aligned} Q_{wall} &= F_{wall,south} \cdot q_{wall,south} + F_{wall,north} \cdot q_{wall,north} \\ &+ F_{wall,east} \cdot q_{wall,east} + F_{wall,west} \cdot q_{wall,west} \end{aligned} \tag{2}$$

$$Q_{window} = F_{window,south} \cdot q_{window,south} + F_{window,north} \cdot q_{window,north} + F_{window,east} \cdot q_{window,east} + F_{window,west} \cdot q_{window,west} \tag{3}$$

$$Q_{floor} = F_{floor} \cdot q_{floor} \tag{4}$$

$$Q_{ceiling} = F_{ceiling} \cdot q_{ceiling} \tag{5}$$

$$Q_{air-leak} = \rho_{air} \cdot N \cdot V_i \cdot (T_{room} - T_{outdoor}) \tag{6}$$

整栋建筑的能耗计算式为：

$$Q_{building} = \sum_{i=1}^{n} (F_i \cdot Q_i) / F_{building} = (F_1 \cdot Q_1 + F_2 \cdot Q_2 + \cdots + F_{n-1} \cdot Q_{n-1} + F_n \cdot Q_n) / F_{building} \tag{7}$$

$$F_{building} = \sum_{i=1}^{n} F_i \tag{8}$$

式中，$Q_{building}$ 为单位建筑面积能耗，kWh/m^2。Q_{wall} 为通过墙体造成的能耗损失，kWh。Q_{window} 为通过窗户造成的能耗损失，kWh。Q_{floor} 为通过地板造成的能耗损失，kWh。$Q_{ceiling}$ 为通过天花板造成的能耗损失，kWh。$Q_{air-leak}$ 为漏风造成的能耗损失，kWh。Q_h 为室内热扰造成的能耗损失，kWh。Q_{sun} 为太阳辐射造成的能耗损失，kWh。F_{wall} 为各朝向的外墙面积，m^2。F_{window} 为各朝向的外窗面积，m^2。$F_{building}$ 为建筑总建筑面积，m^2。q_{wall} 为各朝向的单位外墙面积造成的能耗，kWh/m^2。$q_{ceiling}$ 为天花板的单位面积造成的能耗，kWh/m^2。q_{floor} 为单位地板面积造成的能耗，kWh/m^2。N 为换气次数，$1/h$。ρ_{air} 为室外空气密度，kg/m^3。T_{room} 为室内空气温度，K。$T_{outdoor}$ 为室外空气温度，K。

对于标准层，建筑布局、外墙面积、窗户面积、楼板面积相同，而外墙外侧对流传热阻和外墙内侧对流传热阻分别按 0.04 和 0.11 计算时[2]，$q_{wall,south}$、$q_{wall,north}$、$q_{wall,east}$、$q_{wall,west}$ 相同；如果窗户的热工参数相同时，$q_{window,south}$、$q_{window,north}$、$q_{window,east}$、$q_{window,west}$ 相同。因此，根据方程式（1）~（8），若 q_{floor}、$q_{ceiling}$ 也相同，则建筑物的能耗就可按下列简化方法计算：

$$Q_{building} = \left(\sum_{i}^{\text{未简化层数}} (F_i \cdot Q_i) + m \cdot F_{st} \cdot Q_{st}\right) / F_{building} \tag{9}$$

式中，Q_{st} 为单位建筑面积的能耗，kWh/m^2。F_{st} 为标准层建筑面积，m^2。m 为简化层数。

q_{floor}、$q_{ceiling}$ 主要受屋面和地面热状况的影响。数值模拟计算结果表明，屋面和地面的热状况仅对其邻近几层建筑的能耗产生较大影响，而对其它层建筑的能耗影响甚微。因此，在评估过程中，可对屋面和地面影响很小的标准层进行简化计算，从而在不影响能耗评估结果的基础上达到缩短评估计算时间的目的。

3 方法比较

为研究简化方法的可行性与合理性，本文结合上海某一高层建筑进行具体分析。

3.1　建筑概况

该建筑属于条式建筑，混凝土剪力墙结构，南偏东 15°，总 31 层（包括地下 1 层），高 97m，有效计算建筑面积 23762.47 m^2。体形系数为 0.23。

3.2　计算条件

针对此高层建筑，本文采用 DeST 软件对其进行节能评估。评估过程中，建筑标准层平面分布如图 1 所示，实际建筑与简化建筑立面图如图 2 所示。

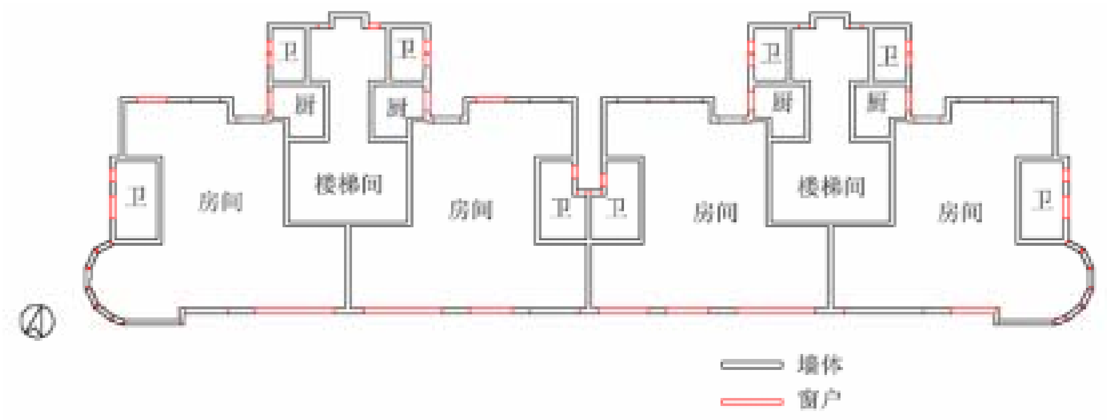
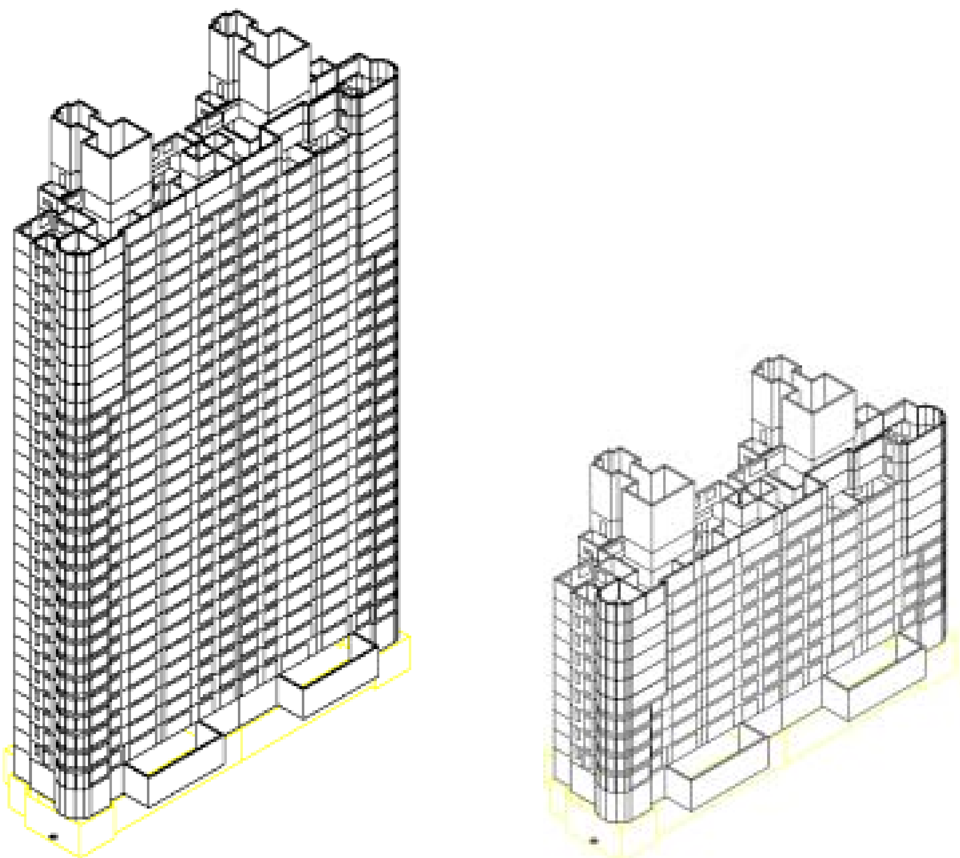


图 1　建筑标准层平面图



（*a*）　实际建筑　　　　（*b*）　简化建筑

图 2　整体建筑立面图

3.2.1 围护结构热工参数设置

建筑具体的围护结构热工参数为：屋面传热系数为 1.0W/m^{2}K，外墙和窗户则分 XPS 外保温、ZL 胶粉聚苯颗粒保温浆料外保温和节能标准中的标准外墙三种工况进行讨论。

XPS 外保温系统的外墙构造为：XPS 保温层 25+水泥砂浆 20+钢筋混凝土 250（填充墙为多孔空心砖）+混合砂浆 20，其平均传热系数 0.86 W/m^{2}K。各朝向窗墙比分别为：南 0.61；北 0.32；东 0.20；西 0.20。窗户传热系数为 3.7 W/m^{2}K，遮阳系数为 0.83。

ZL 胶粉聚苯颗粒保温浆料外保温系统的外墙构造为：ZL 胶粉聚苯保温砂浆 35+水泥砂浆 20+钢筋混凝土 250（填充墙为多孔空心砖）+混合砂浆 20，其平均传热系数 1.11 W/m^{2}K。各朝向窗墙比分别为：南 0.61；北 0.32；东 0.20；西 0.20。窗户传热系数为 3.7 W/m^{2}K，遮阳系数为 0.83。

标准节能建筑的外墙按节能设计标准[3]要求设置，即其平均传热系数取 1.5 W/m^{2}K。窗户传热系数按节能标准根据窗墙比选取：南 2.5 W/m^{2}K（0.5）；北 3.2 W/m^{2}K（0.32）；东 4.7 W/m^{2}K（0.20）；西 4.7 W/m^{2}K（0.20），括号内为相对应的窗墙比，遮阳系数为 0.83。

3.2.2 其他参数设置

其它参数均按《夏热冬冷地区居住建筑节能设计标准》中的有关数值计算。具体为：居室室内计算温度，冬季全天为 18℃；夏季全天为 26℃。室外气象计算参数采用典型气象年。采暖和空调时，换气次数为 1.0 次/h。空调额定能效比取 2.3，采暖额定能效比取 1.9。室内照明得热为每平米每天 0.0141kWh。室内其它得热平均强度为 4.3W/m^2。

4 结果分析

表 1 列出的是两种方法针对 XPS 外保温系统的计算结果，表 2 为针对 ZL 聚苯胶粉颗粒外保温系统的计算结果，表 3 为针对标准节能建筑的计算结果。

表 1 XPS 外保温系统的计算结果

	全年累计热负荷，kWh	全年累计冷负荷，kWh	采暖年耗电量指标，kWh/m^2	空调年耗电量指标，kWh/m^2	总年耗电量指标，kWh/m^2	计算时间，h
实际建筑	504842.42	1587541.77	11.18	29.05	40.23	78
简化建筑	505431.50	1586648.87	11.19	29.03	40.23	5
计算偏差	-589.084	892.898	-0.013	0.016	0.003	

表 2 ZL 胶粉聚苯颗粒外保温系统的计算结果

	全年累计热负荷，kWh	全年累计冷负荷，kWh	采暖年耗电量指标，kWh/m^2	空调年耗电量指标，kWh/m^2	总年耗电量指标，kWh/m^2	计算时间，h
实际建筑	540108.36	1580270.70	11.96	28.91	40.88	77
简化建筑	540631.29	1579492.67	11.97	28.90	40.87	5
计算偏差	-522.93	778.03	-0.012	0.014	0.003	

从计算结果可以看出，除了全年累计热负荷和全年累计冷负荷稍有偏差外，运用简化方法可得到与实际建筑相符的计算结果，而其计算所需时间则分别从 78h，77h 和 76h 减少到 5h 以内。这说明：通过简化方法，DeST 软件可完全满足工程实际对高层住宅节能评估计算的需要与要求。

表 3　标准节能建筑的计算结果

	全年累计热负荷，kWh	全年累计冷负荷，kWh	采暖年耗电量指标，kWh/m^2	空调年耗电量指标，kWh/m^2	总年耗电量指标，kWh/m^2	计算时间，h
实际建筑	537225.35	1597385.56	11.90	29.23	41.13	76
简化建筑	535644.20	1597429.50	11.86	29.23	41.09	5
计算偏差	1581.15	-43.94	0.035	-0.001	0.034	

5　结论

为尽可能缩短 DeST 软件对高层建筑节能评估的时间，本文结合上海某一高层建筑，通过简化建筑与实际建筑能耗的计算分析简化方法的可行性与合理性。

计算结果表明：其他条件相同时，采用简化方法完全可以得到与实际建筑相同的计算结果，且计算所需时间却大幅缩短，完全达到了工程界对评估软件的要求，因此可使 DeST 评估软件在工程界得到进一步认可与更广泛应用。

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空调负荷预测方法研究

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摘　要　准确预测空调负荷不仅对蓄能系统高效运行意义重大，而且也是新兴的冷热电三联产技术发挥技术优势的关键所在。本文针对同一幢建筑，分别采用了多元线性回归、季节性指数平滑法以及神经网络方法等三种典型性预测方法进行负荷预测研究，并对三种方法做了进一步改进。然后从预测精度、建模的复杂程度、工程上的可行性以及模型的其它特性（诸如在线性能和新建筑预测问题）等四个方面对负荷预测方法进行分析。结果表明：神经网络方法具有较高预测精度，而改进的季节性指数平滑法则具有较好的工程应用价值。

关键词　负荷预测；线性回归；指数平滑；神经网络

Air Conditioning Load Prediction Methods Competition

By He Dasi★ ,Zhang Xu and Li Yuandan

Abstract　Accurate prediction of air conditioning load is not only very important to efficiency of thermal storage technology, but also combined cooling heating and power technology. This paper selects three typical prediction methods to carry out load prediction to a same objective building, which are linear regression (LR), seasonal exponential weight moving average (SEWMA), and artificial neural network (ANN). And then, some conditions for comparison which are relative to prediction accuracy, complexity, feasibility, as well as other specialties are put forward. The result of competition shows: ANN is most accurate of the three methods., but SEWMA can be applied in projects most easily.

Keyword　load prediction, linear regression, seasonal exponential weight moving average, artificial neural network

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前言

采用合理的运行调节方法是提高空气调节系统的能源利用效率主要途径之一。从已有的文献报道来看，实行负荷预测是空气调节系统优化运行的基础，也是蓄能空调系统高效经济运行[1]和新兴的冷热电三联产技术发挥技术优势的关键所在。关于负荷预测方法，虽然有很多学者提出过不同的观点和方法，但都有各自的局限性和使用条件[2-6]。如何选择工程应用切实可行的方法，仍然是一个值得探讨和研究的问题。由于预测方法门类繁多，本文拟从不同类别的预测方法中选取具有典型性的线性回归（Line Regression）、指数平滑(Exponential Weighted Moving Average)和神经网络（Artificial Neural Network）等三种方法进行负荷预测的研究，以期得到有指导意义的空调系统负荷预测方法。

1　基准数据与评价指标

出于对数据精度要求的考虑，本文选用 1997 年日本空气调和与卫生工学会(SHASE)负荷预测方法基准测试（Benchmark）竞赛的相关数剧作为负荷预测模型的基准数据[7,8]。基准数据包含某建筑物 6、7 月份逐时室外、室内气象参数、空调机组开启数量以及空调系统的总负荷测量值，以及 1996 年 8 月

的室内外逐时气象参数、空调机组开启数量。负荷预测模型将根据基准数据给出 8 月份空调系统负荷值。

负荷预测模型的准确度用以下三个指标来评价：

1. 累积误差平方和（Squared Difference Summation）

$$SDS=\sum_{i=1}^{n}(q_i-\hat{q}_i)^2 \tag{1}$$

2. 平均相对误差（Mean Relative Error）

$$MRE=\frac{\frac{1}{n}\sum_{i=1}^{n}(\hat{q}_i-q_{ave})}{q_{ave}}\times 100\% \tag{2}$$

3. 加权绝对百分比误差（Plus Weighted Absolute Percentage Error）

$$PWAPE=\sum_{j=1}^{n}\left(\left|\frac{q_j-\hat{q}_j}{q_j}\right|\times\frac{q_j}{\sum_{i=1}^{n}q_i}\right)\times 100\% \tag{3}$$

式中：

$$q_{ave}=\frac{1}{n}\sum_{i=1}^{n}q_i \tag{4}$$

q 为实测负荷值， $\hat{q}$ 为预测负荷值， n 为预测期间的总的时间数。

2 线性回归模型

回归分析方法是最为常见的一种数据处理方式。将回归分析方法应用于预测领域时，所建立的预测模型是一种解释性模型。

假设空调负荷(y)和各影响因素（x_i）之间呈线性关系，则可以用式（5）来描述：

$$y=\beta_0+\beta_1x_1+\beta_2x_2+\cdots+\beta_px_p+\varepsilon \tag{5}$$

应用最小二乘法和数理统计的知识，t+1 时刻的负荷可以通过式(6)求出：

$$y_{t+1}=\hat{\beta}_0+\hat{\beta}_1x_{1,t+1}+\hat{\beta}_2x_{2,t+1}+\cdots+\hat{\beta}_px_{p,t+1} \tag{6}$$

式(6)中系数 $\hat{\beta}_0,\hat{\beta}_1,\cdots\hat{\beta}_p$ 称为经验回归系数,通过参数估计得到。

由于负荷日变化具有周期性，单一方程模型很难描述这种变化。作为一种改进，本文采用了逐时模型，即 24 小时分别建模。运用选元技术，最终每个时刻模型中定义了 10 个输入参数和一个输出参数。输入参数分别是提前 1 个小时到 5 个小时室外温度值和提前 1 个小时到 5 个小时室外太阳辐射值。输出参数为空调系统负荷。

模型预测结果见后面部分。

3 季节性指数平滑模型

指数平滑法是根据预测对象本身的历史数据来进行预测的，属于时间序列预测技术范畴。经典的季节性指数平滑模型原理详见文献[9]，它无需额外的相关数据，也即无输入。因而，指数平滑法实施起来非常容易，预测代价非常小。不过，有时这也成了它的缺点，限制了进一步提高预测精度的可能。本文结合建筑物空调负荷和影响因素之间的关系——空调日总负荷和日平均气温之间的强烈相关性，提出了一种改进的季节性指数平滑模型。区别于一般的指数平滑法，它是带输入的，在实施预测是需要提供未来时刻的室外日平均温度。具体模型如下：

$$S_t^{'} = \alpha \frac{x_t}{C_{t-l}^{'}} + (1-\alpha)S_{t-1} \qquad (7)$$

$$C_t = \beta \frac{x_t}{S_t} + (1-\beta)C_{t-1} \qquad (8)$$

$$S_t = \gamma \xi_d S_t^{'} + (1-\gamma)S_t^{'} \qquad (9)$$

式中：α, β, γ：平滑系数； S_t：水平因子；C_t：季节因子；ξ_d：水平因子修正系数。

和经典的温特季节性指数平滑法相比，这个模型主要有两点不同：其一、少了趋势因子；其二、对水平因子 S_t 进行了修正。

新的方法中去掉趋势因子是基于这样的考虑：长期来看，建筑物负荷有周期性增大和减小的趋势，但这种趋势在短期内表现并不明显。这在后面的预测结果中有所体现。去掉一个平滑项带到的好处不言而喻，既降低的模型应用难度，又方便了平滑系数的寻优工作。

对水平因子进行修正，是这个模型特点所在。水平因子和平均值概念类似，它决定了预测值的大小水平；水平因子越大，意味着预测值也越大，从温特季节性指数平滑模型中不难发现这种关系。在常规的指数平滑方法中，水平因子基本上放映了当前周期预测对象大小水平，所以把它当作下一周期预测对象大小水平就引起了一定的误差。减少这误差的办法是：对水平因子乘以系数　予以修正，修正系数 ξ_d 定义为下一周期预测对象大小水平和当前周期预测对象大小水平的比值。

具体到负荷预测，定义 ξ_d 为第二天负荷大小水平与当天负荷大小水平的比值。那么 ξ_d 怎么计算呢？

我们知道，日平均气温与日总负荷间有较强的相关性。日平均气温越高，日总负荷就越大。本文中采用如下多项式方程来回归它们之间的关系，取得了较好的效果。

$$L_d = a_0 + a_1 T_{d,ave} + a_2 T_{d,ave}^2 + a_3 T_{d,ave}^3 \qquad (10)$$

式中：L_d：日总负荷，$T_{d,ave}$：日平均温度。a_0, a_1, a_2, a_3：回归系数。

显然，日总负荷就代表了当日的负荷大小水平。因此 ξ_d 可通过下式确定：

$$\xi_d = \frac{L_{d+1}}{L_d} \qquad (11)$$

式中：L_{d+1}：第二天日总负荷。L_d：当天日总负荷。

L_{d+1}，L_d 通过式（11）求得。计算 L_d 时用到的当天平均温度值，通过实测值平均得到。计算时 L_{d+1}

用到了第二天的平均温度值，通过气象预报得到。

改进的季节性指数平滑模型的计算过程类似于温特季节性指数平滑模型[10]。

4 神经网络模型

本文采用三层前向反馈网络。网络结构为 11×10×1。即输入层神经元数为 11，中间隐含层神经元数为 10，输出层神经元数为 1。输出层和输入层神经元对应的物理意义具体见表 1。

表 1　神经网络拓扑结构及参数说明

输入层	隐含层	输出层
t 时刻实测室外温度(℃)	没有明确的物理意义，需要通过不断地测试进行调整	某一时刻(*t*)建筑物待预测的空调负荷
t-24 时刻实测室外温度(℃)		
t-168 时刻实测室外温度(℃)		
t-24 时刻的实测负荷值(*kcal/h*)		
t-168 时刻的实测负荷值(*kcal/h*)		
t 时刻实测室外太阳辐射强度 ($kcal/m^2$)		
t-24 时刻实测室外太阳辐射强度 ($kcal/m^2$)		
t-168 时刻实测室外太阳辐射强度 ($kcal/m^2$)		
t 时刻 AHU 数量		
t-24 时刻 AHU 数量		
t-168 时刻 AHU 数量		

对上述网络结构，利用给出的 6~7 月份的实测负荷和室内外气象参数数据，对网络进行了训练，求解工具采用了 Math Works 的神经网络工具箱（Neural Network Toolbox）。

在选定的神经网络结构中，隐含层的传递函数采用了 S 型函数（Sigmoid 函数），定义见（12）式，输出层采用了线性函数（Purelin 函数），定义见（13）式。训练采用贝叶斯（Bayes）学习算法，收敛速度快且可以有效防止在训练过程中神经网络收敛于局部最小，同时采用神经网络算法中的“早停和正则化”技巧，防止网络训练过程中发生数据“过拟合”（表现为训练精度很高而预测精度很差）现象。

$$\phi(\alpha v)=\frac{1}{1+\exp(-\alpha v)} \tag{12}$$

$$\phi(v)=\alpha v \tag{13}$$

在利用 6、7 两个月的数据对网络进行训练后，对 8 月份的建筑物负荷进行了预测。在预测过程中采用了所谓的“逐日更新训练法”——首先利用训练好的网络对 8 月 1 日的负荷进行预测并将预测的结果保存，再将 8 月 1 日的实测负荷值和室内外气象参数等 24 组数据添加到训练样本中；然后利用扩大了的样本对网络进行训练，再次预测 8 月 2 日的负荷值，依次循环直到 31 日结束。

5　负荷预测方法比较与分析

表 2　三种负荷预测模型预测结果

指标	LR	SEWMA	ANN
累积误差平方和	9.61E+11	3.21E+11	2.85E+11
平均相对误差	-6.0%	-2.5%	-2.3%
加权绝对百分比误差	19.4%	10.0%	8.9%
最大日累积误差平方和	1.44E+11	4.23E+10	9.2E+10
预测值与实测值相关度	0.908	0.994	0.989

表 2 表明：无论是从累积误差平方和还是相对误差或加权绝对百分比误差来看，神经网络方法的预测精度最高。改进的季节性指数平滑法也取得了相当高的精度，就累计误差平方和而言，和神经网络方法仅相差 10%左右，加权绝对百分比误差也仅相差 1 个百分点，在最大日累积误差平方和和预测值与实测值相关度两个评价指标上甚至优于神经网络方法。多元线性回归方法的预测精度最差，和其它两种方法在预测精度上有显著性差别。

神经网络方法作为一种高度智能的非线性算法，只要选取的网络结构和训练方式得当，并有足够多的数据供网络训练，理论上神经网络模型能够以任意精度逼近实际的物理模型。

虽然本文中的神经网络方法比改进的季节性平滑法精度提高的不多，但随着网络构成方式以及训练方式的变化，神经网络方法预测精度有进一步提高的潜力。而对于指数平滑法来说，由于模型结果简单，不能有效利用与建筑物负荷有密切关系的相关因素的数据，很难再进一步提升预测精度；但从预测结果来看，它已取得了足够高的精度，平均相对误差为-2.5%，加权绝对百分比误差也仅为 10%，足以满足一般工程应用要求。多元线性回归方法的预测结果表明，对于建筑物负荷这样一类高度非线性的系统，线性的多元回归方法基本上是失效的。

总的来说，仅考虑预测精度的话，神经网络方法无疑是最佳选择，改进的季节性指数平滑法对于一般的工程应用也足以胜任，而多元线性回归方法在大多数情况下都将是不可取的。以上结论对不同类型的建筑物负荷预测工作有一定的指导意义。

一般来说，模型的预测精度与建模的复杂度相关。模型的预测精度越高，建模的复杂度就越大。在三种模型中，神经网络方法的建模复杂度最高。多元线性回归建模其次，季节性指数平滑法最容易。这主要和各个模型的结构有关系。由于仅根据负荷的历史值作预测，指数平滑法建模上相对简单。同时，在平滑系数通过计算机实现自动寻优后，平滑模型的通用性大大增强，用平滑模型建立的针对某个建筑物的负荷预测系统几乎可以不加修改的应用到另外一幢建筑物。神经网络方法建模则不能实现自动化，在选择网络结构和训练网络时相当一部分工作需要借助于人的分析，也就是存在大量的试算过程，增大了建模的难度。同时，神经网络模型通用性非常差；神经网络是通过输入与输出来调整自身的结构和参数的，它对输入与输出有强烈的依赖关系。用神经网络方法建立的负荷预测系统要想应用到另一幢建筑物上，除了重新训练网络外，别无它途。多元线性回归方法也存在同样的问题。总的来说，指数平滑法建模代价最小，神经网络方法建模代价最大，这给神经网络方法的应用带来不便。

选择合适的预测模型需要考虑的另一个因素是工程上的可行性。复杂的模型引入的参数较多，模

型预测精度也比较高。但相应也带来不少问题。参数越多，需要的传感器数量也就越多，带来了工程成本的增加；在计算机上开展预测工作时需要的存储量也就越大。另外，传感器本身的测量误差（也即数据噪声）又造成了模型预测精度的下降。还可能会出现因某一个传感器出现故障而使负荷预测工作无法开展局面。所以，需要在模型的参数个数与预测精度之间寻求一个好的平衡点。也即希望模型引入的参数尽可能的少，同时预测精度也足够的高。

表 3　不同模型参变量个数

模型	参变量个	累积误差平方和
LR	11	9.61E+11
SEWMA	2	3.21E+11
ANN	11	2.85E+11

表 3 表明，改进的季节性指数平滑法是三种方法种引入参量最少的一个，仅 2 个参变量（历史负荷值与室外日平均温度），同时模型的精度也足够的高。这说明改进的季节性指数平滑法正是具有上述平衡点的预测模型，具有良好的工程应有可行性。

另外，模型的在线性能也是需要考虑因素。良好的在线性能是进一步提高预测精度的有效手段。从表 3－6 不难看出，季节性指数平滑法具有较好的在线性能。多元线性回归基本上不具备在线调整性能，因为当前的新值对整个模型的回归系数产生的影响微乎其微。引入适当的参数，神经网络方法也将会具有一定的在线性能。

还有一个值得关注的问题是新系统的负荷预测问题。由于新系统是没有历史数据的，而神经网络方法和多元线性回归方法均需要通过历史数据来训练网络，然后才能预测，所以就不能运用这两种方法了。季节性指数平滑法则不一样，根据季节性指数平滑法计算过程，理论上只要有两个周期（也即 2 天）的数据，就可以应用指数平滑了。所以对新系统的负荷预测问题，指数平滑法是一个好的解决方案。

6　结论

三种负荷预测方法中神经网络方法预测精度最高，改进的季节性指数平滑法对于一般的工程应用也足以胜任，而多元线性回归方法在大多数情况下都将是不可取的。

在预测精度有保证的情况下，相对于其它两种方法，改进的季节性指数平滑法具有更优越的工程应用价值。改进的季节性指数平滑法属于时

间序列分析方法中的一类，运用季节性的时间序列分析方法解决建筑物负荷预测问题是有效的。

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热湿独立控制型空调系统
在生态示范楼中的研究和应用

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摘 要 对目前传统空调方式存在的问题进行了分析，以此为背景，在兴建的生态示范楼中研究和应用了一种热泵驱动的热湿独立控制的空调系统，并对此系统进行了分析。

关键词 热湿独立控制；空调系统；生态建筑

Independent humidity control air conditioning systems in green building

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Abstract The problems of the traditional air conditioning systems are analyzed. On the basis, one independent humidity control air conditioning systems is studied and used in one green building. Studies the characteristic of the new air conditioning systems.

Keywords independent humidity control，air conditioning system，green building

1 研究背景

在上海市建筑科学研究院位于莘庄基地的建筑面积约 2000 平方米的生态建筑示范楼中，研究和应用了一种热湿独立控制的新型空调系统。研制和应用该空调系统是在人们对室内空气品质IAQ（Indoor Air Quality）日益关注、全社会对节约能源和保护环境高度重视的背景下进行的。

在室内空气品质方面：近年来，随着人们对健康问题的日益重视，室内空气品质得到了人们的广泛关注，并提出了病态建筑综合症 SBS（Sick Building Symptom）的问题。室内空气品质可以简化成人们普遍关心的两个问题：即人体舒适和人体健康。一般来说，温度、相对湿度、空气流动及噪声水平主要影响人体的舒适，而室内污染物主要影响人体的健康。室内污染可以有多种分类方式，例如可以把室内空气的污染物分为四类，即微生物粒子，可呼吸颗粒，气态物质污染及汽态物质污染[1]。室内空气污染已对人们带来很大的损失，例如因空气微生物的污染造成的呼吸道疾病给人民健康造成极大的灾难和损失。据统计，我国每年发生的呼吸道感染病例 500 万，损失达 10 亿元[2]。在美国，IAQ 问题已变成一个主要的环境问题并且已有立法要求业主对该问题负责。在目前建筑中，空调系统普遍使用表冷器换热，通过降温将空气中的水分冷凝下来，以达到降温除湿的目

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的。潮湿的表冷器表面，是滋生大量霉菌的最好环境，同时也能造成其它病菌和病毒的聚集和滋生[3]。特别是在空调箱停机期间（如下班或放假），在空调箱的密闭空间内，细菌浓度能骤然上升几十万倍[4]。这些微生物通过送风系统大量进入室内，会对室内的空气品质造成严重的影响。当前，用表冷器同时处理热、湿负荷的空调方式仍然是国内外应用最普遍的空调方式，空调系统本身就可能是一个很大的污染源。在这样的空调系统中，要解决好霉菌等问题已成为一个难题。

在节约能源方面：随着中国的改革开放和经济发展，商业建筑的面积日趋增大，建设规模和建设速度逐渐加大。我国自 1991 年起新建建筑平均每年 10 亿 m^2，城镇约 3 亿 m^2。随着经济建设的发展，商用建筑（包括写字楼、宾馆饭店、大中型商场等）大量兴建，致使用电量增长迅猛、环境恶化、全球变暖、用电峰谷差增大。保护资源和环境的可持续发展已成为中国的基本国策，建筑节能上升到前所未有的地位，商业建筑的能耗问题已引起了政府、社会的普遍关注。在商业建筑能耗中，空调系统的能耗是最主要的部分，通常达到商业建筑全年能耗的 50%左右。所以研究节能、高效的空调系统是社会发展的必然需求。

在环保方面：地球臭氧层的破坏会导致地球表面许多物种的消亡、粮食减产、人类皮肤癌患者的增加。因此，臭氧层的破坏，也是人类当前面临的主要环境问题之一。而目前空调系统广泛采用的制冷剂 HCFC 和 CFC 类物质，对臭氧层有明显的破坏作用。所以空调系统大量减少甚至完全替代 HCFC 和 CFC 类物质的使用，也是空调行业的发展趋势。

寻求一种健康、节能、环保的空调方式是社会发展的必然需求，也可以说是空调系统今后发展的重要方向。

目前，国内外也有采用固体吸附材料除湿的系统，可以消除换热器的冷凝水表面，实现热、湿分开处理。其主要有固定床式和转轮式两种。固定床式固体吸附除湿装置是通过改变空气侧流向实现间歇式的吸湿再生；转轮式除湿得到了更广泛的应用，它可实现连续的除湿和再生。这两种除湿方式有着致命的弱点就是运行过程的混合损失大，影响效率，另外，很难实现等温的除湿过程，而除湿过程释放出的潜热使除湿剂的温度升高，吸湿能力大打折扣，整个过程传热传质的不可逆损失大，效率太低。相反，其造价较高。所以目前在国内外都没有进行大规模的商业应用。

在上海市建筑科学研究院生态建筑示范楼中研制和应用热湿独立型空调系统正是为研究一种能够实现热、湿分开处理，消除换热器冷凝水表面，又能实现较大幅度的节能，造价合理，可实现产业化和大规模商业应用的空调系统的一种尝试。

2 热湿独立控制型空调系统的主要形式研究

热湿独立控制型空调系统包括新风除湿机、再生器、热泵、储液灌、干工况盘管等主要设备，如图 1 所示。

各设备的主要功能及系统的主要原理如下。

新风除湿机向室内输送新风，其包括全热回收段和冷却除湿段。首先通过全热回收段使室外高温高湿的空气和室内较低温度和湿度的排风进行一次全热交换，经过全热回收段的新风再进入除湿段与高浓度溶液（即溴化锂与氯化锂混合溶液）接触进行热湿交换，并利用一定量的冷水冷却除湿过程。这样，通过新风除湿机，新风被除湿降温，同时浓溶液吸湿后浓度降低，成为稀溶液，最

终将被送入再生器浓缩再生。

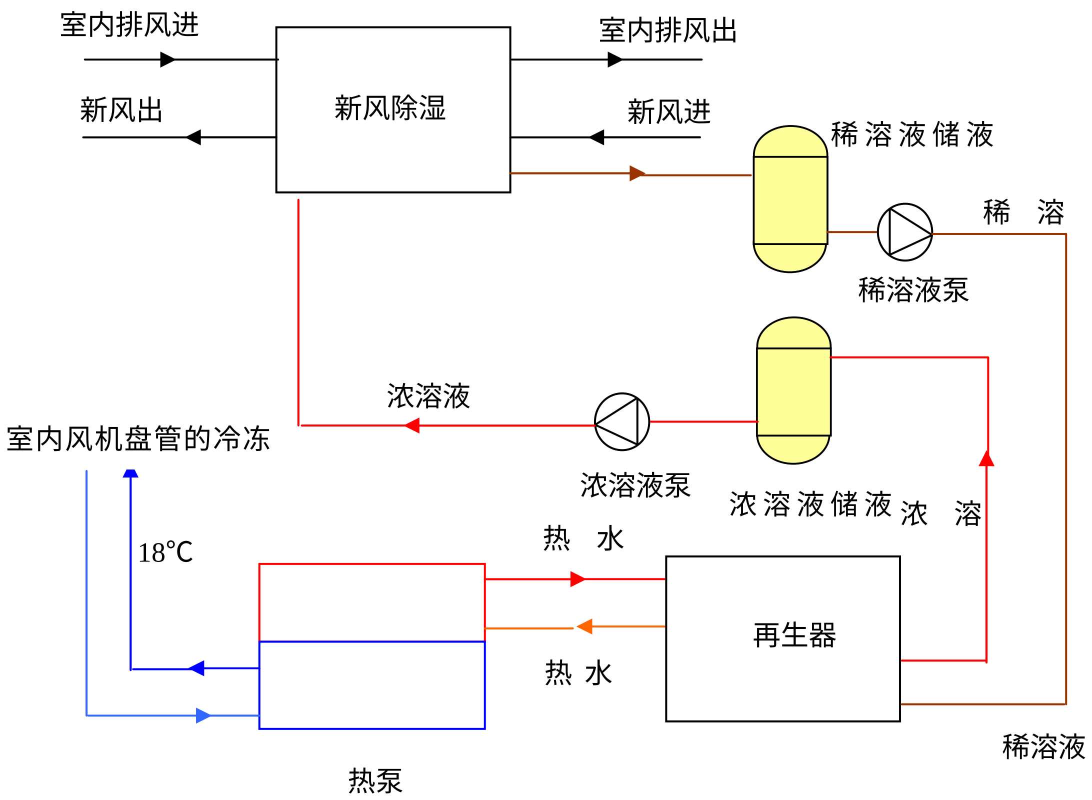

图 1 热湿独立控制型空调系统原理图

再生器的主要功能是浓缩除湿后的稀溶液，在此过程中，需要有较低品位的热源驱动。

在新风除湿机和再生器之间还分别设置了浓溶液和稀溶液两个储液罐。其主要用来储存溶液，相当于一个蓄能的装置。湿负荷小的时候储存浓溶液，负荷大的时候用储存的浓溶液作为补充来除湿，从而减小了系统的容量和相应的投资。

系统中还设置有一个高温热泵，其主要作用是一方面产生约 18°C的高温冷水为风机盘管提供冷源，处理空调的显热负荷，另一方面，由热泵排热产生热水，驱动再生器，为处理空调的湿负荷提供能量。这样，通过同时利用热泵的制冷和排热，以及对空调排风进行全热回收，提高了整个空调系统的能效比。

干工况的风机盘管，作为房间的空调末端设备，处理房间的显热负荷。

这样，该空调系统使用新风除湿机处理空调的湿负荷（即潜热负荷）；使用干工况风机盘管处理空调的显热负荷；同时利用热泵提供的高温冷水给风机盘管供冷，利用热泵的排热驱动再生器。

3 生态示范楼热湿独立控制型空调系统主要设计参数

1 室、内外空调设计参数

	干球温度（°C）	相对湿度（%）	湿球温度（°C）
室外空气设计参数	34.2	64	28.2
室内空气设计参数	26	55	19.5

2 建筑的空调总负荷及新风负荷

生态楼建筑面积约 1900 平方米，但除去有特殊环境要求的实验室（其空调系统另配）外，约有空调面积 1200m^2。建筑内人员总数设计 30 人，新风量设计指标为每人每小时 30m^3。经计算，空调系统的总负荷及新风负荷如下。

	总负荷（KW）	新风负荷（KW）
空调设计负荷	110	50

3 空调房间室内换热盘管干工况能否得到保证的分析

室内干球温度 26℃，相对湿度 55%，绝对湿度 11.6g/kg 干空气，新风送风的绝对湿度最低可以处理到 7～8g/kg 干，取新风送风绝对湿度 8g/kg 干，则每处理 1g 湿量，需要的新风送风量为 0.231 m^3，即 0.231 m3/g。人体产湿按照 100g/(人，h)计算，去除一个人的产湿量，需要新风量为：100×0.231 = 23.1 m^3/h。而目前新风量设计标准 30 m^3/(人，h)，于是，可以得出，在设计的新风量下，新风能够将房间人员的产湿量全部带走，不存在房间内空气结露的危险。房间内存在的风机盘管，能够在干工况状态下运行。

4 结论

这种热泵驱动的热、湿负荷独立控制的空调系统通过避免使用有凝结水的盘管，解决了目前空调系统中存在的霉菌滋生问题。同时通过除湿机内盐溶液的喷洒除去空气中的尘埃、细菌、霉菌及其他有害物，有效改善室内空气品质。并通过新排风之间的全热回收、同时利用热泵的制冷量和制热量等措施提高系统的能效比。其在解决室内空气品质、节能、以及环保等方面都将比目前的传统空调方式具有非常突出的优势，具有很好的应用前景。

目前在上海市建筑科学研究院生态示范楼中研究和应用该热湿独立控制型空调系统仍然仅仅是对这种新的空调方式进行探索和研究的开始。其仍有不少的设计、运行、控制以及参数优化等问题有待进一步的分析和研究。我们将以建成的生态示范楼及其空调系统为平台进行进一步的实测和研究。

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太阳能发电与建筑相结合的新发展

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摘　要　随着太阳能光伏发电系统的大量推广应用，光伏与建筑相结合（BIPV）近年来得到了迅速的发展。本文介绍了光伏与建筑相结合的特点及其发展，提出了屋顶并网光伏发电系统的设计要点及其计算方法，并对实例进行了分析。指出光伏发电与建筑相结合将成为光伏应用最重要的领域之一，也将为越来越多的建筑师所接受并投入实际使用。作为庞大的建筑产业与潜力巨大的光伏发电结合点的（BIPV），有着十分广阔的发展前景。

关键词　（BIPV）；并网系统；光伏方阵

Progress of Building-Integrated photovoltaic

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随着人们对环境污染和化石燃料储量逐渐枯竭的日益重视，大力开发利用可再生能源，逐渐改变能源的消费结构，在能源供应方面必须实施可持续发展的战略决策。已成为人们的共识。有人提出“ 21 世纪建筑 ”的特点之一是“ 建筑物产生能量 ”，在可再生能源迅速发展的今天，这个观念已经成为现实。

近年来，太阳能光伏发电应用的规模及范围正在迅速扩大，其中与建筑行业相结合已成为当前的热门领域，随着太阳电池价格的不断下降和制造技术的飞速发展，光伏发电与建筑相结合必将成为光伏应用最重要的领域之一。

1　光伏与建筑相结合（BIPV）的形式

1.1　光伏系统与建筑相结合

将一般的光伏方阵安装在建筑物的屋顶或阳台上，可以配备蓄电池独立供电，也可以通过逆变控制器输出端与公共电网并联，共同向建筑物供电，这是光伏系统与建筑相结合的初级形式。

1.2　光伏器件与建筑相结合

光伏组件与建筑材料融为一体，采用特殊的材料和工艺手段，将光伏组件做成屋顶、外墙、窗户等形状，可以直接作为建筑材料使用，既能发电，又可作为建材，一举两得，能够进一步降低发电成本[1]。

2　光伏与建筑相结合的优点

光伏与建筑相结合应用时，通常采用并网发电的方式，这类系统与独立光伏系统相比，有其突出的优点。

2.1　电能互补

光伏方阵在有日照时所发出的电能，供给建筑物内负载使用，如有多余，可反馈给电网。在阴

雨天或晚间，则由电网向负载供电。因此系统不必配备储能装置，这样，可以降低系统造价，也免除了维护和更换蓄电池的麻烦，同时还增加了供电的可靠性。

2.2　充分利用电能

在并网光伏系统中，可以随时向电网存取电能，不受蓄电池荷电状态的限制，所以在设计太阳电池方阵倾角时，可以取全年能接收到最大太阳辐照量所对应的角度。以最大限度地发挥太阳电池方阵的发电能力。

2.3　就地供电

光伏方阵一般可以安装在闲置的屋顶或阳台上，不必占用宝贵的土地资源，也不影响人们的日常生活。同时可以就地供电，不需要另外架设输电线路，避免了长距离输配电所造成的线路损耗。这种分散供电的模式具有很多优点，逐渐发展后，最终将改变目前单一的集中供电模式。

2.4　调峰作用

由于天热时空调、制冷等设备利用率高，耗电量大，因此每年夏天都是用电高峰期。同时夏天的太阳辐射强度大，太阳电池方阵所发的电能也多。正好可以起到调峰作用]。

3　光伏与建筑相结合的发展简史

由于光伏与建筑相结合有着巨大的市场潜力，各国很早就开始了研究开发。早在 1979 年，美国太阳联合设计公司（SDA）在能源部的支持下，研制出了面积为 0.9m×1.8m 的大型光伏组件，建造了户用屋顶光伏实验系统。并于 1980 年在 MIT 建造了有名的“ Carlisle House ”，屋顶安装了 7.5kw 光伏方阵，并结合被动太阳房及太阳能集热器，除了供电外，还提供热水和制冷。

20 多年前日本三洋电气公司研制出了瓦片形状的非晶硅太阳电池组件，每一块能输出 2.7 瓦，但由于价格太贵，性能也不太稳定，而未能大量推广。后来各国经过不断的开发改进，陆续推出了多种形式的（BIPV）产品，到 1997 年就已经安装了数兆瓦。特别是美国和欧盟先后实施了“ 百万屋顶 ” 计划，日本计划到 2010 年光伏系统的装机容量要达到 5GW[2]，这些都极大地推动了光伏与建筑相结合技术的发展。现在世界上规模最大的是德国慕尼黑展览中心的屋顶光伏系统，第一期安装的光伏系统容量为 1 MW[3]，后来又增加了一倍，达到了 2MW。

4　光伏与建筑相结合系统的特点

4.1　组件的要求

与一般的平板式光伏组件不同，（BIPV）组件既然兼有发电和建材的功能，就必须满足建材性能的要求，如：隔热、绝缘、抗风、防雨、透光、美观，还要具有足够的强度和刚度，不易破损，便于施工安装及运输等。为了满足建筑工程的需要，已经研制出了多种颜色的太阳电池组件，以供建筑师选择，使得建筑物色彩与周围环境更加和谐协调。根据建筑工程的需要，已经生产出多种满足屋顶瓦、外墙、窗户等性能要求的太阳电池组件。其外形不单有标准的矩形，还有三角形、菱形、梯形、甚至是不规则形状。也可以根据要求，制作成组件周围是无边框的，或者是透光的，接线盒可以不安装在背面而在侧面。

4.2　容量的确定

对于并网光伏系统，由于不受到蓄电池容量的限制，并且有公共电网作为后盾，确定光伏方阵

容量时，不必像独立光伏系统那样一定要经过严格的优化设计，只要根据负载的要求和投资情况经过适当计算就可决定[4]。对于一般家庭使用，通常太阳电池方阵容量的范围为 1~5 千瓦。

4.3　方阵倾角

在独立光伏系统中，光伏方阵要尽量朝向赤道倾斜安装，与水平面之间的倾角要经过严格的计算，以达到光伏方阵输出的极大性和均衡性[5]。而在并网光伏系统中，只要考虑光伏方阵输出的极大性即可。然而在实际应用中，往往因为要服从于建筑物外形的需要，方阵可能会有各种朝向，倾角也可能从 $0\sim90^0$ 都有，这就需要光伏和建筑设计师共同协商，兼顾的双方的需要，妥善解决。

4 .4　计量电表

家庭使用的并网光伏系统中，光伏方阵所发出的电能，主要供给用户负载使用，多余部分输入电网，用户负载所消耗的电能，也是由光伏方阵和公共电网共同供应。原则上可以用一块电表来进行计量，电网供电时电表正转，光伏方阵向电网馈电时电表反转。实际上由于各国政府对于开发利用新能源大多实行优惠政策，目前太阳能发电的上网电价要远大于用户的用电电价，常常用两块电表来分别计量，所以有“ 买入 ”电表和“ 卖出 ”电表的区别。

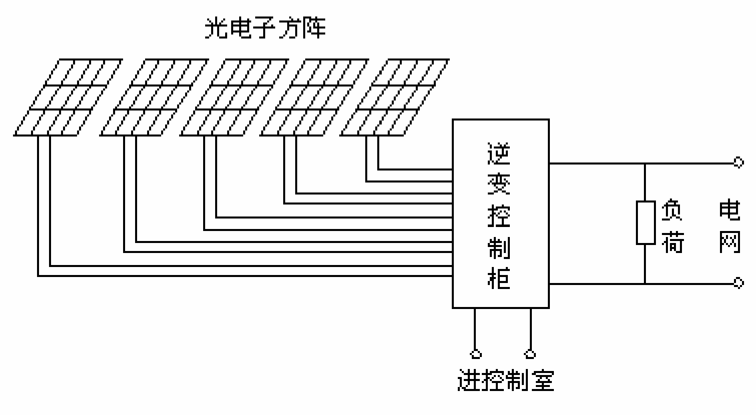
4.5　逆变和控制器

太阳电池方阵所发出的是低压直流电，要与电网连接，必须变换成 220 伏、380 伏甚至更高电压的交流电，而且对于电能质量如：电压、波动、频率、谐波和功率因素等参数都有严格的要求。为了保证电网、设备和人生安全，还必须配备并网检测保护装置，如对于处理：过/欠电压、过/欠频率、电网失电（防孤岛效应）、恢复并网、直流隔离、防雷和接地、短路保护、断路开关、功率方向保护等都有明确的规定。所以逆变和控制器是并网光伏系统的关键设备。

5　实例分析

我们在上海市莘庄工业园“ 生态建筑办公样板楼 ”的屋顶上安装了一套 5 千瓦光伏并网发电系统，系统主要由以下几个部分组成。示意图如下

5.1　光伏方阵



根据屋顶的结构情况，将光伏方阵分为 5 个子方阵，每个子方阵由 12 块 85 瓦的单晶硅太阳电池组件串联而成，然后将 5 个子方阵输出端并联。总功率为 5100 瓦，工作电压 210 伏。

按照上海地区的长期气象统计资料进行计算，得到上海地区全年接收最大太阳辐射量所对应的

倾角为 22^0，而屋顶斜面的坡度为 20^0，只要把上端抬高 7.5 厘米即可。同时还要考虑子方阵与屋面之间要留有一定空隙，以便通风降温。

5.2　逆变控制柜

光伏方阵输出的是 210 伏直流电，通过逆变器变换成 220 伏交流电，波形为 50 周正弦波。供给办公楼内用电，同时与电网并联。有多余电能时可以输入电网，控制器具有必要的并网安全及保护功能。

5.3　数据采集及显示系统

为了进行分析研究，配备了一定的数据采集系统，可以记录和显示方阵的工作电压、电流和功率，输出的交流电压及功率，以及累计发电量等参数。

此外还有开关箱等多种附件。

5.4　光伏系统发电量计算

并网光伏系统发电量计算较为简单，各月发电量为

$$Q = N \cdot H \cdot P \cdot \eta_1 \cdot \eta_2$$

其中：Q 为当月发电量，N 是当月天数，H 为该月太阳平均辐照量，P 是光伏方阵功率，η_1 为方阵到逆变控制器的输出效率，包括组件失配损失、线路损耗、灰尘覆盖、温升等损失，η_2 为逆变控制器的效率。

将上海地区的太阳辐射资料代入，得到各月发电量如表 1。

表 1　5 千瓦光伏方阵各月发电量

月份	1 月	2 月	3 月	4 月	5 月	6 月
H (kwh/d)	2.481	2.926	3.138	4.050	4.485	3.963
Q (kwh)	307.6	327.7	389.1	486.0	556.1	475.6
月份	7 月	8 月	9 月	10 月	11 月	12 月
H (kwh/d)	4.635	4.550	3.961	3.483	2.907	2.620
Q (kwh)	574.7	564.2	475.4	431.9	360.5	314.4

由此得出全年发电量为 5263.2 kwh，平均每天可以发电 14.4 kwh。

6.　结束语

据统计，现在建筑物消耗的能量大约占总能耗的一半以上，美国提出的目标是新建的建筑物要减少能源消耗 50%，并逐步对现有的 1500 万座建筑物进行改造，使其减少能耗 30%。其中重要的措施之一就是推广光伏与建筑相结合的屋顶并网光伏系统。

当然，光伏发电和建筑原来是完全互不相关的两个不同的领域，要将两者结合在一起，还有很多问题需要解决。但是随着科技的进步，（BIPV）新产品还将不断涌现，光伏系统的大规模应用，将促使其价格进一步下降，光伏发电与建筑相结合将成为光伏应用最重要的领域之一，也将为越来越多的建筑师所接受并实际使用。作为庞大的建筑产业与潜力巨大的光伏发电结合点的（BIPV），是光伏系统的应用由偏远农村地区进入城市的重要标志，有着十分广阔的发展前景。

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广州市某建筑水环热泵空调方案经济分析

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摘　要　水环热泵系统是一种具有热回收特性的空调形式，建筑物内既有需供冷又有需供热的房间时，水环热泵系统能取得较好的节能效果。本文对空调季节只需供冷的广州地区某建筑的水环热泵空调系统进行了分析，与集中制冷式风机盘管系统比较，该水环热泵空调系统的主要设备初投资和运行能耗高于集中制冷系统。本文还探讨了水环热泵空调系统在广州以及我国夏热冬暖地区的应用。
关键词　水环热泵；空调系统；节能

The Economy Analysis of a Building’s WLHP Air-conditioning System in Guangzhou

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Abstract　Water Loop Heat Pump(WLHP) is a air-conditioning system with the character of heat recycling, when some rooms need heating but some need cooling in the building, the WLHP can achieve a good effect of saving energy. This article analyzed the WLHP system in Guangzhou where the buildings only needs cooling in the air-conditioning season, compared with the system of concentrate refrigerating, the WLHP system’s first vast and running consume of energy is higher. This article also discussed the WLHP system’s application in Guangzhou and in hot summer and warm winter zone.
Keywords　WLHP,　air-conditioning system,　saving energy.

1　引言

水环热泵空调系统(Water Loop Heat Pump, WLHP)是一种由数量众多、形式各异的水源热泵(WSHP)通过一两管制闭合环路并联联接的空调系统。水环热泵系统始创于上世纪 60 年代初的美国加州，并在美国加州得到了应用，70 年代这种系统在西欧广泛应用于 5000-20000m^2 的商业建筑中[1]。近年来，水环热泵空调系统在我国发展迅速，水环热泵空调系统作为一种新的空调形式越来越多地应用于工程建设中。目前在我国不同气候地带的许多建筑如北京、上海、广州、深圳等地的许多工程采用了水环热泵空调系统。

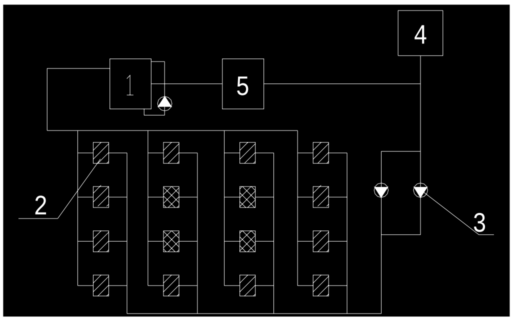
目前工程上具有实用价值的由水源热泵机组(WSHP)所配置的空调系统有：土壤源热泵(地耦合热泵)系统、地下水水源热泵系统、地表水水源热泵系统、水环热泵系统。前三种系统主要用于具备相应热源的建筑，而后一种水环热泵系统不但可以用于多层公寓住宅，而且在商业建筑中如办公楼、零售商场、寄住宿舍、医院等应用较多。

然而，至今大多数人对水环热泵空调系统的性能认识仍不是很全面，人们对于水环热泵空调系统的应用经济性也说法不一。本文以广州市某工程为例，分析了水环热泵系统与集中制冷风机盘管系统二种方案的经济性和水环热泵空调系统在广州地工区以及在夏热冬暖地区应用的性能。

2 水环热泵空调系统

2.1 水环热泵空调系统原理

水环热泵空调系统主要由水源热泵机组、冷却水循环泵、闭式冷却塔、加热设备和膨胀水箱组成（图 1），水源热泵机组供热运行时，以循环水为加热源，水侧热交换器作为蒸发器用，风侧热交换器作为冷凝器用；机组供冷运行时，二者作用刚好相反，水侧热交换器作为冷凝器用，风侧热交换器作为蒸发器用。当水源热泵空调机组制冷的放热量与其它热泵机组制热的吸热量相等时，系统既不吸热也不放热，在设计中系统水温保持在 13℃～35℃间时[2]，无需开动加热设备或冷却设备。当系统吸热量大于放热量时水温降低，水温低于 13℃时回热设备运行，反之系统水温升高，高于35℃时冷却设备运行。



1、密闭式冷却塔；2、水源热泵机组；3、冷却水循环水泵；4、膨胀水箱；5、加热闹设备

图 1　水环热泵空调系统原理图

在广州以及夏热冬暖地区，空调季节一般为夏季，空调区域只需供冷不需供热，因此在水环热泵系统中不需设置加热设备。系统原理图如下：

1、密闭式冷却塔；2、水源热泵机组；3、冷却水循环水泵；4、膨胀水箱

图 2　夏热冬暖地区水环热泵空调系统

2.2 水环热泵空调系统的优点

① 水环热泵空调系统从出现、存在到得以推广的主要优点是系统具有热回收功能，可以利用供冷空调房间排放的冷凝热来加热供热空调房间，从而提高建筑物内部的能源利用系数。在建筑物内有多区域多房间同时需供冷和供热要求时，水环热泵空调系统能取得很好的节能效果，因此，从某种意义上说，水环热泵空调系统是一种热回收系统。

② 水环热泵空调系统空调区域分区设计灵活，各分区可以在同一系统中按不同要求独立选择供冷或供热的运行方式。

③ 系统运行可靠，由于制冷设备分布在空调区域的各个房间，不会因个别机组的故障而影响其它空调房间的正常使用。

④ 水环系统中没有集中式制冷机组集中热源，因此系统取消了冷源机房面积和节省了热源机房面积。

⑤ 水环热泵空调系统的能耗主要是水源热泵机组，各用户能够安装独立的电表分户计费，便于物业管理和系统能源的管理。

2.3 水环热泵空调系统的不足

① 与风机盘管相似，水环热泵空调系统需设置独立的新风系统，且系统的凝结水管理不善易污染室内环境。

② 水源热泵机组一般安装于空调区域内，机组运行的噪音对室内的影响较大。

③ 系统中水源热泵空调机组大多容量小且数量多，分布广泛，尤其是分体式水源热泵机组增加了制冷剂泄漏的可能。

④ 目前水环热泵空调系统需选用开式冷却塔加板式换热器或密闭式冷却塔，以防止热泵内热交换器细铜管免受腐蚀和结垢，目前这种方案的工程造价高或系统维护复杂。

3 广州市某项目水环热泵空调系统经济性分析

3.1 工程设计简况

工程为广州市某大型批发市场，商业区建筑面积 24 万平方米，其中空调面积 20 万平方米。建筑共由三个区域组成。建筑内各业主具有一定的独立性，因此建设单位要求空调方式选用水源热泵机组。其中较大区域建筑面积约 15 万平方米，空调为密闭式冷却塔加水环热泵式空调系统为主，分体式空调机为补充的空调形式。冷却塔设置于屋面，水源热泵冷却循环水为双管闭式循环系统。夏季空调设计参数如下：

夏季空调室外计算干球温度：33.5℃；

夏季空调室外计算湿球温度：27.7℃；

空调室内设计干球温度：25～28℃；

空调系统设计总冷负荷为 26311KW (7475RT)，循环水量为 5846m^3/h，空调系统主要设备如下：

表 1 密闭式冷却塔

循环水流量 (m3/h)	电机功率 (kw)	数量 (台)
325	4*7.7	10
290	4*7.0	6
225	3*7.0	1
180	3*7.0	3

表 2　冷却水泵

循环水流量 (m3/h)	电机功率 (kw)	数量 (台)	备注
350	55	9	8 用 1 备
270	45	14	11 用 3 备
180	30	2	1 用 1 备
140	22	6	3 用 3 备

表 3　水源热泵机组

制冷量 (kw)	电机功率 (kw)	数量 (台)
2.7	0.7	2508
3.9	1.05	1669
5.7	1.55	981
7.8	2.25	325
10.0	2.9	25
14.0	4	110

表 4　水冷整体式吊挂新风机

制冷量 (kw)	电机功率 (kw)	数量 (台)
19.25	5.9	2
22.4	6.9	6
27.06	8.0	15
38.5	10.5	24
44.88	12.5	18
57.75	16.1	28

3.2　选用螺杆式冷水机组系统的设计

采用常规的半集中式制冷方式，螺杆式冷水机组加风机盘管空调系统，冷却水采用开式冷却塔，其主要设计参数和设备如下。

系统冷负荷与水环热泵空调形式相同为 26311KW (7475RT)，系统冷冻水供回水温度为 7～12℃，冷却水供回水温度为 32～37℃。冷冻水流量为 5846m^3/h，冷却水流量为 7015 m^3/h。主要设备中冷却塔采用开式超低噪音横流式冷却塔，集中制冷机组采用螺杆式冷水机组，集中制冷方案的冷冻水泵设计与水环热泵方案的冷却水泵相同，冷却水泵采用空调用双吸泵，集中制冷方案中风机盘管、新风柜等与水环热泵方案中水源热泵机组、水冷整体工吊挂新风机的数量和制冷量分别相等。

3.3　初始投资分析

在分析比较中，为了使二种方案有可比性，螺杆式冷水机组、水源热泵空调机组、风机盘管等设备选用同一空调厂的产品资料；集中制冷空调系统冷冻水泵选用原设计冷却水泵相同，冷却水泵选用空调用双吸泵，水泵均按某水泵厂的产品资料计算。经过市场调查，目前市场上的开式冷却塔（玻璃钢冷却塔）价格约为 3 万元/100(m^3*h)，密闭式冷却塔的价格约为 30 万元/100(m^3*h)以上。

表 5　水环热泵空调系统与集中制冷系统主要设备初投资

项目	水环热泵系统 （万元）	螺杆制冷系统 （万元）
螺杆冷水机组	---	1706.3
风机盘管	---	506.0
新风机	301.2	169.4
水源热泵机组	2322.6	---
冷却塔	1753.8	210
冷冻水泵	---	50.2
冷却水泵	50.2	45.6
合计	4427.8	2687.5

3.4　运行能耗分析

空调系统运行时的能耗主要有电力消耗和水消耗。水消耗主要在冷却塔，开式冷却塔和密闭式冷却塔的工作原理，均是利用水蒸发带走空调系统排出的热量，因此在进行二种空调方式的能耗比较时，我们假定在本工程中二种系统的水量消耗相等，只对二种方式中主要设备的电力消耗进行分析比较。

表 6　二种方案主要设备功率

项目	水环热泵系统 (kw)	螺杆制冷系统 (kw)
螺杆冷水机组	---	5915
风机盘管	---	492.1
新风机	1101	153.9
水源热泵机组	6272.5	---
冷却塔	646.8	168
冷冻水泵	---	740
冷却水泵	1031	1031
合计	9051.3	8500.0

空调系统运行中，大部分时间在部分负荷下运转。广州地区夏季供冷通常为 5～10 月，共 184 天，假定一天空调运行的时间为 9:00—21:00 共 12 小时，一年中空调运行的时间总共为 2208 小时。根据季节的变化和每天环境温度的变化情况，认为地区夏季空调满负荷运行时间为 5%，冷量 80%部分负荷运行时间为 25%，冷量 60%部分负荷运行时间为 55%，冷量 40%部分负荷及以下运行（按 30%计算）时间为 15%。

表 7　二种系统年用电量及运行费用比较：

项目	水环热泵系统	集中制冷系统
满负荷(kwh)	999264	938400
80%负荷(kwh)	3997054	3753600
60%负荷(kwh)	6595139	6193440
40%负荷(kwh)	899337	844560
年用电总量(kwh)	12490794	11730000
电价(元/kwh)	1.2	
年用电费用(元)	14988953	14076000

4　讨论

① 从工程初始投资分析，本工程二种方案中，水环热泵机组的初投资比螺杆冷水机组加风机盘管的初投资高 242.1 万元，其中密闭式冷却塔比开式冷却塔的初投资高 1543.8 万元。二种方案相比，目前水环热泵空调系统的主要设备比集中式螺杆机组加风机盘管系统的初投资高约 1740.3 万元即设备初投资高 64.76%。然而，水环热泵系统由于没有集中制冷机组，可以取消制冷机房，节省建筑面积约 1200 平方米[3]，相应可以减少建筑的造价。

② 从运行费用分析，从运行费用分析，系统运行能耗主要在水源热泵机组和螺杆冷水机组，在本工程中，水源热泵机组与新风机的设计功率比螺杆冷水机组加风机盘管、新风机的设计功率多 812.6KW，水环热泵空调方案比集中制冷方案设计总功率多 551.3KW，年用电多 760794kwh，即每年空调系统运行费用多 91.3 万元。本工程始建于 2003 年，目前空调系统仍在建设中，因此本工程空调系统的实际运行能耗有待以后验证。

③ 噪声控制。空调系统的噪声是人们比较关心的问题之一，二种空调方案的冷却塔均设置在屋面，集中制冷系统主机房可设置在地下室，这样可以减少噪声对环境的影响，对人们生活影响较大的是空调末端设备的噪声，由于水源热泵机组均安装于室内，因此水环热泵空调系统对室内环境的噪声影响较大。

④ 一般情况下，密闭式冷却塔的冷却水供水温度要比当地夏季空调湿球温度高 4～6℃，冷却水温差为 4～6℃，热泵循环水的出水温度比冷却水供水温度高 2℃左右，循环水温差约为 5℃[4]。因此本工程的热泵机组在夏季设计工况下的出水温度一般取 39℃。本工程水环热泵系统的冷却水管道安装于室内，冷却水的温度比室内空气温度高 11～14℃，冷却水的部分热量将散入室内最终成为室内冷负荷，这样将增大系统的能耗。因此系统冷却循环水温度较高时，应对室内管道保温或对室内部分高温管道保温。

⑤ 水环热泵空调系统的电力消耗主要在水源热泵机组，本工程中水源热泵空调机组的功率占系统总功率的 70%左右。因此，利于运行费用的分户计费，便于以后的运行管理。

⑥ 前已述及，水环热泵空调系统运行可靠。但本工程由于系统庞大，共有 5618 台水源热泵机组和 93 台水冷吊挂式整体新风机组，每台机组即为一个制冷压缩循环系统，因此这些设备分散管理和维修工作量将很大。

5　水环热泵空调系统在广州地区的应用探讨

笔者还分析了广州市另一商业建筑的水环热泵空调系统的能耗，该建筑的建筑面积 42792 平方米，其中空调面积（商铺和会所）8517 平方米，空调系统总冷负荷为 2091KW（595RT）。空调系统的能耗分析分三种方案进行比较，即水环热泵空调系统、集中制冷空调系统、风冷分体空调系统。其中水环热泵空调系统的冷却塔采用密闭式冷却塔，集中制冷采用开式冷却塔和螺杆式冷水机组，风冷分体空调系统中制冷量大于 6KW 采用柜式分体空调机，小于等于 6KW 采用壁挂式分体空调机。

表 8　水环热泵、集中制冷、风冷分体空调主要设备功率

项目	水环热泵系统 (kw)	螺杆制冷系统 (kw)	风冷分体空调系统 (kw)
分体空调	---	---	114.9
螺杆冷水机组	---	539.4	---
风机盘管	---	51.6	---
水源热泵机组	708.6	---	---
冷却塔	42	8.8	---
冷冻水泵	---	66	---
冷却水泵	66	66	---
合计	816.6	731.8	1142.9

比较以上三种方案的功率可以得到，未考虑水环热泵系统和集中制冷系统的自动控制耗电量时，风冷分体空调系统的部功率最大，比水环热泵空调系统高约 40%，集中制冷系统功率是水环热泵系统的 90%左右。

在目前的能源结构中，建筑能耗已占全国总能耗的 30%左右，而空调耗能一般占整个建筑能耗的 60%以上，近年来由于能源需求量的增长，部分地区电力紧张的局面明显加剧，以致出现拉闸限电的现象。2004 年我国政府出台了《公众节能行为指南》，为节能节电提出了相关的措施。对于空调系统尤其是电制冷空调系统，在空调系统设计中，系统的运行能耗应为确定空调方案的最主要因素之一。对于可集中控制的空调系统，宜选用集中制冷或水环热泵系统，商场、写字楼等建筑中空调用户同时使用系数高且负荷较稳定的空调系统，选用集中制冷方案能取得较好的节能效果。

在住宅区的空调系统中，由于住宅建筑的特点，白天上班时间各用户的同时使用系数小，且负荷震荡较大，大部分时间系统的负荷不足满负荷的 50%，在低负荷率与不稳定负荷下运行时，集中制冷机组的能效比（EER）较低，而水环热泵空调系统能满足负荷的变化特性。

另外，水环热泵空调系统取消了制冷机房，对于空调机房布置受限制的建筑，这种空调方式具有较明显的优势 ;水环热泵系统实行分户计费，能很好地解决商业建筑中央空调分户计费难的问题。

因此，在设计中应根据建筑物的使用功能、初投资和运行能耗等方面进行综合比较，选择最佳空调设计方案。与集中制冷加风机盘管系统相比，采用水环热泵空调系统一定要分析空调负荷的特点，一定条件下才有环保和节能的意义。

6　水环热泵空调系统应用展望

从以上二个工程实例可以得到，与集中制冷系统相比，水环热泵空调系统初投资较高的是密闭式冷却塔。目前水环热泵系统常采用密闭式冷却塔或开式冷却塔加板式换热器，以防止水源热泵中换热器铜管表面腐蚀和形成水垢和生物垢，影响铜管的换热量。

在保证冷却循环水水质的条件下，采用开式冷却塔，可以降低水环热泵空调系统的初投资；而且采用开式冷却塔供水，可以使水源热泵机组的冷却水温度降低约 2℃，提高机组的制冷效率，同

时也能降低冷却塔的运行能耗。因此，开发这方面的新技术，更能促进水环热泵空调系统在广州以及我国夏热冬暖地区的应用。

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蒸发冷却空调系统在我国西部地区应用的能耗分析 [1]

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摘　要　利用编制的数学模型，对乌鲁木齐地区某一实际建筑中的蒸发冷却空调机组进行了整个夏季的动态能耗计算。选用普通风冷螺杆式空调机组作为冷源，对所选的建筑进行空调系统的设计，并计算其动态能耗。通过比较两种空调系统的计算结果，说明了在相同情况下蒸发冷却空调系统的能耗约是风冷螺杆机组空调系统能耗的 1/3。

关键词　蒸发冷却；空调负荷；能耗；节能

The Energy Consumption of Evaporative Cooling System in Summer

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Abstract　Using the established emulator, the whole summer consumption of one building in Urumchi city is calculated. In order to compare the energy consumption of evaporative cooling system with others, the air-cooled heat pump screw chiller is selected and used in the same building. The whole summer energy consumption of air-cooled heat pump screw chiller is calculated. Through comparing the two calculation results, it is proved that the energy consumption of evaporative cooling system is about 1/3 that of air-cooled heat pump screw chiller at the same condition.

Keywords　evaporative cooling, air-conditioning load, energy consumption, energy saving

0　引言

蒸发冷却技术作为一种被动式供冷技术,其最大的特点是节能。但是，由于这种技术的使用受到环境条件的限制，不同地区由于自然条件的差异，使用效果也各不相同[2]。为了研究蒸发冷却技术的节能特性，本文选择乌鲁木齐地区的一幢实际建筑为研究对象，利用所编制的直接蒸发冷却器的计算程序，并结合以中国建筑科学研究院空调所为主开发的空调负荷计算程序 BDP/HVAC/ACL 来对蒸发冷却空调机组的夏季运行能耗进行计算，以此来分析蒸发冷却空调机组的节能特性。

1　空调系统的设计

1.1　实际建筑简介

本文所选用的建筑是新疆乌鲁木齐地区的一幢商业楼，该楼共三层，地下一层，地上两层。总建筑面积约为 6000 m^2，其中裙楼面积约 1500m^2，主楼面积约 4500 m^2，楼高 9.4 m。

裙楼部分用作普通办公用房，主楼部分作为营业厅来使用，底层为设备层和仓库。办公和营业时间均为 10:00—18:00。该建筑标准层平面图如图 1 所示。

为了便于比较，本文以上述建筑的 2，3 层为一个独立的系统，进行蒸发冷却空调机组和以风冷螺杆式机组作为冷源的风机盘管加新风系统两种空调方案的设计，并进行能耗的分析和

比较，从而得出蒸发冷却空调机组的节能数据。

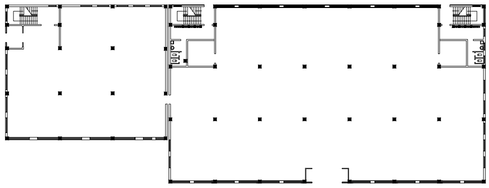


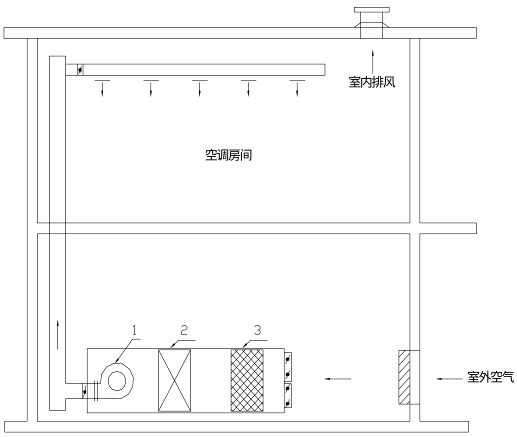
图 1　实际建筑平面示意图

1.2　设计负荷的计算

乌鲁木齐地区夏季室外计算干球温度 34.1℃，室外计算湿球温度 18.5℃。根据所选择的各设计参数，利用中国建筑科学研究院空调所为主开发的空调负荷计算程序 BDP/HVAC /ACL 计算得到建筑物的夏季设计冷负荷为 170kW[3]。

1.3　蒸发冷却制冷空调系统的设计

本文在设计的过程中，主要是以乌鲁木齐地区某厂家的 ZZK 型和 JZZK 型两种蒸发冷却空调机组为依据，进行设备的选型和设计的。ZZK 型主要适用于室外湿球温度小于 20℃，对空调房间相对湿度要求不高的地区。当室外空气湿球温度大于 20℃，或舒适度要求较高时，宜选用 JZZK 型机组。两种机组的构造基本相同，不同之处在于 ZZK 型机组的冷却段是直接蒸发冷却填料，而 JZZK 型既有直接蒸发冷却填料，又有间接蒸发冷却填料。



1—送风风机　2—蒸发冷却器　3—过滤器

图 2　ZZK 型蒸发冷却空调机组使用原理图

由于房间所需要的冷负荷全部由新风来承担，因此，蒸发冷却空调机组的制冷量应包括空调房间冷负荷和新风冷负荷两个部分。根据空调房间的冷负荷，新风负荷，室内要求的干球温度以及夏季空调室外计算干，湿球温度，在 ZZK 型直接蒸发冷却段性能尺寸表中选出最接近和大于所需冷负荷的机组。根据计算结果，本文选择 ZZK-900 型机组作为空调冷源，其制冷量为 488kW，额定风量为 90000m^3/h。根据选定的 ZZK-900 型机组所需要的淋水水泵的扬程和功率，选用某厂家一台 LSP-100A 型管道泵，其电机功率为 7.5kW, 喷水流量为 37.8m^3/h。根据选定的 ZZK-900 型机组所对应的额定风量，以及系统的最不利环路压力降情

况，选用一台 Y225M-8 型风机，其电机功率为 22kW，额定风量为 94700m^3/h。

1.4　风机盘管加新风系统的设计

本方案选用一台风冷螺杆冷水机组作为冷源。室内空调系统均采用风机盘管加新风系统。新风负荷由新风机组承担，新风经初效过滤处理后，由新风机组经风管输送给各层空调系统。空调水系统采用双管同程水系统。

风机盘管加新风系统所需设备主要包括：空调冷源（即风冷螺杆冷水机组），新风机组，风机盘管，循环水泵，冷却塔风机等。各设备容量可根据设计负荷进行相应选择。选择结果如下表所示：

表 1

设备名称	型号	数量
风冷螺杆冷水机组	JCFLR-60 型	1
风机盘管	FP-10 型	35
新风机组	39F680 型	1
水泵	SB-100-65-300 型	1

2　夏季空调能耗分析

2.1 书馆　建筑物夏季动态负荷计算

利用空调负荷计算程序 BDP/ HVAC/ ACL 计算了所选建筑 6-8 月围护结构负荷和新风负荷。计算结果如下表所示：

表 2

月份	围护结构+内热负荷（kWh）	蒸发冷却空调机组新风负荷（kWh）	风冷螺杆冷水机组新风负荷（kWh）
6	18842.1	57398.2	3642.7
7	23817.7	76980.5	3791.8
8	19458.0	60986.3	1001.2
总计	62117.8	195365.0	8435.7

由计算结果可知，对螺杆式风冷冷水机组来说，在夏季工况下围护结构和内热负荷占总空调负荷的比例约为 88%，新风负荷占总空调负荷的比例约为 12%，7 月份的空调负荷最大，其它依次为 6 月和 8 月。对蒸发冷却空调机组来说，在夏季工况下围护结构和内热负荷占总空调负荷的比例约为 24%，新风负荷占总空调负荷的比例约为 76%，7 月份的空调负荷最大，其它依次为 8 月和 6 月。由于本文所选建筑在使用蒸发冷却空调机组时，实行全新风设计，因此新风负荷所占例要远远大于围护结构和内热负荷所占比例。

据此计算的室内冷负荷随时间的变化关系如下图所示：

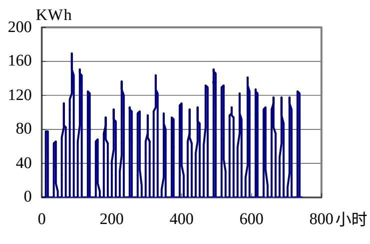


图 3　六月份动态空调负荷

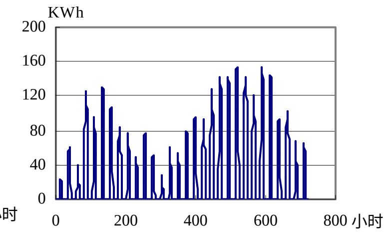


图 4 七月份动态空调负荷

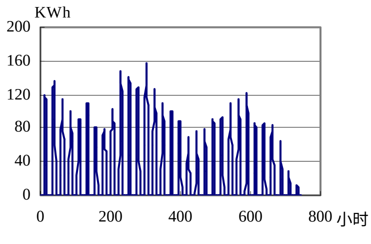


图 5　八月份动态空调负荷

3 蒸发冷却空调系统和风冷螺杆冷水机组空调系统能耗的分析

3.1 蒸发冷却空调系统能耗的分析[4]

蒸发冷却空调系统的能耗包括风机和喷水水泵两部分的能耗。

3.1.1 风机的能耗的计算[5]

风机的耗能水平和系统的运行方式有关。由于乌鲁木齐地区夏季气候干燥,室外气温较低，风机保持变风量运行既可满足室内的空调要求，因此本文采用了变风量的运行方式来进行风机能耗的计算。风机能耗的计算步骤如下：

1.根据建立的直接蒸发冷却器的数学模型，编程计算出风机所输送的逐时风量。

2.由于风量已知，因此根据所选风机的 L-P（流量-扬程）曲线，回归出扬程 P 与流量 L 的函数关系式，再根据 L-η(流量-效率)曲线，回归出流量 L 与效率η的函数关系式。根据公式（4-1)，计算出风机的逐时轴功率

4.将电机逐时电功率相加，即可得到运行期间风机的总能耗。

3.1.2 水泵的能耗计算

系统在运行的过程中保持喷水量不变，因此，只要求出系统总的运行时间，就可以根据水泵的功率求出水泵消耗的能量。

3.1.3 蒸发冷却空调系统能耗的计算结果

根据上述各部件计算方法，计算得到蒸发冷却空调系统夏季运行能耗如下表所示：

表 3

月份	风机能耗 (kWh)	水泵能耗 (kWh)	总能耗 (kWh)
6	2278.8	1447.5	3726.3
7	3006	1807.5	4813.5
8	2146.3	1410	3556.3
汇总	7431.1	4665	12096.1

3.2 风冷螺杆冷水机组空调系统能耗的计算

3.2.1 风冷螺杆冷水机组能耗的计算

对风冷螺杆冷水机组的能耗计算，由于没有现成的能耗模拟程序，因此本文采用样本上给出的该机组全负荷特性以及风冷螺杆冷水机组的特性曲线进行夏季能耗分析。风冷螺杆冷水机组的部分负荷特性曲线如下图所示。

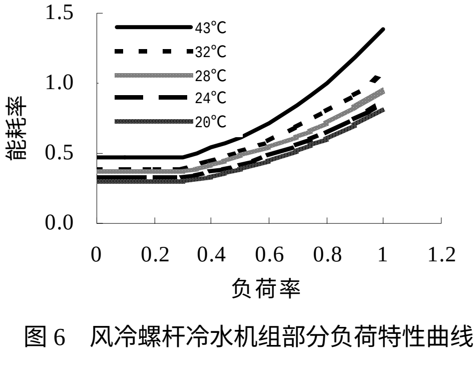


图 6　风冷螺杆冷水机组部分负荷特性曲线

图 6 中，负荷率为机组实际制冷量与其额定制冷量的比值，能耗率为机组的实际能耗与其额定能耗的比值。每一条曲线代表一种环境温度下的能耗率值。由于图 6 中只列出了有限的几个室外干球温度条件下负荷率和能耗率的关系，其它室外干球温度条件下负荷率和能耗率的关系则通过拟合而得到。

风冷螺杆冷水机组能耗计算步骤如下：

1.由空调负荷计算程序 BDP/HVAC/ACL，可以计算出运行季节逐时围护结构负荷和内热负荷。

2.由新风负荷计算公式，结合室外动态气象参数，编程计算该系统所需新风逐时负荷。

3.通过对上表中的数据进行拟合，可以得到不同出水温度室外环境温度下和机组满负荷制冷量，室外环境温度和机组功率的关系式。

4.用不同时刻的动态空调负荷值除以对应环境温度下机组满负荷制冷量，得到该工况下的空调动态负荷率。

5.把步骤 4 得到的负荷率代入回归出的负荷率和能耗率的关系公式中，可以得到机组的能耗率。

6.用该能耗率乘以该工况下机组的满负荷功率，则为机组的该时刻能耗。

7.将各时刻机组能耗进行累加，即为机组在运行季节的总能耗。

3.2.2 其它设备能耗的计算

冷凝器风机，新风机组，风机盘管为定风量运行，风机在运行季节能耗不变，因此风侧换热器电机，新风机组电机，风机盘管电机的能耗为其电机功率乘以运行时间。本文在设计中，考虑水泵以变流量方式运行，并以此种方法为基础来计算水泵的全部能耗，其计算方法和前述变风量风机能耗计算方法类似，限于篇幅，本文不再详述。

3.2.3 风冷螺杆冷水机组空调系统能耗结果分析

根据以上各步骤能耗计算方法，可以得出 6-8 月，风冷螺杆冷水机组空调系统运行总能耗，其结果如表 4 所示：

由计算结果可以看出，在夏季运行能耗中，风冷螺杆冷水机组能耗所占比例最大，约占总能耗的 65%，新风机组所占的能耗次之，约为 13%，风侧电机和风机盘管所占的能耗分别为 11%和 6%。水泵能耗所占比例最小，约为 5%。由此可见，风冷螺杆冷水机组是该空调系统主要耗能设备。由计算结果还可以知道，系统在夏季运行工况下，7 月份的能耗最高，6 月份次之，8 月份最低。

表 4

月份	风冷螺杆冷水机组能耗 (kWh)	风侧电机能耗 (kWh)	新风机组能耗 (kWh)	风机盘管能耗 (kWh)	水泵能耗 (kWh)	总能耗 (kWh)
6	7477.9	1158.0	1447.5	587.7	581.5	11252.6
7	9691.2	1446.0	1807.5	860.4	747.0	14552.1
8	5688.8	1128.0	1410.0	572.5	330.9	9130.2
汇总	22857.9	3732	4665.0	2020.6	1659.4	34934.9

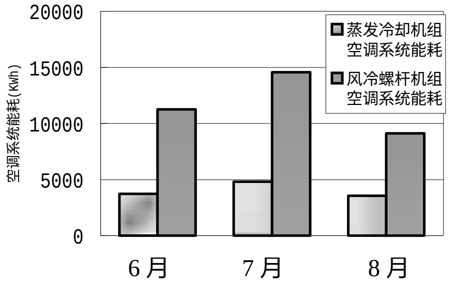


图 7 两种空调系统夏季动态能耗分布图

4 蒸发冷却空调系统和风冷螺杆冷水机组空调系统夏季能耗的分析比较[6]

由上述两种空调系统的能耗计算结果来看，对于所选实际建筑，在夏季运行工况下，蒸发冷却空调系统的能耗约为风冷螺杆冷水机组系统能耗的 1/3。由此说明，蒸发冷却空调系统的节能性远远优于风冷螺杆冷水机组空调系统，蒸发冷却空调系之所以具有这种节能性，主要是因为它具有以下优点：

1.利用水的蒸发吸热来实现制冷，省去了传统机械制冷系统中的压缩过程，使得制冷能耗大大降低。

2.耗能部件少，系统运行效率高。

3.对风机实行变风量运行，可以大大节省系统能耗。

普通风冷螺杆冷水机组在部分负荷时虽然可以实现无级调节，但其调节范围比较小，同时，机组采用水作为载冷剂，在制冷时要经过两次热交换，也会造成能量的损耗，而且，该机组还有许多附属的耗能设备，如水泵，新风机组和空调末端装置(风机盘管)，这些设备也在一定程度上增加了空调系统的能耗。

由图 7 可以看到，蒸发冷却空调系统的能耗和风冷螺杆冷水机组空调系统的能耗 7 月份相差最大，其次为 6 月份和 8 月份。由图 7 还可以看到，虽然两种空调系统的能耗随时间的变化规律相同，但蒸发冷却空调系统各月间的能耗相对变化不大，而风冷螺杆冷水机组空调系统的能耗变化比较大。由此说明，蒸发冷却空调机组的调节性能要优于风冷螺杆空调机组。

5 结论

1. 通过对计算结果的分析比较可以得到，对同一建筑，在相同工况和运行时间下，蒸发冷却空调系统的能耗约是风冷螺杆冷水机组空调系统能耗的 1/3，由此说明，蒸发冷却空调系统的节能性要远远优于风冷螺杆冷水机组空调系统。

2. 由于蒸发冷却空调系统实行全新风运行，因此新风负荷所占的比例要远远高于风冷螺杆冷水机组空调系统，也远远高于围护结构负荷和内热负荷，如何回收排风冷量，是今后的研究工作当中应该考虑的一个重要问题。

3.由于蒸发冷却空调机组的制冷量和室外空气状态有关，因此，根据干燥地区建筑物所做的能耗分析，只能在环境条件相近的区域内适用，对于其它地区，则只具有参考意义。

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关于居住建筑节能评估方法的探讨

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摘　要　本文将对比评定法与《夏热冬冷地区居住建筑节能设计标准》中的节能评估方法相比较，并采用 DeST 能耗模拟软件对三种不同建筑类型的节能效果进行了实例分析，模拟计算结果表明对比评定法比现有标准中的限值法更符合实际情况，且有利于住宅节能技术的推广应用。
关键词　居住建筑；节能评估；对比评定法；动态模拟

1　前言

居住建筑采用节能措施是改善室内热舒适环境和减少建筑能源消耗的重要手段，近年来随着上海地区住宅产业的蓬勃发展，大量的新型住宅节能技术得到了广泛的推广及应用，一系列与节能相关的标准也相继出台对居住建筑提出了节能要求。正确评价住宅的节能效果，合理推广适用的节能技术和措施已成为实现居住建筑节能的关键。

按照《夏热冬冷地区居住建筑节能设计标准》（以下简称《标准》）的规定，评估节能建筑应首先校和该建筑各个朝向窗墙比、各个朝向外窗和围护结构热工性能等各项参数是否都满足《标准》的要求，即采用“ 规定性指标 ”来评价居住建筑的节能效果。然而，住宅建筑的设计日趋多样化和个性化，许多住宅建筑往往不能完全满足《标准》中“ 规定性指标 ”的要求，例如南向外墙采用大面积玻璃窗导致南向窗墙比超标，建筑体形复杂多变导致体形系数过大，此时应按照《标准》中的“ 性能性指标 ”，即采用动态模拟分析方法，计算建筑物全年的采暖空调能耗，对其节能效果进行评价。

采用动态方法计算住宅建筑能耗，一般又包括两种节能评价方法：“ 节能综合指标限值法 ” 和“ 对比评定法 ”。下面对这两种方法分别加以阐述并进行对比分析。

2　节能综合指标限值法

采用“ 节能综合指标限值法 ” 评价建筑物的节能效果是指在《标准》规定的计算条件下，计算建筑物的节能综合指标，即采暖年耗电量和空调年耗电量之和，并与该建筑所在城市的节能综合指标限值相比较，如果计算值不高于标准规定的限值，就认为该建筑达到了节能要求，如果计算值高于标准规定的限值，则认为该建筑未达到节能要求，此时需调整该建筑物的热工性能，直到计算结果满足限值要求。

夏热冬冷地区范围内的不同城市由于气象条件的差异，节能综合指标限值也有所不同，其具体数值是在标准工况下，通过对两栋典型六层建筑的全年采暖空调耗电量进行模拟计算来确定的。这两栋建筑的建筑面积各 2200 m^2 左右，体形系数 0.31 和 0.35，南北朝向，每层两个单元四户，每户建筑面积稍小于 100 m^2，分为 2~3 个卧室，1 个起居室，1 个厨房，1~2 个卫生间。卧室和起居室控制温度和换气次数，卫生间和厨房不控温。东西山墙不开窗，南北墙上的窗户都有水平遮阳。外

墙的传热系数为 1.54W/（m^2· K），屋顶的传热系数为 0.93 W/（m^2· K），窗户的传热系数为 3.1 W/（m^2· K）。将这两栋典型建筑放到夏热冬冷地区的合肥、南京、上海、杭州、武汉、长沙、南昌、成都、重庆 9 个大城市的逐时气象条件下计算，把计算出来的一些结果按采暖度日数 HDD18 和空调度日数 CDD26 回归，得到与 HDD18（CDD26）相对应的建筑耗热量（耗冷量）指标和采暖（空调）年耗电量关系。根据回归得到的关系式计算并绘制出对应不同采暖度日数 HDD18 和空调度日数 CDD26 下的建筑物节能综合指标限值的数据表格，然后根据具体建筑所在城市对应的采暖和空调度日数，采用线性内插法确定该市的全年采暖及空调耗电量限值，例如通过这种方法可以确定上海地区住宅建筑的节能综合指标限值为 **55.1** kW· h/ m^2。由此可见，限值法中的“限值”仅与典型多层建筑的全年采暖空调耗电量相对应。

3　对比评定法

采用“对比评定法”评价建筑物的节能效果是指将评估建筑物的采暖空调能耗和相应的参照建筑物的采暖空调能耗作对比，根据对比的结果来判定所设计的建筑物是否符合节能要求。其中参照建筑是对比评定法中一个非常重要的概念，参照建筑是一个假想建筑，它与评估对象在大小、形状等方面完全一致，其围护结构的热工性能满足《标准》中规定性指标的要求，因此参照建筑是符合节能要求的建筑。将评估建筑与参照建筑进行能耗的计算对比，如果评估建筑的能耗不高于参照建筑的能耗，则认为它满足节能标准的要求；如果评估建筑的能耗高于参照建筑的能耗，则认为该建筑达不到节能要求，必须调整该建筑的热工性能，然后再进行对比计算，直到不高于参照建筑的能耗。

采用对比评定法评价住宅建筑的节能效果关键在于参照建筑的热工参数的正确选取。参照建筑应按以下规定确定：(1）参照建筑的建筑外形、朝向、建筑面积、外墙表面面积、屋面面积均应与评估建筑相同；(2）参照建筑各朝向的开窗面积应与评估建筑相同，但当评估建筑某个朝向窗的面积超过《标准》规定时，参照建筑该朝向的外窗面积应减小到使该朝向窗墙比达到规定的上限值；（3）参照建筑围护结构的各项热工性能指标均取《标准》规定的相应限值。

“对比评定法”是一种灵活、切实的方法，已被我国《夏热冬暖地区居住建筑节能设计标准》和美国许多建筑节能标准广泛采用。

4　两种方法的对比分析

通过以上介绍，可以发现“节能综合指标限值法”和“对比评定法”的主要区别在于选取的实际评估建筑的能耗比较对象不同，前者以固定数值作比较，后者则选取参照建筑的计算值作为比较对象。限值法操作方便，采用固定数值来评估所有类型建筑的节能效果。然而，不同类型的建筑要达到相同的能耗指标所采用的节能措施有很大差别。一般而言，高层建筑比较容易满足节能要求，而低层建筑则较难达标，即使对同类型建筑，由于体型系数等参数不同，建筑能耗也相差很大。另外，计算建筑面积和空调面积稍有误差也会导致最终评估结论大相径庭。而“对比评定法”比较灵活，参照建筑的能耗是变化的数值，即节能评估时不同的建筑采用不同的对比基准，因而更加切合实际。下面通过三个实际的工程实例进行具体说明，这几个实例均采用清华大学建筑技术科学系研发的 DeST 住宅版模拟软件进行能耗计算，并分别采用两种评估方法进行节能评估。

实例 1：东方金门花园

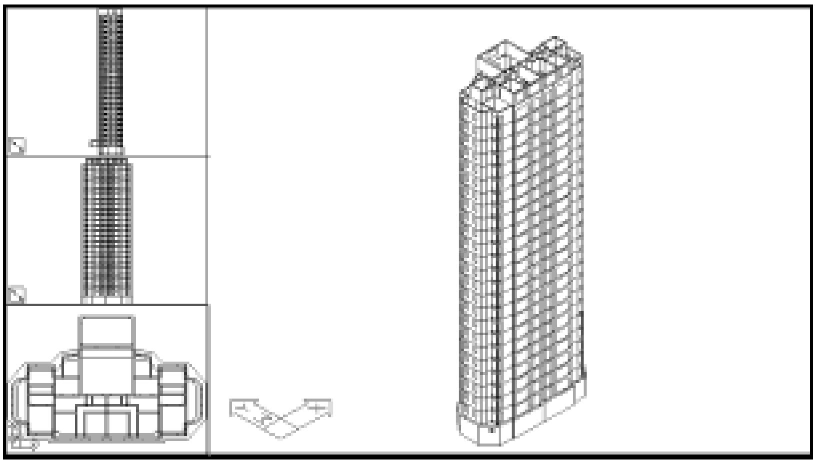

图 1　东方金门花园建筑模型图

该建筑有 25 层，建筑类型为高层住宅，采用了 ZL 胶粉聚苯颗粒保温浆料作内保温。围护结构热工参数为：1－5 层外墙平均传热系数 Km＝1.48 W/（m^2· K），6－25 层外墙平均传热系数 Km＝1.50 W/（m^2· K），屋面平均传热系数 Km＝1.00 W/（m^2· K），外窗传热系数 K＝3.70 W/（m^2· K），计权窗墙比 0.25。计算和评价结果和如下表：

表 1　东方金门花园能耗计算结果

评价方法	节能综合指标限值法		对比评定法	
	标准限值	实际建筑	参照建筑	实际建筑
年采暖空调耗电量 (kWh/ m^2)	55.1	42.8	42.9	42.8
节能效果评价	节能效果显著		达到节能要求	

实例 2：漓江山水花园

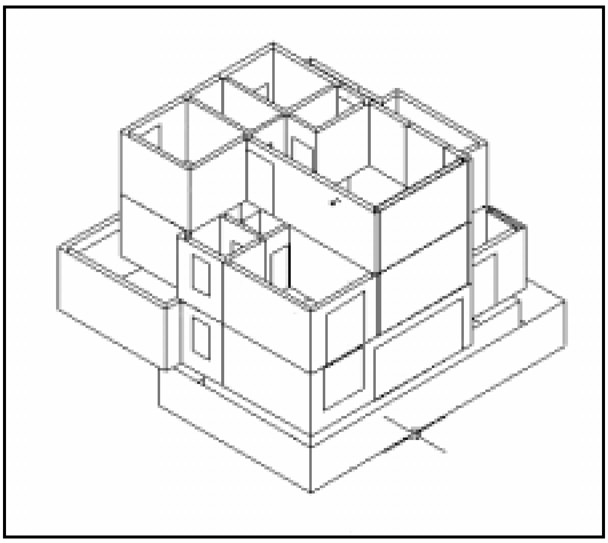

图 2　漓江山水花园建筑模型图

该建筑属于低层独立建筑，采用了挤塑聚苯板作外保温。围护结构热工参数为：外墙平均传热

系数 Km＝0.84 W/（m^2· K），屋面平均传热系数 Km＝0.51 W/（m^2· K），外窗传热系数 K＝2.70 W/（m^2· K），计权窗墙比 0.19。在统计建筑面积时，未考虑地下室和车库的面积。计算和评价结果如下表：

表 2　漓江山水花园能耗计算结果

评价方法	节能综合指标限值法		对比评定法	
	标准限值	实际建筑	参照建筑	实际建筑
年采暖空调耗电量 (kWh/ m2)	55.1	57.9	68.1	57.9
节能效果评价	未达到节能要求		节能效果显著	

实例 3：万科朗润园

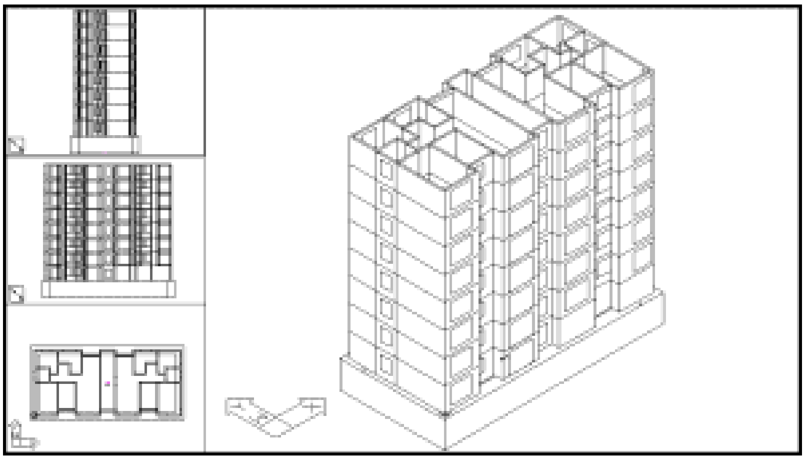

图 3　万科朗润园建筑模型图

该建筑属于多层住宅，采用了膨胀聚苯板作外墙外保温，挤塑聚苯板作屋面保温。围护结构热工参数为：外墙平均传热系数 Km＝0.86 W/（m^2· K）左右，屋面平均传热系数 Km＝0.67 W/（m^2· K），外窗传热系数 K＝3.0 W/（m^2· K），计权窗墙比 0.25。计算和评价结果如下表：

表 3　万科朗润园能耗计算结果

评价方法	节能综合指标限值法		对比评定法	
	标准限值	实际建筑	参照建筑	实际建筑
年采暖空调耗电量 (kWh/ m^2)	55.1	47.4	55.8	47.4
节能效果评价	达到节能要求		达到节能要求	

以上三个实例的模拟计算结果表明，对不同类型的住宅建筑采用两种方法得出的节能评估结论不尽相同：对高层住宅——东方金门花园，“ 综合指标限值法 ” 评价较高，“ 对比评定法 ” 则基本达标；对独立别墅——漓江山水花园，“ 综合指标限值法 ” 评价是不节能，“ 对比评定法 ” 则是节能效果明显；对多层住宅——万科朗润园，两种方法的评价都是达到节能要求。如果从建筑物围护结构

热工性能方面来进行评估，以上三个建筑基本都能满足标准的节能要求，这与“ 对比评定法 ”的评估结论是一致的，而“ 限值法 ”的误差较大。这是由于“ 限值法 ”中的限值与一般多层住宅建筑的能耗相对应，不适用于其他的建筑类型，所以采用限值法评估多层住宅得出的结论与对比法一致，而评估高层建筑和低层建筑却不一致。对于高层建筑，若采用限值法进行节能评估，则较容易达到节能标准要求，甚至出现对其不采用节能措施也能达标的情况，而城市高层住宅的采暖空调能耗总量巨大，这显热与推广建筑节能的目的相悖。

5　结论

综上所述，本文得出以下结论：

（1）“ 节能综合指标限值法 ”主要适用于多层住宅的节能评估，对高层住宅和低层住宅并不完全适用。

（2）“ 对比评定法 ”是一种灵活、切实的节能评估方法，可以适用于不同建筑类型的节能评估，因而比采用限值法更为科学合理，更有利于建筑节能事业的推广。

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高效低污染燃气红外线热水锅炉的研制与性能特点

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摘　要　为燃气红外线热水锅炉锅炉研制了 NO_X，CO 排放量低、燃烧效率高、燃烧安全的新型金属纤维燃气红外线燃烧器。经测试，热水锅炉烟气中 NO_X 排放浓度一般小于 10ppm，CO 小于 30ppm，热效率可提高 5%，经估算，冷凝型热效率可提高 10%~20%。所研制的锅炉是一种新型节能、低污染产品，该产品节能及环境效益显著，可作为宾馆、商厦、公寓、学校等建筑的生活用热水供应及空调（采暖）的热源。
关键词　燃气红外线；热水锅炉；研制；性能特点

Development and performance of the gas-infrared hot water Boiler with high efficiency and low pollution

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Abstract　A new type of metal fiber gas infrared burner, which had low NO_X and CO emission, high combustion efficiency and high combustion safety, was developed for the gas infrared hot water boiler. Testing showed NOx concentration in the flue gas of the hot water boiler was generally less than 10 ppm, and CO concentration was less than 30 ppm. The boiler efficiency was 5% higher than the conventional ones. Through estimating, The boiler efficiency would be 10%~20% higher than the conventional ones if the boiler was the condensing type. So the developed boiler was a new product, which was energy saving and low pollution. It had remarkable advantages in energy efficiency and environment protection. It could be used as the heating sources of the hot water supply and/or air conditioning (heating) system for the hotel, shopping, residential or school buildings.
Keywords　gas infrared, hot water boiler, development, performance

1　前言

天然气作为一种清洁能源越来越受到世界各国的重视。我国制定了以西气东输、俄气南供、进口液化天然气（LNG）、海洋气登陆、煤气层开发为主要内容的天然气长期规划。西气东输工程在 2000 年已完成前期立项研究，基本确定了用气项目，2001 年已正式动工建设，2004 年元旦已正式向上海供气。西气东输工程管线全长达 4176 公里，途径 9 省，预计向上海供气 100 亿 m^3/年，向沿线供气 20 亿 m^3/年。我国能源结构规划中将逐步提高天然气的比例。在这种背景下，课题组将燃气红外线加热技术应用于热水锅炉，实现了锅炉的高效与低污染运行，是一种新的尝试。

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2　锅炉的金属纤维燃气红外线燃烧装置

2.1　金属纤维多孔介质

为热水锅炉研制的燃气红外线加热装置为金属纤维燃烧器，属于全预混表面燃烧器。金属纤维燃烧器的多孔介质有两种：烧结式金属纤维板和片状金属纤维编制物，它们都是由直径大约为 22 μm 的超细金属纤维加工而成。烧结式金属纤维板采用了烧结工艺，片状金属纤维编制物采用的是编制工艺。金属纤维是一种名为 FeCralloy 的合金丝，特殊的化学成分保证其长期工作的耐温极限可达 1100℃，并有很强的耐腐蚀性能。

片状金属纤维编制物柔韧性高，易于加工成各种形状，形状适应性强，所以燃烧用多孔介质采用了片状金属纤维编制物。

2.2　金属纤维燃烧器的基本构造

金属纤维燃烧器采用强制鼓风方式，其基本构造示意图见图 1，锅炉用金属纤维燃烧器实物见图 3。金属纤维燃烧器的设计功率为 60kW，设计气源为天然气。金属纤维面积约为 0.3m^2，表面热强度为 200kW/m^2。

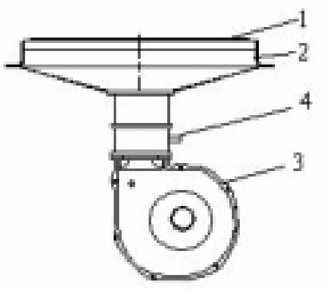

图 1　强制鼓风式金属纤维燃烧器构造示意图
1 金属纤维与多孔支撑板 2 壳体 3 风机 4 燃气-空气混合器

对于全预混式燃烧器来说，燃气-空气混合装置的混气性能直接关系到燃烧器运行的稳定性和污染物排放特性。若燃气-空气混合的好，则燃烧器运行稳定安全，污染物排放浓度低，反之燃烧器表面可能出现火焰脉动、表面温度不均匀和不完全燃烧等。另外，混气性能好的燃气-空气混合装置在较小的混合空间内可以达到空气燃气的良好混合，可以缩小燃烧器的整体尺寸，这对于民用燃气具尤其重要，所以有必要寻求混气性能好的燃气-空气混合装置。采用的燃气-空气混合器结构见图 2，这种文丘里结构的混合器在喉部形成低压区，提高了燃烧器的燃气压力适应性，同时喉部形成强烈湍流，有利于燃气与空气的均匀混合。

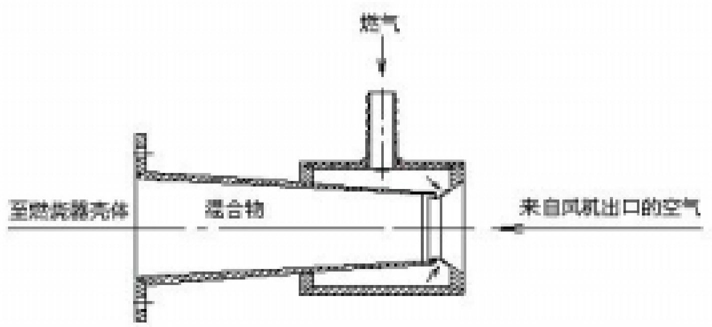

图 2　燃气-空气混合器

图 3　锅炉用金属纤维燃烧器

2.3　所研制金属纤维燃烧器的特点

所研制金属纤维燃烧器有如下特点：①污染物排放低。金属纤维燃烧器的氮氧化物、一氧化碳和不完全燃烧物的排放浓度低。由于全预混燃烧的过量空气系数小，同时燃烧释放的热量通过辐射与对流方式迅速带走，降低了火焰温度，所以，相对于其他燃烧器，金属纤维燃烧器具有更低的 NO_X 水平（体积分数一般在 60×10^{-6} 以下，$O_2\%=0$）。全预混和多孔介质的表面燃烧方式保证了低过量空气系数下的完全燃烧,一氧化碳和不完全燃烧物的排放浓度低(CO 体积分数一般在 100×10^{-6} 以下，$O_2\%=0$)。②节能。金属纤维燃烧器的全预混燃烧方式燃烧完全，燃烧器效率高；因为金属纤维燃烧器的过量空气系数较低，在应用中，同样的排烟温度下，金属纤维燃烧器的排烟损失小。③安全性高。金属纤维介质孔隙的细密性决定了金属纤维燃烧器的回火倾向性极低。另外，金属纤维的抗腐蚀性强，抗热冲击性能高，抗机械冲击性能强，热惰性低。

3　样机本体结构

锅炉的本体结构为典型的水火管锅炉结构，见图 4。

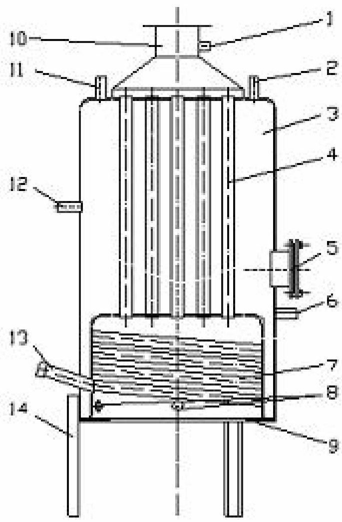

图 4　锅炉的本体结构

1 排烟温度测孔及烟气取样孔；2 安全阀接管；3 锅筒；4 垂直烟管；5 检查口；6 进水口；7 倾斜对流水管束；8 炉膛温度测孔； 9 燃烧装置连接板；10 排烟口； 11 出水口；12 水温测孔；13 窥火孔；14 支撑脚。

4　热效率与污染物排放试验

根据国家标准的要求，利用正平衡法对锅炉的热效率进行了测试[1]，测试系统见图 5，热效率

和烟气中 CO、NOx 浓度测试采用的主要仪器见表 1，测试结果见表 2。从表 2 可以看出，随着锅炉热负荷的增大，烟气中 CO 和 NOx 的浓度有增大的趋势，在锅炉的额定负荷下（60kW），锅炉的热效率达 90%左右，比一般的燃气锅炉高约 5%，烟气中 CO 的浓度<30ppm，NOx 的浓度<10ppm，都远小于采用常规燃烧器的燃气锅炉和规范要求值[2]。另外，若锅炉为冷凝式锅炉，经计算热效率可进一步提高 5-15%。

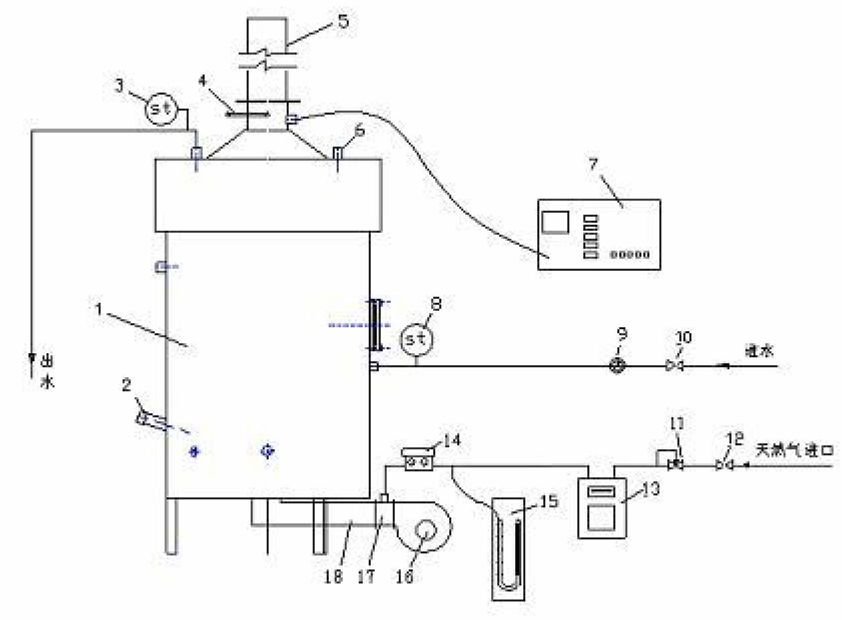

图 5　热效率测试系统示意图

1 锅炉样机；2 窥火孔；3 出水温度测点；4 排烟蝶阀；5 烟囱；6 安全阀；7 燃烧分析仪+温度传感器；8 进水温度测点；9 旋翼式水流量计；10 截止阀； 11 压力调节器；12 总关断阀；13 天然气干式流量计；14 电磁阀；15 U 型压力计；16 风机； 17 燃气-空气混合装置；18 送气管。

表 1 主要测试仪器

序号	测量项目	使用仪器、仪表	精度	最小刻度
1	CO 浓度	KM9003 燃烧分析仪		1ppm
2	燃气流量	湿式流量计		0.001m^3
3	温度	镍铬-镍硅热电偶 XMZ-101 显示仪	0.5	
4	NOx 浓度	Testo 烟气分析仪		1ppm

表 2　锅炉性能测试结果

输入功率	排烟温度	热效率	CO 体积分数 a=1	NOx 体积分数 a=1	备注
kW	℃	%	10^{-6}	10^{-6}	锅炉出水温度在 60℃左右。
52.3	157	—	<30	<10	
60.4	165	90.3	<30	<10	
71.5	186	—	<50	<15	
78.9	198	—	<50	<15	

5　节能经济性与环保效益

红外线锅炉效率高可以节省燃料，低排放可以降低 NOx 的排放。表 3 是该形式锅炉年燃料节省量和年 NOx 排放量计算结果。从表 3 可以看出，热负荷为 60kW 的燃气红外线锅炉，每年比普通燃气锅炉节省天然气 1143Nm^3，相应每年节省燃料费用 2857.5 元，每年减少 NOx 排放量为 21.2 kg。

表 3　红外线锅炉节能性与环保效益

	年燃料耗量 (Nm^3)	年 NOx 排放量 (kg)	备注
普通燃气锅炉	20567	33.9	额定功率 60kW; 年运行时数 2880h
红外线锅炉	19424	2.7	

目前，我国拥有小型锅炉约 55 万-60 万台，锅炉平均负荷约为 2t/h[3]，锅炉总负荷约为 805GW，若全部实现燃气红外线装置替代常规燃气装置，年节省燃料费用约为 38.3 亿元，每年减少 NOx 排放约为 28.4 万吨。

6　结论

（1）为燃气红外线热水锅炉研制的金属纤维燃烧器有污染物排放低、燃烧效率高、抗腐蚀性强、抗热冲击性能高、抗机械冲击性能强、热惰性低、燃烧功率调节范围宽等优点。

（2）所研制的新型热水锅炉是一种新型节能、低污染产品，额定功率下，热水锅炉烟气中 NO_X 排放浓度小于 10ppm，CO 排放浓度小于 30ppm，热效率可提高 5%，冷凝型热效率可提高 10%~20%，具有较好的经济效益和环保效益。

（3）该形式锅炉可作为宾馆、商厦、公寓、学校等建筑的生活用热水供应及空调（采暖）的热源，市场前景广阔。

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地源热泵冬夏暖冷联供实验研究*

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摘　要　介绍了地源水－水热泵全年冬夏暖冷联供的实验结果，分析了系统流量对热泵系统性能参数的影响，获得了最佳运行流量。并实测得到单位管深换热率及埋管的有关性能指标。对比分析了冬季吸热曲线和夏季放热曲线。

关键词　地源水－水热泵；冬夏暖冷联供；实验研究

地源热泵因其显著的节能和环保特点，受到越来越多的重视，美国、德国及瑞典等西方国家的地源热泵技术尤其是供暖方面的应用日趋成熟。由于受初投资大、本地地理气候影响大等限制，我国地源热泵尚处初级开发阶段。这就需要结合我国的具体地理气候特征，研究积累大量设计、施工及运行的数据资料，以制定出设计技术规范和应用软件。

在我国长江流域及浙江、福建等冬冷夏热地区，大地初始温度为 15～20℃，地源热泵既可实现冷暖联供，又可降低能耗，具有重要的应用意义。在长江流域城市重庆建成的浅埋竖管地源水－水热泵实验装置上，进行了连续一年暖冷联供的观察和测试，获得大量运行和技术数据。

1　实验装置简介

热泵的实验系统由以下三部分组成（平面布置原理见图 1）：

1）室外地下埋管换热器部分:地下埋管多管群换热器的总设计换热量为 10kW。地下管群实验装置共 5 组，组间采用并联同程式，考虑到管间换热影响，组间是错排布置。套管管径分别为φ50、φ75、φ90 三种，内管为φ15，埋深 10m，管材采用普通 PVC 管。每组串联换热器进出口都有阀门控制，可根据实验要求运行不同的管组组合。主管道及管群阀门安装在靠墙管沟内，以方便调节和维修。

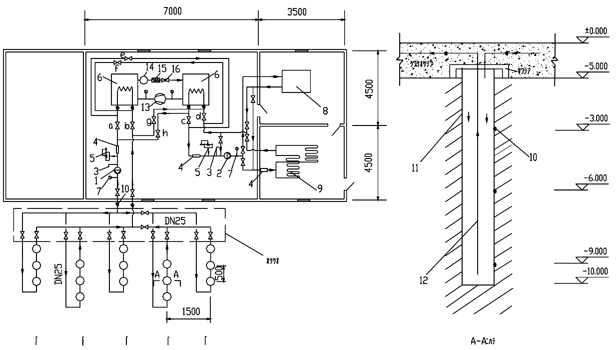
2)室内热泵机组部分：由风冷热泵空调器自行改装成的水-水热泵套管换热器连接地下埋管侧的进出水（冬季作为蒸发器，夏季则为冷凝器），另一端套管换热器连接用户侧的进出水。水-水热泵系统采用较简便的制冷剂不换向、水侧换向方法进行，即夏季 e、f、g、h 四个旁通阀关闭，a、b、c、d 阀门开启，冬季阀门的关、开与夏季相反。如图 1，虚线表示的管路为冬季供热工况，实线表示的管路为夏季制冷工况，而埋管侧和用户侧的水路循环则冬夏不变。

3）冬供暖夏供冷用户系统:热泵系统分别供给空调房间 A 和空调房间 B。A 间 $15m^2$,地板下埋设了冷暖地板蛇行盘管；相邻的 B 间亦为 $15m^2$，内设的立式风机盘管。

2　测试系统和测试方法

温度测试对象为地下埋管壁温、埋管换热器总进出水温、室内外温度及用户管路系统的水温，测点布置参见图 1。温度测试采用铜-康铜热电偶温度传感器，适用温度范围-200～400℃。输入转换及显示采用 WP-L80 型带打印多回路巡回测量显示仪，测量精度为 0.2%FS±1 字,经冰点修正仪表测温误差为±0.3℃。全年设定为每隔 4 小时打印一次，由于热泵是间歇运行，打印时不一定是运行时的值，所

以在冬夏运行期间每日采用人工方法测试，每日测 4 次，每次等开始运行几分钟稳定后读取 3～5 组温值，每组间隔 1～2 分钟。



1.埋管侧水泵；2.用户侧水泵；3.放气阀；4.转子流量计；5.膨胀水箱；
6.套管式换器；7.压力表；8.风机盘管；9.冷暖地板；10.热电偶测点；
11.套管；12.内管；13.压缩机；14.贮液器；15.干燥器；16.膨胀阀

图 1　地源水-水热泵实验装置平面布置原理图

流量测试采用 LZJ-40 转子流量计，精度 1.0 等级。实验的水流量范围为冬季 960～1060 L/h，夏季 760～1345 L/h。为研究地下埋管的换热特性和热泵运行性能，建立埋管侧和用户侧的热平衡，需要测试埋管侧管路系统和用户侧管路系统中各自的流量，即地下埋管进出水流量 G 和进出地板及风机盘管的总流量 G_0。

记录累计耗电量的精密电表与记录时间的电控电子钟采用连锁控制，当间歇运行的水-水热泵一启动，电表和时钟瞬间同时开始通电记录，两表的对时差即为一天的热泵机组运行时间。热泵耗电量包含了压缩机和埋管测水泵的能耗。

本实验装置经合成两大误差：温度误差与流量误差，在可信度为 99.73%下，得出测试误差为±4.98%，可见其测试结果是可信的。

实验测试分四个阶段：冬季供暖和夏季供冷(机组昼夜间歇运行)；夏-冬过渡季和冬-夏过渡季(机组停机不停测)，全天 24 小时不间断测试，以了解大地温度恢复状态。除因停电、机器维修故障停机近 10 天，全年机组间歇运转 2808h，测试 6900h。

3　测试数据处理

3.1　地下换热器换热量 Q,W：　　$Q=1000\times G\rho c_p(T_{进}-T_{出})$

地下换热器日换热量 Qh,kWh：$Qh=\dfrac{Q\times h}{1000}$

式中，G ——循环水流量，m^3/s;

ρ ——管内流体即水的密度，kg/m^3;

c_p——水的定压比热容，kJ/(kg.℃);

$(T_{进}-T_{出})$——埋管换热器进出水温差，℃；

h——热泵日运行时间，h。

夏季 $T_{进}>T_{出}$，Q 为正，埋管换热器对土壤放热；冬季 $T_{进}<T_{出}$，Q 为负，埋管换热器从土壤中吸热。

3.2 单位深度埋管换热率 Q_l,W/m：$Q_l=\dfrac{1000\times Qh}{n\times L\times h}$;

单位面积埋管换热率 Q_S,W/m^2: $Q_S=\dfrac{1000\times Qh}{n\times L\times \pi\times d\times h}$

式中， n——埋管根数；

L——埋管深度，10m;

d——埋管套管的直径，III组管群的套管管径为 75mm ,IV组为 90mm。

3.3 平均传热系数 K,w/(m.℃): $k=\dfrac{Q_l}{\left|\bar{t}_{水}-t_0\right|}$

式中，$\bar{t}_{水}$ ——热泵运行中，埋管进出水平均温度，℃；

t_0 ——大地初始温度，对重庆地区，夏季 t_0 =21.1℃，冬季 t_0 =18.27℃。

3.4 能效比和性能系数:

夏季制冷能效比 EER，即热泵制冷运行工况下，制冷量与输入功率之比，W/W：EER=$\dfrac{Q-P_k}{P_{in}}$;

冬季制热性能系数 COP，即热泵制热运行工况下，制热量与输入功率之比,W/W: COP=$\dfrac{Q+P_k}{P_{in}}$

式中，P_k——热泵压缩机日输入功率, W；

P_{in}——地源热泵系统日输入功率，$P_{in}=P_k+P_b$,W;

其中，P_b 为水泵计算日输入功率，W,用下式计算: $P_b=\dfrac{G\times P\times 1000}{\eta_{全}\eta_{电}}$

式中，$\eta_{电}$——水泵电机效率，查电机样本 0.67；

$\eta_{全}$——水泵全效率，由水泵铭牌为 0.35；

P——水泵扬程,kPa,由水泵出口压力表测得。

为更科学合理地使用数据，找出数据的规律，从最小二乘意义上，所测数据经过在数学软件中编程预处理，再进行最佳拟合和误差分析。且对在实验中因设备损坏检修、停电等造成的少数不完整数据，在拟合基础上进行插值。

4 实验结果与分析

4.1 水流量对热泵性能参数的影响

冷暖联供一直采用III、IV两组埋管匹配运行。由于室外温度变化及冷暖地板和风机盘管房间的温度需要不同，并且流量过高过低 受系统运行效果和流量计测试范围限制，对变流量根据具体情了天数

不等的运行测试。因重庆是夏热冬冷地区，设计主要以夏季参数为主，所以夏季从 7 月 6 日～8 月 30 日分别进行了流量为 1345、1245、1125、1000、850、760(L/h)的多种变流量运行（测试结果如表 2）；在冬季，流量变小导致蒸发温度过低，系统运行易出现故障，因而参照夏季的较佳流量仅作了 960、1060、1160（L/h）的变流量运行（测试结果如表 1）。

表 1　地源热泵冬季供暖运行性能参数计算表

水流量 GL/h	运行时间 天	热泵日运行时间 h 小时	热泵压缩机输入功率 Pk W	地下埋管进出水温差 ΔT ℃	冷暖地板房间平均室温 Tn1℃	风机盘管房间平均室温 Tn2℃	地下换热器换热量 Q W	热泵系统日输入功率 P_{in} W	日输入功率 P_b W	单位深度埋管换热 Q_l W/m	单位面积埋换热率 Q_s W/m^2	制热性能系数 COPW/W	千瓦埋管长度 Dqlm/kW	千瓦埋管面积 Dqsm^2/kW
960	13(12.21～1.2)	9.36	1025	3.24	18.75	18.39	3612	1159	134	60.2	255.5	4.00	16.6	3.9
1060	30(11.21～12.20)	9.81	1075	2.69	19.02	20.61	3311	1223	148	55.2	234.3	3.59	18.1	4.3
1160	14(1.5～1.20)	13.18	1027	2.36	17.31	20.33	3179	1189	162	53.0	224.9	3.54	18.9	4.4

表 2　地源热泵夏季制冷运行性能参数计算表

水流量 G L/h	运行时间 天	热泵日运行时间 h 小时	热泵压缩机日输入功率 PkW	地下埋管进出水温差 ΔT ℃	冷地板房间平均室温 Tn1 ℃	风机盘管房间平均室温 Tn2 ℃	地下换热器换热量 QW	热泵系统日输入功率 P_{in} W	日输入功率 P_b W	单位深度埋管换热 Q_l W/m	单位面积埋管换热 Q_s W/m^2	制冷能效比 EerW/W	千瓦埋管长度 Dqlm/kW	千瓦埋管面积 Dqsm^2/kW
1345	10(7.6~7.14)	10.46	1152	2.94	22.6	20.5	4591	1339	187	76.5	324.8	2.57	13.1	3.1
1245	7(7.27~8.2)	9.98	1215	3.16	25.3	24.8	4568	1388	173	76.1	323.1	2.42	13.1	3.1
1125	6(7.21~7.26)	10.23	1208	3.29	26.6	25.2	4298	1364	157	71.6	304.0	2.27	14.0	3.3
1000	6(7.15~7.20)	10.32	1119	4.03	25.1	24.7	4679	1259	139	78.0	331.0	2.83	12.8	3.0
850	16(8.3~8.20)	10.00	1200	3.32	25.2	23.3	3277	1318	118	54.6	231.8	1.58	18.3	4.3
760	10（8.21~8.30）	9.77	1167	2.94	24.1	23.0	2594	1273	106	43.2	183.5	1.12	23.1	5.5

表中：$Q_s=Q_l/(\pi*d)$,d 为埋管外径；Dql(m/kW),千瓦埋管长度，$Dql=1000/Q_l$;Dqs(m^2/kW),千瓦埋管面积，$Dqs=1000/Q_s$。

由表 1 作出夏季变流量运行的性能参数 EER 和 Q_l 变化曲线图（见图 2），结合图表可看出：

⑴系统的能效比及单位埋管深度换热量随流量的变化有明显变化，除了最佳流量处峰值波折，总的大致趋势是过流水量越大，换热效果越高，Q 上升；

⑵对于该测试系统，当夏季流量为 1000（L/h）时，系统的能效比和埋管单位深度换热量均达到最大值，

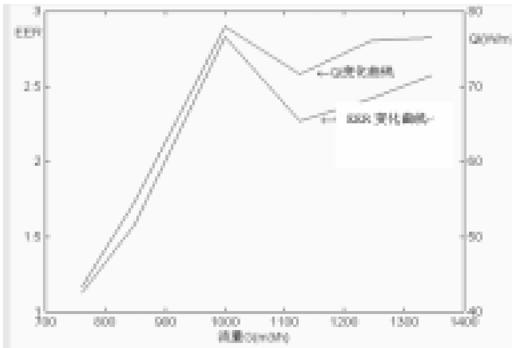


图 2 变流量运行性能曲线图

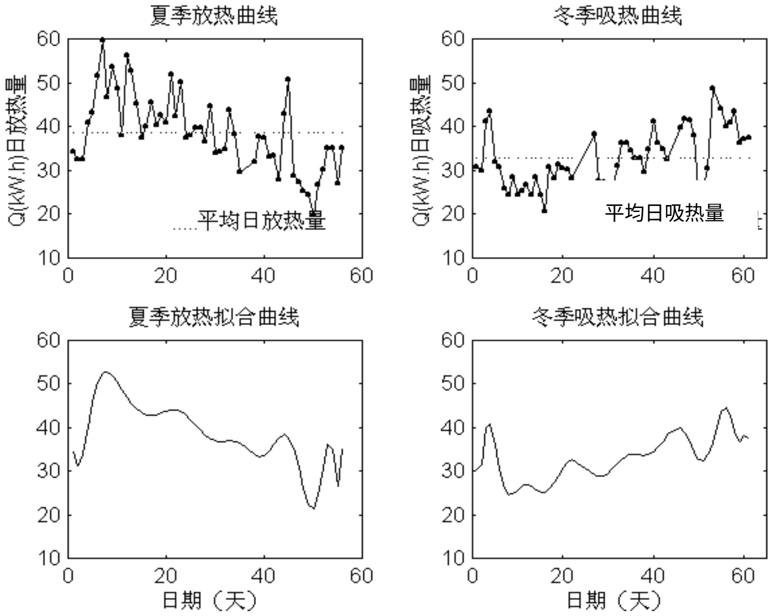


图 3　地下埋管放热、吸热曲线拟合曲线

故可认为该系统的流量 1000（L/h）为最佳流量，单管过流量为 500（L/h）；

⑶从图中可明显看出，在最佳流量坡峰之前的变化趋势较波峰之后的陡得多，说明流量越小，其能效比曲线和单位管深换热量降低就愈剧烈，这主要是因为系统流量越小，管内水流速低，换热值下降，但随着流量连续加大，Q_L 和 EER 变化平缓。同时受外界环境影响成分也增大，系统运行性能越差。

冬季的较佳流量则为 960(L/h),此时 Cop 和 Q_l、Q_s 均为最大。

测试还获得了全年运行浅埋套管的单位埋管深度换热量和单位面积换热量，其中夏季分别为 50～80（W/m）、185～330(W/m^2)。据国外有关文献资料，一般单位深度埋管换热率即 Q_l 的值为 40～60（W/m），单位面积埋管换热率即 Q_s 的值为 48～227（W/m^2）。可以看出测试数据与国外设计数据很接近，且换热效果要稍好。由于各地气温变化不同，而且水-水热泵与地面水系统的设计、设备的选取等也有很大关系，因此上述数据可供参考。

4.2　冬夏换热曲线对比

图 3 左部为地下埋管夏季放热曲线及其拟合曲线（2000.7.6～2000.8.30），右部则为冬季吸热曲线及其拟合曲线（2000.11.21～1.20）。

从拟合的日放热量曲线和日吸热量曲线可看出，⑴其共同特点是刚开机运行的十日左右，换热量增加最大，以后逐渐下降，曲线变得平缓，基本趋于稳定。这是因为在夏季制冷运行初始阶段，地温较低，故冷凝温度较低，埋管向地下放热较多，随着累积放热量增多，地温逐渐升高，冷凝温度也升高，所放的热量逐渐降低，随着冷凝温度趋于稳定，埋管向地下释放的热量也基本趋于稳定；对冬季供暖同理，初始地温较高即蒸发温度较高，使得开始吸热量较大，而随地温减低并趋于稳定而稳定下来；⑵由于是浅埋，地下埋管换热受室外气温变化影响较大；⑶由于冬夏是变水量运行，其换热量规律与定水量不同。

在该次全年冷暖联供运行测试中，夏季制冷连续运行 56 天，埋管向地下平均日释放热量为 38.70

（kW.h）,总释放热量为 2167.2（kW.h）;冬季供暖连续运行 61 天，埋管从地下平均日吸取热量为 33.75（kW.h），总吸取热量为 2058.75（kW.h)。可见，冬夏换热量较为均匀，全年大地换热基本平衡，初始地温得以保持，对长期运行较为有利。证明采用全年冷暖联供比单独夏季制冷或冬季供暖更有利于地温全年平衡和连续长期使用。

5　结论

本文是在浅埋套管换热器地源水-水热泵实验装置上，从 2000 年 7 月至 2001 年 6 月进行了冬夏暖冷联供全年测试，针对夏热冬冷地区及重庆地区土壤热物性条件，获得大量数据，对地源热泵的应用和设计很有参考价值。

1）在该测试系统下，夏季最佳运行流量 1000(L/h),此时单位管深换热率 74.12（W/m）；且获得管路系统设计参考参数：

制冷工况：按埋管深计算为 13～23m/kW, 按埋管面积计算为 3.0～5.5m^2/kW；

制热工况：按埋管深计算为 16～20m/kW, 按埋管面积计算为 3.5～4.5m^2/kW。

2）竖埋套管系统既可用作冬季供暖，又可用作夏季制冷，对冬冷夏热地区具有很重要的节能意义。对于夏季测试得到的单位管深换热率达 45～80（kW/m）,证明其换热效果较好；且联供运行有利于土壤热量平衡，有利于长期连续运行。

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某政府大楼集中水源
—分散制冷/热式热泵空调系统技术经济分析

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摘　要　该政府大楼空调系统原采用集中水源－分散制冷/热的水源热泵系统，冬季由电加热器作为辅助热源，针对原系统能耗过高的问题提出两种改造方案。方案一：在冬季，用风冷热泵代替电加热器作为辅助热源，采用“双级泵”的形式向大楼供暖；方案二：通过详细计算发现由于冬季和夏季向地下排放和摄取的热量相差较大（夏季排放的热量远大于冬季），在夏季，采用深井和冷却塔同时冷却回水的混合式热泵系统。在不改变原系统的末端的情况下，对两种方案进行了经济和技术上的比较。

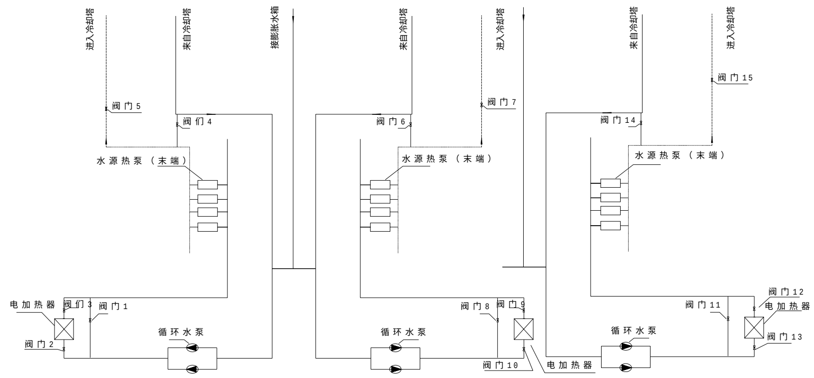
关键词　水源热泵；风冷热泵；技术；经济；比较

1　引言

众所周知，政府机构不仅代表政治经济活动的重要组成部分，而且也是最大的能源消耗者和能耗产品的最大购买者。我国政府机构的能源消费约占全国能源消费的 5%，政府机构每年仅能源消费费用就超过了 800 亿，已成为政府财政支出的重要组成部分，政府机构的节能已成为许多国家的一项重要的节能政策。水源热泵在中国的应用刚刚起步，许多业主甚至部分暖通空调专业人员对此还知之甚少，因此，在推广应用的初期，尚有一定难度；然而，随着中国进入 WTO，国外的水源热泵企业看到了中国的巨大市场，抢先在中国进行水源热泵的工程试点，以经济上的各种优惠作为切人口，在北京和部分沿海城市已取得了一些工程设计施工的总承包项目。这里针对某政府大楼的空调工程对采用地下水作冷热源和采用风冷热泵代替电加热器作为辅助热源的集中水源—分散制冷（热）的水源热泵空调技术进行详细的技术经济性分析比较，使业主基于技术和经济考虑的基础上，选择的改造方案更为合理。

2　工程概况

该工程位于湘江河畔，政府大楼建筑面积 15000 平方米，空调面积 8000 平方米左右。原方案设 3 个独立的水系统，冷却塔 6 台，电加热器 3 台（2*240kw，1*50kw），水泵 6 台（3 用 3 备）。系统在夏季用冷却塔散热，冬季用电加热器辅助加热，末端采用水冷分离式的水源热泵，见图 1。这种系统冬季采用高品位的电能直接加热回水，能耗太大。为降低运行费用决定对原系统进行改造，改造方案一：夏季仍然采用冷却塔散热，冬季采用风冷热泵代替电加热器作为辅助热源；改造方案二：用深井水直接作冷热源，夏季和冷却塔同时使用对冷却水进行冷却，冬季代替电加热器作为辅助热源，通过板式换热器交换热量后，提供达到进泵所需温度的冷/热水。



图一　原方案系统图

3　改造方案一设计

3. 1　可行性分析

风冷热泵由于长期在室外暴露，寿命较其他机组要短，且运行时噪声较大，冬季进风温度过低时还要进行除霜，但是由于它的使用地域较之地下水源热泵广泛，加之产品型号更加齐全，因而使用相当广泛。

风冷热泵在此方案中作为代替电加热器的辅助热源，制备达到末端水源热泵进泵温度所需的热水。从技术上分析，基于对衡阳地区气象资料的调查，最冷月的平均气温高于-2℃,最热月的平均气温低于 40℃，在风冷热泵的使用范围之内，因而从技术上来说完全可行。从经济上分析，他比电加热器作辅助热源要节能，从后文的经济比较可以看出。

3.2　系统设计

1.方案说明

夏季,仍然用冷却塔进行散热，冷却水不经过风冷热泵；冬季，风冷热泵代替电加热器作为辅助热源对回水进行加热，达到末端水源热泵的进泵温度后，进入末端，向大楼供暖。系统流程图如图 2 所示。

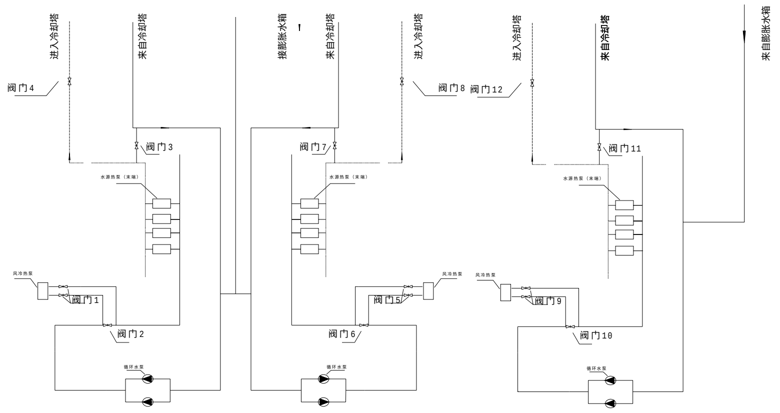
2 .设备选择

使用风冷热泵代替电加热器做辅助热源，则每个系统的风冷热泵的额定制热量至少需要等于电加热器的制热量。根据开利机组所提供的额定计算参数（室外气温 7℃，出水温度 45℃）按照逆卡诺循环进行计算，则 cop_2＝8.3，由于衡阳地区的冬季室外空调设计温度为-2℃，风冷热泵作为辅助热源只需提供 21℃的热水即可，同样按照逆卡诺循环计算得到 cop＝12.7。可知，在压缩机功率不变的情况下，制热量提高到原来的 1.53 倍。1－4 层和 5－8 层两个系统分别可采用联合开利公司型号为 30SHB160、额定制热量为 180kw 的风冷热泵机组，耗电量为 50kw，此机组在实际工况下制热量可达到 270kw，可满足需要。9－10 层采用中宇公司型号为 LSFRQ－30IIFZ 的空气源模块式机组，在室外气温－5℃，出水温度 21℃额定制热量为 60kw，耗电量为 12kw，同样可以满足要求。

3 土建工程

由于在原系统的基础上要增加二台尺寸为 1740×850×1800mm^3的中宇模块式风冷热泵和两台尺寸为 4450×2000×2400 mm^3的开利螺杆式风冷热泵机组。屋顶撤去 50kw 制热量的电加热器，

可放置二台中宇机组，另外两台开利机组可在原有机房的后面的绿化地带，挖掘一定深度的土方放置机组。



图二　改造方案一系统图

4　改造方案二设计

4.1　可行性分析

使用地下水源热泵有这良好的环保意义，它不会对大气造成热污染，且由于地下水温恒定，有利于机组效率的提高，但在对水质的要求和使用地域上有局限性，并且由于我国的水源热泵技术刚刚起步，产品规格较少，回灌技术落后等众多不利因素的影响，使得这种技术在推广过程中存在很多阻力。

对于用地下水做冷热源的热泵系统来说工程可行性的关键在于建筑物附近有无充足的地下水来满足建筑物内峰值冷（热）负荷的需要。此政府工程位于离湘江 1000 米左右的地域，经探测，此处地下水埋藏再 100 米以内，含水层厚度为 40－50 米，地下水恒温层在地面 25 米以下，恒温水层温度为 19℃—21℃且年变化不大，类型以承压水和潜水为主，水源相当丰富，可以断定水源热泵再此处具有可行性。

4.2　系统设计

1.方案说明

根据原系统可把大楼分为三个系统：1—4 层的冷负荷为 702.7kw，热负荷为 421.62kw；5—8 层的冷负荷为 637.7kw，热负荷为 382.62kw；9—10 层的冷负荷为 162.7kw，热负荷为 97.62kw。以运行一年为周期，夏季制冷需要向外界排放的热量为 1740000kwh，而冬季只有 626400kwh 。为了保持冬夏季的负荷平衡而不至于地下水的温度变化太大，夏季用冷却塔结合回灌井的方式冷却回水。其中，5—8 层夏季排除热量为 764400kwh，和整个冬季从井中抽取的热量基本相当，可直接注入回灌井；1—4 层和 9—10 层夏季用冷却塔散热。冬季，地下水作冷却水，直接进入末端水冷分离式的水源热泵机组对大楼提供采暖，系统如图三所示。

2.设备（施）选择

（1）水井和水质　根据地下水承担的负荷计算总水量：

$$Q_R = q_R/4050（t_{D2} - t_{D1}）\times（cop-1）/cop$$

Q_R——夏季供冷的地下水流量，这里取 m^3/h；

q_R—— 建筑物冬季峰值负荷，这里取 870×1000×3.6 kj/h；

t_{D2}—离开热交换器的地下水温度，＝建筑物环路回水温度+热交换器接近值，这里 t_{D2}＝7℃＋1.7℃＝8.7℃；

t_{D1}——进入热交换器的地下水温度，取 21℃；4050 为系数；

因为末端设备的 cop 值在 4.5—5.0 之间，取 cop=5.0，得出所需最大地下水流量 Q_R＝50.3m^3/h

计划打三口井，一抽两灌，每口井相距 100 米，呈一等边三角形，这样可以节约使用的面积，建议回灌井和抽水井做成结构和井泵设置和结构相同，这样可以互为备用和养井，省去洗井这一程序。

表一　水井和水质

井深（/m）	管径直径（/mm）	含盐量（/g/l）	水温（℃）	PH 值
100	350	42	19-21	7.5

（2）水源水泵　水源水泵选型时，主要考虑地下水温度、成井情况、用户费用承受能力等因素。结合工程的实际情况，水源水泵选用了井用潜水泵。潜水泵的特点是：扬程较高，体积较小，但价格略高。我们这里选用 200QJ50—50/7 型潜水泵，扬程为 40—60m，输入功率为 22kw，输出管径为 3 寸。这里采用三台同一型号的潜水泵.

（3）水源水管　考虑到此处地下水的酸碱度和矿化度，会对钢或或其他合金造成腐蚀，在设计时，水源水管采用聚乙烯 PE 塑料管。另外，水源水管上的附件和阀门亦选用抗腐蚀性较强的产品。

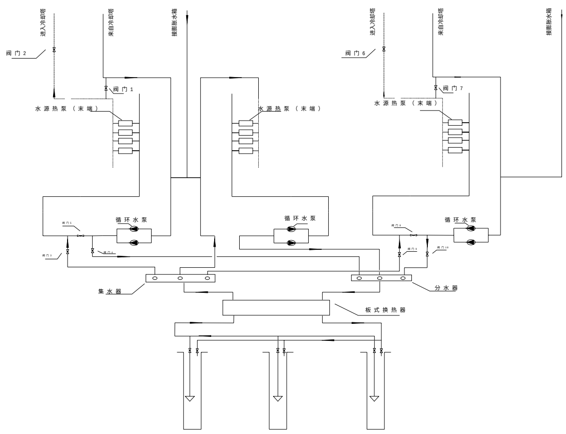
（4）机房　原有的机房大小可以满足现在设备的要求，无需要从新建设或扩充原有的机房

（5）板式换热器　由于此处地下水矿物质的 含量较高，如果水源直接进入水源中央空调机组，会对蒸发器和冷凝器造成损害，从而影响机组的使用寿命。为了减少水源对机组的损害，在设计中增加钛板式换热器，以防止水源直接进入机组。因为在夏天并不是全部的冷负荷都由地下水来承担，只有 5—8 层的冷量取自地下水，所以取最大循环散热量为冬季工况的散热量 870kw。设计流量为 175m^3/h。

循环水侧温差＝Qr/500×GPM_{wl}＝60×870×1000×3.4119/500×400×264.17＝3.37℉＝1.88℃；进水温度＝循环水侧温差＋进泵温度＝86℉-3.37℉＝82.37℉，设逼近温差为 3℃，则地下水回水温度＝进水温度-逼近温差＝82.37℉-5℉＝75.37℉＝41.9℃ 则地下水温差 95.4℉-75.37℉＝20.03℉＝11.3℃，则板式换热器的设计流量为：Qr/500×地下水温差＝870×1000×3.4119/500×20.03＝296.4 加仑/min＝67.3 m^3/h；

其中，Qr：对循环水的总散热量，kw；

GPM_{wl}：为设计流量，m^3/h；可根据此流量来选择板式换热器尺寸。



图三　改造方案二系统图

5　经济比较

5.1　改造方案初投资增减比较，见表 2

表 2　改造方案初投资增减比较

类别	方案一	方案二
机组耗资（万元）	LSFRQ－30IIFZ　4.4 万元/台 30SHB160　30 万元/台	无
土建（打井）费用（万元）	0.2	三口，每口 3 万元，共 9 万元
其他设备费①（万元）	无	30
电力增减容	可减少一个 800kvA 的变压器可回收 4 万元左右	可减少一个 800kvA 的变压器可回收 4 万元左右
其他设备的减少	可减少三台电加热器，可回收约 5 万元	可减少三台电加热器，和两台 L＝175m^3/h 的冷却塔总共可回收约 8 万元
合计（元）	600000	270000

①：其他设备包括热交换器，潜水泵，集水器，分水器，水源水管，阀门及其安装费用

5.2　运行费用分析

表 3　各种设备的耗电量

设备	耗电量
水源热泵	313.45 kw（夏季）
	323.75 kw（冬季）
风冷热泵	50kw 的两台，6kw 的两台
冷却塔	流量为 175m^3/h 的耗电量为 4 kw
	流量为 50m^3/h 的耗电量为 1.1 kw
电加热器	2 台 240kw，1 台 50kw
潜水泵	22kw

1. 计算数据

（1）电力为：0.65/千瓦时

（2）夏天平均制冷 150 天，运转时间为 8 小时/天，夏季的平均负荷率按 70%计算；冬季平均采暖 90 天，运转时间为 8 小时/天，冬季的平均负荷率按 80%计算。

（3）各种设备的耗电量，见表 3

2. 三种空调方案冬季和夏季的费用比较：

表 4　夏季三种方案年运行费用比较

方案	用电设备耗电（元）			合计
	空调机组	冷却塔	潜水泵	
原方案	171144	3370	0	174514
方案一	171144	3370	0	174514
方案二	154029①	1872	9610	165511

表 5　冬季三种方案年运行费用比较

方案	用电设备耗电（元）				合计
	空调机组	电加热器	风冷热泵	潜水泵	
原方案	121212	198432	0	0	319644
方案一	121212	0	41932	0	188604
方案二	121212	0	0	8237	129449

①由于夏季采用的深井水为 21℃，比原来冷却水的冷凝温度降低了 10℃，根据计算可知在相同的送风温度下冷凝温度下降 10℃，理论上可比原系统节能 20%，但由于各种原因，实际可能只有 10%左右，所以空调机组耗电量：313.45×8 小时/天×150×0.65×70%×90%＝154029 元。

3. 三种方案的经济性比较见表 6

表 6　三种方案经济性比较

	原系统	方案一	方案二
改造初投资（元）	0	600000	270000
年运行费用（元）	494158	337658	294960
与原系统比较的节省（元）	0	156500	199198
收回年限	/	4.38	1.46

注： 收回年限的计算中，年利率按 6%计算。

6　结论

根据衡阳的年气候特征、地下水文资料和标准年气象数据等，对这两种改造方案进行了能耗和技术经济性分析后，通过比较可以得出一下结论：

（1）两种方案在技术上各有优势，在年运行能耗方面较之冬季采用电加热作为辅助热源的原系统方案都有不同程度的节能。并且两种方案收回年限时间都较短。

（2）在地下水丰足的冬冷夏热地区，采用地下水作水源的集中水源－分散制冷/热的热泵空调系统是政府机构大楼的适用、经济的空调方案；在缺水的地区，可采用风冷热泵作为辅助热源的“ 双级泵 ” 系统。

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Technical And Economical Performance Analysis of Central Water-Source－Divided Cooling/Heating on a Governmental Building Air condition system

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Abstract This governmental building air condition system adopt water-source heat pump system which is concentrated water-source－divided cooling/heating, heating resistance is auxiliary heat source in winter, Put forward two kinds of schemes of transforming to the question that the original system is too high in energy consumption. Scheme one: The air-source heat pump replaces the electric heater as the auxiliary heat source in winter, it adopt the form of " one pair of pumps " to heat to the building; Scheme two:we find that difference between heat that absorbs in winter and heat that discharges in summer is too great through calculating in detail(The heat that discharges in summer is far greater than winter). Adopt the composite heat pump system cooling the return water at the same time in the deep well water and cooling tower in summer. Compare them on the economy and technology when the systematic end does not change,

Keywords water-source heat pump air-source heat pumps technology economy compare

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地源热泵研究与应用进展

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摘　要　本文对地源热泵技术进行了阐述，分析了能源结构对环境的污染和地源热泵技术应用的意义，介绍了地源热泵的发展历史和国内对地源热泵研究现状和最新成果，以及地源热泵技术在工程中的应用，分析了目前存在的需要注意的问题和地源热泵在中国的发展前景。
关键词　地源热泵；发展历史；研究现状；成果应用；前景和展望

1　前言

地源热泵技术，是利用地下的土壤、地表水、地下水温相对稳定的特性，通过消耗电能，在冬天把低位热源中的热量转移到需要供热或加温的地方，在夏天还可以将室内的余热转移到低位热源中,达到降温或制冷的目的。地源热泵不需要人工的冷热源,可以取代锅炉或市政管网等传统的供暖方式和中央空调系统。冬季它代替锅炉从土壤、地下水或者地表水中取热,向建筑物供暖;夏季它可以代替普通空调向土壤、地下水或者地表水放热给建筑物制冷。同时,它还可供应生活用水，可谓一举三得，是一种有效地利用能源的方式。地源热泵（ground source heat pumps,GSHP）系统包括三种不同的系统：以利用土壤作为冷热源的土壤源热泵，也有资料文献称为地下耦合热泵系统（ground-coupled heat pump systems）或者叫地下热交换器热泵系统（ground heat exchanger）；以利用地下水为冷热源的地下水热泵系统（ground water heat pumps）；以利用地表水为冷热源的地表水热泵系统（surface-water heat pumps）。这样的分类在国内的暖通空调界已经达到了共识。

在中国，煤作为主要能源, 煤炭在我国能源体系中占主导地位。长期以来，煤炭在我国能源生产结构、消费结构中一直占有绝对主导地位。尽管近年来比例略有下降，但仍保持在 65%以上，并再次呈现出上升的迹象。2002 年煤炭在我国能源生产结构、消费结构中的比例分别由 2001 年的 68.6%和 65.3%上升为 70.7%和 66.1%[1]。从表 1 可以看出，虽然占能源消费总量的比重在逐渐降低，但煤炭在能源消费中依然是高居榜首。特别在冬季,在国内的农村和部分城市几乎全部靠煤取暖。煤是各种能源中污染环境最严重的能源,只有减少城市地区煤的使用,城市大气污染问题是才可能得到解决。现在各地都在采取措施控制燃煤的数量,选用电采暖、燃油或者燃气采暖等措施,但都存在运行费用高、资源不足和排放 CO^2 这些问题。受能源、特别是一次能源与环保条件的限制,传统的燃油、燃煤中央空调方式将逐步受到制约。从降低运行费用、节省能源、减少 CO^2 排放量来看,地源热泵技术是一个很好的选择。

2　地源热泵的发展历史

地源热泵是一种先进的技术，它高效、节能、环保，有利于可持续发展。这项技术最先开始于1912年，瑞士 Zoelly 提出了“地热源热泵”的概念。1946年美国开始对地源热泵进行系统研究，在俄

勒冈州建成第一个地源热泵系统，运行很成功，由此掀起了地源热泵系统在美国的商用高潮。1985年美国安装地源热泵14000台，1997年则安装了45000台，目前已安装了400000台以上的地源热泵，并且以每年10%的速度递长。1998年美国商用建筑的地源热泵空调系统已经占到空调保有量的19%以上，其中在新建筑里面占30%[2-3]。在欧洲国家里更多的是利用浅层地热资源，来供热或者取暖。

上个世纪70年代以来,随着能源和环境问题变得突出,在各个方面也更多的考虑节能，以可再生的地热源为能源的地源热泵又引起了人们的重视。尤其是近年来,随着能源和环境问题的日益突出,地源热泵的研究和应用发展迅速,国内外的很多高校和研究机构相继开展了理论和实际应用方面的研究。随着研究的深入，我们的地源热泵研究工作者在全国范围内举行了各种交流探讨会。中国制冷学会第二专业委员会主办了“全国余热制冷与热泵技术学术会议”；1988年中科院广州能源研究所主办了“热泵在我国应用与发展问题专家研讨会”[4]；中国能源研究会地热专业委员会于1994年9月6日至8日在北京召开了第四次全国地热能开发利用研讨会；从90年代开始，每届全国暖通制冷学术年会上都有“热泵应用”的专题；2000年6月19～23日，中美地源热泵技术交流会在北京召开，会议介绍了地源热泵技术，国外的应用状况和在中国的推广；山东建筑工程学院地源热泵研究所与山东建筑学会热能动力专业委员会联合发起并承办“国际地源热泵新技术报告会”于2003年3月17日在山东建筑工程学院举行，加强了国内外地源热泵先进技术的交流。

表1　能源消费总量及构成

年份	能源消费总量（万吨标准煤）	占能源消费总量的比重%			
		煤炭	石油	天然气	水电
1957	9644	92.3	4.6	0.1	3.0
1970	29291	80.9	14.7	0.9	3.5
1980	60275	72.2	20.7	3.1	4.0
1990	98703	76.2	16.6	2.1	5.1
1999	122000	67.1	23.4	2.8	6.7

3　研究现状及成果

从上个世纪80年代开始，国内对地源热泵进行了一系列的研究工作，主要集中于以下几个方面：

3.1　地下埋管换热器的传热模型和传热研究

地源热泵地下传热模型的理论基础有三种：Ingersoll and Plass 提出的线源理论；1983年 BNL 提出的修改过的线源理论；1986年 V.C.Mei 提出的三维瞬态远边界传热模型[5]。文献[5]同时提出了现在比较广泛应用的三种传热模型：基于能量守恒定律的 V.C.Mei 传热模型；IGSHPA（International Ground-Source Heat Pump）模型,该模型提供了计算单根竖埋管、多根竖埋管及水平埋管换热器土壤热阻的方法；NWWA（National Water Well Association）模型,运用该模型可直接给出换热器内平均流体温度。

3.2　瞬态工况数值模拟、热泵装置与部件仿真模型的理论和实践研究

在地源热泵的三种不同的系统形式中，因采用地下埋管换热器使土壤源热泵的技术难度最大，

设计和施工都要很困难，所以一直也是地源热泵技术的难点和核心所在。李凡、仇中柱和于立强应用有限单元法对土壤热源地下 U 型垂直埋管周围土壤的非稳态温度场进行了数值模拟，其结果与实验测试值吻合良好。根据数值模拟计算程序可给出 U 型垂直埋管向地下放热量与埋管的埋深及埋管的热作用半径的对应关系，为 U 型垂直埋深、数量及间距的设计提供了参考依据[6]。对于土壤源热泵在冬季工况下的启动特性，李元旦、张旭等结合实例研究表明，土壤源热泵的冬季启动时间比夏季的短，仅为4-5h。实测获得了单位钻孔长的取热率为40-60W/m，可作为设计参考数据。分析了土壤源热泵冬季制热工况的系统 COP 值和压缩机 COP 值，指出要获得好的节能效果，必须优化系统，减少循环和风机等的能耗[10]。丁勇、刘宪英等根据在所建设的15kW 浅埋竖管换热器地源热泵试验装置上做的冬季供暖效果测试，建立了地下浅埋套管式换热器的传热模型[7]。他们还介绍了根据浅埋竖管换热器地热源热泵冬季测试结果，在夏季试验中对试验装置及实验方法的改进，测试了夏季定水量（63天）的运行效果和变水量运行时各性能指标的变化。采用系统能量平衡结合热传导方程建立的地下竖埋套管管群换热器传热模型和过渡季大地温度场模拟，与实测值吻合较好[8]。大地初始温度是地源热泵设计中的重要参数，实际测量很不现实，在文献[5]中,他们采用计算法来确定大地的初始温度。在不同的地质条件下，地下换热器会受到不同的影响，付祥钊、王勇等人通过建立地源热泵岩土换热器的简易数理模型，在重庆和上海两地进行了岩土换热器试验，结果表明，岩土性能及由年平均温度决定的岩土原始温度对岩土换热器性能有显著影响，在砂岩中设置的换热器比沉积土中的性能好[11]。李新国等人通过螺旋盘管地源热泵供暖制冷实验表明:①冬季从地下取热盘管的出口温度能保持在10℃左右,明显高于冬季环境空气温度,有利于制热性能。但夏季制冷地下盘管的进出口温度已超过标准空调工况的条件。分析原因,认为是地下盘管布置过于密集和未使用适宜的回填土,致使盘管散热性能差。②实验测得的系统 COP 和压缩机 COP 值并不高,这与水源热泵机组设计是否匹配、优化，水泵和风机的选择是否匹配等有关。③对小型地源热泵,垂直螺旋盘管占地面积小,换热性能较优[9]。赵军、袁伟峰等依据能量平衡,建立了地下浅埋套管式换热器传热模型,求解并分析了影响传热的主要因素,提出了强化换热的措施,给出了相应的函数关系图[9]。郑宗和、牛宝联等人提出了把热管应用到地源热泵的水平埋管换热器中,用以提高换热器周围土壤的温度和稳定土壤周围的温度场,以减少埋管换热器的占地面积。通过实例分析,插入热管后,虽然增加了成本,但节约了土地面积,证明了利用热管提高水平埋管的换热效能在经济上是可行的[32]。

3.3　地源热泵空调系统制冷工质替代研究

HCFC 禁用期限的临近，也推进了对地源热泵替代工质的研究。赵 力、涂光备等采用 CSD 方程进行循环工质的理论计算和选择，针对以40～45℃地热尾水为低温能源的热泵系统，在该系统中采用了循环性能较好的、质量分数比为1∶1的非共沸二元混合工质，以达到实际运行和环保要求[12]。R744作为一种天然工质，是热泵系统中最有潜力的替代工质之一，范晓伟、付光轩对此进行了研究，在文献[13]中介绍了近10年来美国、欧洲和日本等发达国家和地区对 R744热泵系统进行的大量研究和取得的一些突破性研究成果，介绍了 R744热泵样机及其压缩机、换热器、膨胀阀等各重要部件的研究状况。黄华军、丁力行等运用基于 AHP（层次分析法）的综合性能评价指标体系，认为 HFCs 及其混合物具有与 R22相近的热力性质，是目前地源热泵系统的理想替代工质，其中 R134a、 R410A 和 R407C 是近期合适的 R22的替代工质[14]。

3.4　其他能源如太阳能、水电等与地热源联合应用的研究

为了更好的利用能源，节约能源，保护环境，也有专家学者进行了其它能源和地源热泵的联合应用方面的研究。曲云霞、方肇洪对太阳能辅助供暖的地源热泵的经济型进行了分析。他们指出，在冬季，我国北方地方土壤温度较低，并且以热负荷为主，如果采用地源热泵供暖，则机组和换热器的初投资比较高，连续运行的效率也较低，夏季运行时机组容量过大，造成浪费。可以利用太阳能集热器作为辅助能源，白天时，依靠地源热泵供暖，夜间利用太阳能集热器储存的热量，由地热和太阳能共同供暖，这样的方案比单纯用地源热泵供暖更经济节能[15]。另外，何小龙、郑利强在文献[16]里面分析了地源热泵系统在水电站中应用的优势，对利用地下水进行了分析，不过，笔者认为，在水电站附近，适当的采取地表水热泵系统，因为地表水丰富，所以会更加节能，降低费用，在地源热泵的三种系统形式里面，国内研究较多的是土壤源热泵和地下水热泵系统，关于地表水热泵系统研究的比较少，主要是合适的地表水资源太少了，或者是因为地理位置的原因限制了地表水热泵的发展。不过，假如条件允许的话，比如在水电站附近，或者附近有丰富的地表水资源，不妨考虑运用地表水热泵系统。

3.5　地源热泵系统的设计和施工

地源热泵系统的设计主要集中在系统地下部分的设计，包括冷热负荷的确定，地下换热器的选型、布置，室内空气气流的组织形式，热泵的容量等，不过要重视对地源热泵空调系统设计的基础资料的准确性和真实性进行鉴别，特别是水文地质、地表情况、试验井(坑)、水质这些资料，以免造成系统失败或者和预期效果大相径庭。对于地下水热泵系统、土壤源热泵系统、地表水热泵系统，都有不同的设计步骤和施工方法，具体可参考文献[17]~[21]，[25]。

3.6　地源热泵系统的经济性能和运行特性的研究

随着地源热泵在中国的逐渐推广，对地源热泵系统经济性能和运行特性的研究也日益受到重视。姜宝成、王永镖、李炳熙针对地源热泵钻井费昂贵、初投资比普通供暖空调高的问题,利用经济评价方法,以哈尔滨地区供暖面积 10000m^2 为计算对象,分析比较了地源热泵 3 种驱动源(电动机、燃气机、柴油机)、3 种辅助热源(电锅炉、油锅炉、燃气锅炉)、共计 9 种系统组合的经济参数(初投资、年经营成本、年总成本、净现值,净现值率及投资回收期),分析计算得出燃气机驱动、190KW 辅助燃气锅炉的地源热泵系统为最佳的结论[22]。许淑惠、邢云绯的研究从节能分析出发,结合工程实例,对地源热泵系统即地下水热泵系统和土壤源热泵系统与风冷热泵系统在技术性能和经济性能方面进行了对比。分析表明地源热泵系统性能参数比风冷热泵系统有较大提高;初投资和运行费用比风冷热泵系统节省 24～30%左右[23]。王景刚、马一太依据圆柱源理论，建立了耦合地面热泵机组和地下埋管换热器特性的模拟模型，探讨了模拟过程中有关参数的确定方法，并运用模型对地源热泵的冬季和夏季运行特性进行了模拟，模拟结果和实验实际测得的数据相符[24]。

3.7　土壤热物性及土壤导热系数的试验研究

对于土壤源热泵来说，土壤作为热泵系统的热源，对土壤热物性及土壤导热系数的试验研究显得尤为重要。张旭采用探针法，通过实验得到了土壤及其与不同比例黄砂混合物的导热系数随含水

率和密度的变化规律，土砂混合比为 1：2 时的混合物的导热系数最大，为寻找最佳的回填材料提供了基础数据[26]。

4　工程应用实例

目前国内地源热泵的应用实例比较少，影响比较大是中美合作在中国建设的三个地源热泵示范工程。1997 年，中国科技部与美国能源部签署了《中华人民共和国国家科学技术委员会与美利坚合众国能源部地热开发利用的合作协议书》。根据协议规定，中美两国政府合作在中国的北部、中部和南部建立三个地源热泵的示范工程。北部示范工程是中国食品发酵研究所综合办公楼及专家楼，中部示范工程是宁波雅戈尔工业城，南部示范工程是广州松田职业技术学院。

除了这些之外，还有其他的一些工程实例。其中比较有代表性的工程有：

清华同方人工环境有限公司承担的山东东营市胜泰大厦的地下水热泵系统和空军丰台招待所、办公楼的地下水热泵空调改造系统。其中，东营市胜泰大厦的建筑面积 4500m^2，制冷量 271KW，冷冻供回水温度 7℃/14℃，输入功率 62KW，制热量 290KW，热水供回水温度 50℃/40℃，输入功率 83KW。设计了 2 口水源水井，当中一口为抽水井时，另一口水源井为回灌井。空军丰台招待所、办公楼冷量 1400KW，热量 1500KW，生活热水约 265KW，采用 3 口供水井，井深 50 米，地下水出水温度为 15℃左右，回灌井 2 口，井深 28 米[4], [27]。

重庆大学城市建设与环境工程学院参与的新疆米泉市小型办公楼和重庆大学 B 区暖通实验楼两个房间采用了土壤源热泵系统。其中，米泉市小型办公楼空调总面积 123m^2，冷量 10.4KW，热量 9.84KW，采用水平埋管土壤源热泵系统。暖通实验楼两个房间 78m^2，采用 15 根深 10m 的浅埋套管换热器，还设有 2 组埋深分别为 1m 和 2m 的水平埋管，埋管长度为 50m，运行效果良好[20]。

山东建筑工程学院地源热泵研究所与烟台荏原空调设备有限公司合作推出地源热泵系统并成功地应用在该院学术报告厅的中央空调系统中,空调总面积为 500m^2，冷量 110KW，采用垂直埋管土壤源热泵系统[2], [4]。

辽宁省辽阳市邮电局的两栋宿舍楼（建筑面积共计 6000m^2）采用了由山东海阳富尔达公司与清华大学工程力学系联合研制出的富尔达地温中央空调。运行结果表明:冬季室内温度始终保持在 18℃以上,最高可达 25℃[2]。

天津市梅江居住区一综合办公楼,建筑面积 2991m^2,建筑热负荷 147KW,建筑冷负荷 320KW。经过了冬季 1 个月、夏季近 3 个月的实际运行，该地源热泵系统运行稳定可靠，总体效果上达到了预期的设计目标，冬季采暖房间的室内温度稳定在 18℃以上，夏季空调房间的室内温度基本稳定在 25℃左右，均达到设计温度的要求[31]。

内蒙古的地源热泵科技攻关项目，由内蒙古机电设计研究院组织人员攻关。科技厅选择了一所宾馆和一幢具有办公、餐厅、商场、体育运动场为一体的建筑,做试验示范基地。总建筑面积为 7900m^2。系统水源为两个深为 180m 井,井的直径为 320mm 的水井,其中一口井为供水井,另一口为回灌井,两口井可交替使用。该系统于 2002 年元月开始试水、试运行,通过冬季采暖期 180 天、夏季运行 90 天的试验证实,该系统制冷时提供的出口温度为 7～12℃冷水,供热时提供出口温度为 45～50℃热水,最高可达 50℃。夏季使室温控制在 25℃以下,冬季使室温保持在 16～25℃,同时可供 42℃

卫生热水,集供热、制冷、供应卫生热水为一体，是一个很成功的例子[28]。

另外，为了将北京 2008 年奥运会办成历史上最为成功的一届，实现“绿色奥运、人文奥运”的目标，北京市政府将地热资源的开发利用列入奥运公园的能源供应规划之中。专家们预测，2008 年北京奥运会之前北京奥运公园将钻 10 眼地热产水井与回灌井，预计井深 3000～4000m，每口井日出水量在 1500m^3 以上，水温均大于 65℃以上[30]。这个是让暖通空调工作者振奋的好消息。

5 存在的需要注意的问题

地源热泵从开始研究到应用的过程中，虽然它是环保、节能、先进的空调方式，但仍然存在一些需要注意的问题：

5.1 水资源利用的问题

水资源的利用，应建立在合理的基础之上，对于地下水的使用问题，国家已经有相关的法律、法规、标准出台，应严格执行《中华人民共和国水法》和《城市地下水开发利用保护管理规定》等法规，确保水资源不受污染，不对地质造成灾害。

5.2 采取可靠的回灌手段

大量的开采地下水而不采取可靠的回灌手段的话，后果不堪设想。应加强对水井抽取后进行回灌，还要对水井进行维护，增加水井的使用寿命。回灌水还不应污染地下水源。

5.3 设计过程中要注意水文地质问题

利用地下水源时，要了解地源热泵系统设计的基础资料。要在当地完成对工程所在地的井深、水温、水量、水质等原始资料的采集，并保证这些资料的有效性和正确性，对这些资料进行分析研究。这是一项很重要的工作，可是经常在工程实践中被忽视，从而造成了系统的失败，比较典型的是宁波雅戈尔工业城的例子。[2]主要是出水量的问题，在提供的可行性报告中提出的是单井每小时的出水量，但实际上是单井每天的出水量，所以造成不得不采用其他的方式进行补救。

5.4 水质处理问题

如果水质不适合直接使用于地源热泵机组，那需要采取相应的水处理措施。

比如用过滤器、水处理仪、沉淀池等装置处理后再用于地源热泵机组。一般情况下地下水不能直接用于供暖，因为地下水一般会含有一定数量的碳酸盐、硫酸盐、腐蚀性气体及泥沙等物质，可以经过板式换热器间接利用地下水，延长机组使用寿命，减少维修费用。

5.5 地下换热器的设计

地下换热器的设计要注意对建筑负荷、回填材料、土壤地层特性等进行精确的勘测和分析。

5.6 国产设备的质量问题

现在国内生产的地源热泵产品的厂家越来越多，但大部分的产品质量和性能堪忧。由于过去没有水源热泵的国家标准，所以各厂家的规格、参数不一。有的设备厂家直接从别的公司买进设备，拆了自己照着做，没有自己的设备研究和开发能力，所以造成这样的局面也在情理之中。2002 年 12 月 6 日全国制冷设备标准化委员会会议已审订了《水源热泵》国家标准，以后可以逐渐达到统一。[29]不过，中国暖通空调界需要更多其他的相关的地源热泵的国家标准或规范。

5.7 合理地配置整个系统

地源热泵虽然是绿色的空调方式，但是没有一套合理的系统，它的节能、环保的优势就无法发挥出来。

6 结束语

地源热泵作为一种环保节能的空调方式，应该得到我们的研究工作者对其进行更为深入的研究，探索其关键性技术。目前在国内地源热泵机组的设计、安装、运行、维护等各个方面还没有成型的行业标准和规范,其推广应用还有待时日。但地源热泵技术在中国就像一个新事物必须经历挫折和教训一样逐渐地发展。作为一门新技术，它为我们的国家的可持续发展带来了契机，在不远的将来，随着国富民强，经济实力的提高和生活水平的进步，研究和技术人员的努力，在中国一定有广阔的市场前景。

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节能型混凝土砌块别墅建筑热工性能及能耗分析

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摘　要　为了分析混凝土砌块别墅建筑外围护结构的热工性能及其对建筑物能耗的影响，本文以上海地区的典型混凝土砌块别墅楼盘为建筑物理模型，该模型的两种围护结构方案采用了建筑物能耗分析软件 DeST 进行动态模拟分析，结果表明：对建筑物屋面和墙体添加保温层、对门窗采用低传热系数门窗，不改变建筑物其它构造，就能大幅减少建筑物的空调采暖能耗量。
关键词　混凝土砌块；别墅；围护结构；能耗

随着社会经济的发展和人们生活水平的提高，混凝土砌块别墅建筑的建造量已越来越大，而混凝土砌块别墅建筑的耗能量在住宅建筑中占据了很大的比例。如何降低其耗能量已成为当前迫切需要进行研究和解决的课题。本文针对上海地区的典型混凝土砌块别墅的热工性能和能耗分析来具体阐述混凝土砌块别墅建筑可采用的节能措施。

上海地区的典型混凝土砌块别墅——“ 漓江山水花园 ”[1]中 K 型混凝土砌块别墅主要是从门窗节能、外墙外保温、屋面保温这三个方面来设计整个建筑的保温节能方案的。(1）窗节能方案中窗采用了环保型断热彩铝中空玻璃门窗技术，使得传热系数比普通玻璃大大下降，同时夏季可以有效的阻止外面热辐射进入室内，而冬季则可以有效的阻止室内暖气向外泄漏。而门则采用了保温门，保温隔热性能要远胜于传统的木门。（2）外墙外保温方案为双排孔砌块复合挤压型聚苯乙烯外保温系统并采用了陶瓷隔热外墙涂料。这两重措施使得外墙体的保温隔热性能十分突出。（3）屋面保温方案采用挤塑聚苯乙烯板进行保温隔热处理，使得屋面具有高抗压强度、低热导性和高抗水气渗透能力等性能。

本文以上海“ 漓江山水花园 ” 中 K 型混凝土砌块别墅的房型为建筑模型，对普通的混凝土砌块别墅的围护结构设计方案和采用了节能措施后的混凝土砌块别墅的围护结构设计方案进行对比，采用 DeST 逐时动态模拟软件来对这两种设计方案进行计算分析，对比得出各自的耗能量，为混凝土砌块别墅围护结构的节能设计方案提供了可靠的科学依据。

1　计算物理模型

混凝土砌块别墅建筑的围护结构基本是由屋面、外墙、门窗等组成。本文进行计算分析的建筑模型如图 1 所示，为一栋三层建筑，内含地下室和车库。第一种方案是普通型的混凝土砌块别墅，其围护结构具体构造如下表所示：

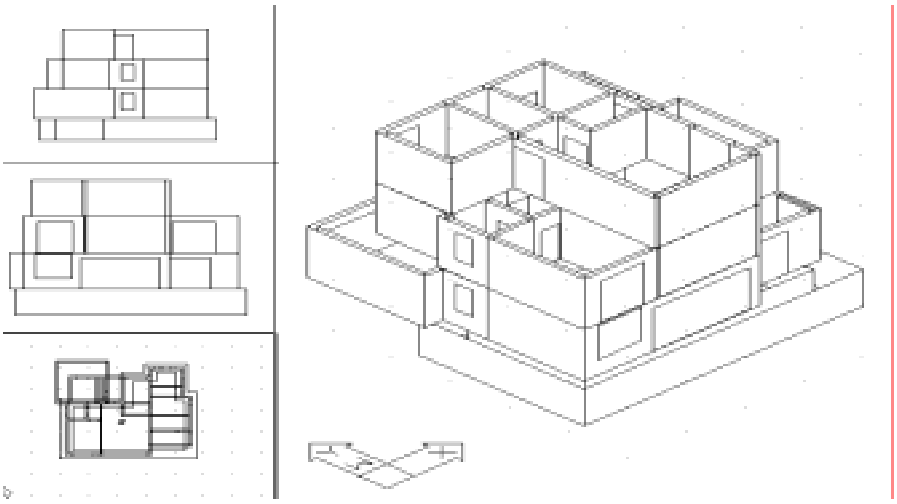

图 1 计算建筑物理模型

屋面	水泥混合砂浆(20mm)＋钢筋混凝土(120mm)＋轻集料混凝土+水泥砂浆(20mm)＋卷材
墙体	水泥混合砂浆(20mm)＋190 单排孔混凝土小砌块(200mm)＋水泥砂浆(20mm)
窗	单玻铝合金窗
门	普通木门

第二种方案是采取了节能措施后的围护结构，具体构造如下表所示：

屋面	水泥混合砂浆(20mm)＋钢筋混凝土(120mm)＋轻集料混凝土+水泥砂浆(20mm)＋卷材＋挤塑聚苯板(35mm)＋细石混凝土(20mm)
墙体	水泥混合砂浆(20mm)＋190 单排孔混凝土小砌块(200mm)＋水泥砂浆(20mm)＋挤塑聚苯板(25mm)＋混合砂浆(20mm)
窗	断热铝合金中空玻璃门窗
门	保温门

2 计算数学模型

建筑物能耗的求解过程就是求解室内空气的温度场和热流场随时间的变化过程。对本文而言，主要是通过求解墙体、屋面、门窗和室内空气的温度的动态变化来计算建筑物的能耗。

2.1 墙体、屋面和门窗的能量控制方程

本文采用一维传热理论分析建筑物各构件的温度场分布和建筑物的能耗。当不考虑建筑物与天空之间的辐射换热时，外墙体、屋面和门窗的能量控制方程为：

$$\frac{\partial t}{\partial \tau} = a\frac{\partial^2 t}{\partial x^2} \qquad 0 < x < l\ ,\ \tau > 0 \tag{1}$$

初始条件

$$t\ \ (x,\tau)\big|_{\tau=0} = t\ \ (x,0)\quad 0 \le x \le l \tag{2}$$

边界条件

$$-\lambda \left.\frac{\partial t}{\partial x}\right|_{x=0} = \alpha_e(t_e(\tau)-t\ \ )+\rho\ I \quad \tau>0 \tag{3}$$

$$-\lambda \left.\frac{\partial t}{\partial x}\right|_{x=l} = \alpha_i(t_i(\tau)-t\ \ )+\rho_i\cdot\beta\ \cdot Q_g(\tau) \quad \tau>0 \tag{4}$$

2.2　室内空气的能量方程

根据能量守恒定律，室内空气的能量方程为：

$$\rho_a C_{p,a}\frac{\partial t_i(\tau)}{\partial\tau} = \alpha_i(t\ \ (\tau)\big|_{x=l}\ -t_i(\tau))F/V+\dot{Q}(\tau)/V \quad \tau>0 \tag{5}$$

初始条件

$$t_i(\tau)\big|_{\tau=0} = t_i(0) \tag{6}$$

其中，t 为温度℃，a 为导温系数 $a=\lambda/\rho C_p$ （m^2/s），λ 为构件的导热系数（$W/(m\cdot K)$），τ 为时间，x 为建筑物外表面到计算单元的距离（m），l 为建筑物构件的厚度（m），α_e 为室外空气与建筑物外表面之间的对流换热系数($W/(m^2\cdot K)$)，ρ 为建筑物构件外表面的太阳吸收率，ρ_i 为建筑物构件内表面的太阳吸收率，，β 为太阳辐射得热在建筑物构件上的分配系数，I 为太阳辐射强度（W/m^2），$t_e(\tau)$ 为室外空气温度（℃），ρ_a 为建筑物构件的密度（kg/m^3），C_p 为建筑物构件的定压比热（kJ／（$kg\cdot$℃）），V 为室内空气体积（m^3），$\dot{Q}(\tau)$ 为热扰（W）。$\dot{Q}(\tau)$ 中包括外扰和内扰两部分，外扰包括玻璃窗逐时辐射得热 $Q_g(\tau)$ 和空气渗透的逐时传热 $Q_{a,l}(\tau)$，内扰为室内人员、照明和其他设备等的潜热和显热 $Q_{in}(\tau)$。

为简化计算，本文中令室内人员、照明和其他设备等的潜热和显热 $Q_{in}(\tau)=0$，即不考虑室内热扰的影响。

2.3　建筑物的能耗

根据室内空气能量方程（5），由于外扰和内扰的作用，室内温度随时间的变化而变化，为了满足《夏热冬冷地区居住建筑节能设计标准》[2]中室内温度冬季全天为 18℃，夏季全天为 26℃的要求，需要加入人为热扰，此人为热扰被称为建筑物的能耗。其中，为满足冬季 18℃的要求而输入的能耗称为采暖能耗，为满足夏季 26℃的要求而输入的能耗称为空调能耗，采暖能耗与空调能耗之和为建筑物的总能耗。

3　模拟计算参数设置

在对本文中的两种混凝土砌块别墅进行能耗分析时，根据《夏热冬冷地区居住建筑节能设计标准》统一设置的参数为：采用上海地区的气象参数，采暖能效比为 1.9，空调能效比为 2.3。室内温度设定为采暖 18℃，空调 26℃。无室内热扰，换气次数 1 小时 1 次。另根据两种混凝土砌块别墅的围护结构差异分别列出计算参数如下表所示：

混凝土砌块别墅	普通型传热系数[W/(m^2×K)]	节能型传热系数[W/(m^2×K)]
屋面	1.6	0.51
墙体	1.8	0.83
窗	6.4	2.7
门	4.5	3.0

4 结果分析与讨论

为了科学设计混凝土砌块别墅围护结构的节能方案，本文采用 DeST 软件对两种混凝土砌块别墅方案的总能耗进行了模拟计算，得出了相关结果如下表所示：

普通型混凝土砌块别墅能耗量（kW· h/m^2）	节能型混凝土砌块别墅能耗量（kW· h/m^2）
85.86	57.87

由表中数据可以看出节能型混凝土砌块别墅的能耗量比普通型混凝土砌块别墅的能耗量要节省 33%，超过了《夏热冬冷地区居住建筑节能设计标准》规定的围护结构节能约 25%的指标。所以节能型混凝土砌块别墅的围护结构设计方案是可行的。

通过对比后的结果可以看出，对于混凝土砌块别墅这类低层建筑，为了达到降低其建筑能耗的效果，在传统的普通混凝土砌块别墅上可采用仅对建筑物的屋面和墙体添加保温层，而不改变其它构造，对建筑物的门窗采用低传热系数的构件的方法。在《夏热冬冷地区居住建筑节能设计标准》中给出了屋面、墙体、门窗的节能设计限值，但是如果为了建筑设计的需要，也可以整体考虑建筑物的节能效果。如本文中所给出的计算物理模型上海“ 漓江山水花园 ”中的 K 型混凝土别墅，它的南向窗墙比相当大，达到了 0.65，远远超过了《夏热冬冷地区住宅建筑节能标准》中的上限值 0.5。其余各向的窗墙比为：北向为 0.3、东向为 0.15、西向为 0.06。但是由于它整体围护结构（屋面、墙体、门窗）的综合保温措施做的好。所以它的节能效果还是达到了要求。因此今后在给混凝土砌块别墅做节能方案时，可以从全局出发，配合建筑师的设计理念，选用合适的保温隔热材料和门窗构件，通过建筑物动态能耗模拟分析软件来给出一个综合的能耗值，以此来判断该混凝土砌块别墅是否达到节能指标。

5 结论

通过本文的典型实例分析，可以得到如下结论：

1、在传统的普通混凝土砌块别墅上可采用仅对建筑物的屋面和墙体添加保温层，而不改变其它层构造，对建筑物的门窗采用低传热系数的构件的方法来减少建筑物的能耗量。

2、在给混凝土砌块别墅做节能设计方案时，可通过建筑物动态能耗模拟分析软件来给出一个综合的能耗值来判断该混凝土别墅是否达到节能指标，而不要为《夏热冬冷地区居住建筑节能设计标准》中的节能设计限值所限制。

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北京奥运建设与绿色奥运评估体系

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摘 要 本文介绍了绿色奥运建筑评估体系的研制过程和在研制和推广过程中的主导思想。同时对这一评估体系的主要结构，评分方法，主要特色进行了介绍。同时文中还提出在我国城市化进程中发展绿色建筑的重要意义和可能的发展途径。
关键词 绿色建筑；可持续发展；北京奥运建筑

一、背景

我国目前正处在城市建设高速发展期。据统计 2003 年城市化水平为 37%，按照规划将在 2020 年时，城市化水平将超过 50%。这意味着近十到二十年间将是我国大规模城市建设期。近年来我国城市年竣工建筑面积连续超过 10 亿平米，大于全世界其它地区建筑量的总和。到 2020 年我国的城市建筑中将有一半以上为本世纪建设的建筑。面对这样的飞速发展形势，怎样在目前的城市建设中坚持可持续发展观念，节约土地，节约资源，保护环境，同时建成适宜人类居住生活的空间环境；而不是浪费资源，破坏环境，制造出一片城市沙漠；这是摆在城市建设者面前的十分严峻的挑战。

然而近年来可持续发展却并没有成为城市建设中的主旋律。即将竣工的北京国家大剧院把三座独立的演出厅置于一个庞大的钛金属外壳下，再摆放于一个人工湖中，露天的人工湖还要在冬季加热以维持不冻，......；这无论从与周边环境的协调，建筑投资，环境污染，运行能耗；还是“以人为本”，为周边人群和建筑使用者提供舒适方便的微环境，都不符合可持续发展的原则。只能是在标新立异，“世界第一”上可以说出几条。难道我们的建筑主要目的就是追求标新立异，“世界第一”吗？建筑“鸟巢”，

进而出现的奥运国家主体育场，同样为了体现“高科技”和“世界第一”，必须采用可开启屋面，从而成就了“鸟巢”。因为其过于新奇的建筑造型和结构，导致了单位建筑面积的用钢量几乎为世界上同样规模的某个体育场的十倍，预算造价接近我国已有的同样规模体育场的 3 倍。而奥运后怎样全面使用使其发挥效益却一直未有完善的方案。我们的钱就多到这种程度了吗？ 。。而

更有甚者，作为奥运场馆的北京五棵松文化体育中心通过国际招标确定的方案，是一座约 160 米见方，40 米高的立方体。将约 6000 平米一面的四面外墙全部设计为电视屏幕——号称“世界第一”大的巨型电视墙。仅电视墙的投资就超过 2.4 亿美金，为建筑主体投资的两倍，耗电量则为建筑本体装机容量的 2 倍。巨大的电视墙还将造成严重的光污染和热污染，影响周围居民，医院和交通的夜间正常活动。

北京的这股“高，大，新，奇”之风同样影响到各地。县城中的一座建筑也要投入巨资进行“国际设计招标”；有的城市建中心广场的形象工程，其可容纳的人数几乎接近该城市人口总和；有的城市要建小的“蛋壳”剧院，并一定要赶在国家大剧院完工前交工。

此风蔓延，将是我国建筑界的灾难！也将严重影响中国城市建设乃至中国社会和经济的可持续发展。因此必须要坚决遏制此风，坚持可持续发展的城市建设之路。其主要内容亦可称为“绿色建筑”。奥运工程是北京目前城市建设的重要主题，绿色奥运又是北京承办奥运的三大宗旨之一。在科技部和北京市科委的支持下，我们就从怎样在奥运建设中贯彻“绿色建筑”出发，从奥运建筑做起，尝试绿色理念在建筑中的落实，扭转标新立异贪大求洋的风气，以“科学、务实”的态度推动绿色奥运的真正落实，也为在全国城市建设中推广绿色理念摸索经验和有效的途径。

基于上述背景，2002 年 11 月作为奥运十大重点科技项目之一的“绿色奥运建筑评估体系”课题启动。由如下九个单位承担：

- 清华大学（建筑学院、土木工程系）
- 中国建筑科学研究院
- 北京市建筑设计研究院
- 中国建筑材料科学研究院
- 北京市环境保护科学院
- 北京工业大学
- 全国工商联住宅产业商会
- 北京市可持续发展促进中心
- 北京城建技术开发中心

同时还得到如下单位和机构的大力协助与支持：

- 华南理工大学
- 美国自然资源保护委员会（NRDC)
- 日本建筑综合环境评价研究委员会（CASBEE)
- 美国能源部（DOE)

2003 年 8 月完成评估体系初稿和初步的研究工作，2004 年 4 月结题。本文对这一评估体系进行简单介绍，并探讨它在奥运建筑中的使用和对全国城市建设“绿色化”的推动。

二、什么是绿色建筑

人类建造房屋，是为了提供一个适宜的空间，以满足人类的生活，生产，及各种社会活动的需要。实现满足这些活动的功能，是对建筑的基本要求。建造房屋必然要占用土地，使用大量的建筑材料。而在维护建筑的正常使用，使其发挥其功能的过程中，也必然需要消耗能源，水，和其它自然资源。这些对自然资源的占用和消耗是房屋的建造和使用所必需的，而从可持续发展的观点看又是必须限制和减少的。在建造和使用房屋中，还必然造成某些对自然环境的改变和破坏：土地的开发利用改变了原有的生态环境和生物链；城镇建设改变了原有的水文地质状况；建筑物建造和使用过程中消耗的能源还会造成大量污染物向空中排放，....。这种对环境的影响和破坏在很多情况下也是很难避免的。房屋总要建造，人类的需求总要满足。怎样在造出满足人类需求的建筑空间的前提下，最大可能地减少对自然资源的占用与消耗，最大可能地减少对自然环境的改变和破坏，这就是绿色建筑追求的目标。取建筑环境质量为 Q，占用和消耗的自然资源为 S，对环境的影响和破

坏为 H，则绿色建筑所追求的就是建筑收益 B 最大化：

$$B = \frac{Q}{S+H} = \frac{Q}{L}$$

式中，L=S+H，是为了获得具有建筑环境质量 Q 所付出的资源与环境负荷。一般地说，追求优良的建筑质量 Q 往往需要付出大的资源与环境负荷 L，绿色建筑就是通过合理的规划设计与先进的建筑技术来协调这对矛盾，力求 B 的最大化。而那些片面追求“洋，新，怪”的建设项目，付出巨大的资源与环境代价的同时，也背离了以人为本的原则，Q 也同时减少，使效益 B 大减，这是我们最应反对的。

三、绿色奥运建筑评估纲要

从上述基本原则出发，并针对北京奥运建设的实际情况，我们完成了“绿色奥运建筑评估体系”[1]。其目的就是用来指导和评价奥运建筑设计建造和管理的全过程。根据我国建设项目的实际情况这一过程可以分为这样以下阶段：

——规划设计阶段，这是设计方案招标评标阶段。此时对建筑和设备系统的方案已基本确定，只是缺少具体的详细设计与材料设备选择。

——详细设计阶段，完成全部施工图与设备材料选择。建设施工部门已可以按图施工。

——施工阶段。由施工部门具体完成主体结构，装修和设备安装。

——调试，验收和由运行部门承担的长期运行管理阶段。

这四个阶段中的任何一个环节都对建筑最终的“绿色性”有决定性影响，哪一个环节也不能忽视。而在各个阶段承担主要责任，完成主要工作的主体并不相同。并且从绿色要求来看，每个阶段的中心任务，主要矛盾也不相同。这样，要通过这一评估体系指导和督促建设项目实现绿色，而不是仅仅在项目全部完成后才用评估体系来检查和考核。就需要在有着四个阶段组成的全过程中，按阶段不断指导，检查和考核，从而实现全过程管理。这样针对每个阶段中心任务与主要矛盾的不同，就需要分别制定不同的评估内容。我们由此分别完成了四个阶段的评估纲要[5]，其涉及内容如下：

第一阶段：规划设计阶段

1-1　场地选址

主要涉及：与城市总体规划的协调；是否满足防灾、减灾的要求，建设用地的性质，是否符合节省土地资源的原则；现场水系与地貌状况评估；对生态环境的影响；建设场地的环境质量；对现有交通和市政基础设施的影响等。

1-2　总体规划环境影响评价

主要涉及：土地规划的合理性；对地下水和地表水系的影响；是否保持了场地的生物多样性；现场的电磁污染，噪声污染状况；建筑的相互遮挡状况和日照间距的保证；由于建筑所导致的周边热环境与风环境状况；可能出现的热岛效应水平等。

1-3　交通规划

主要涉及：规划区域交通网络的评价；与城市公共交通的联系；停车场的设置；以及规划小区的人流组织等。

1-4　绿化

主要涉及：原有绿化的保护及规划设计的绿化率。

1-5　能源规划

主要涉及：规划区域能源供给方案的能源转换效率评价；由于这一新建项目导致对城市能源系统的冲击（增加的用电峰谷差与用燃气的冬夏差）；可再生能源和新能源的使用状况以及建筑能源消耗导致的环境影响。

1-6　资源利用

主要涉及：项目的必要性和规模评价，建筑材料消耗总量的分析评价；现有建筑的利用状况；项目的赛后利用可能性与充分性评价；以及对固体废弃物处置方案的评价。

1-7　水环境系统

主要涉及：用水规划；对给水、排水系统规划的评价；对污、废水处理与回用的评价；雨水利用状况评价；绿化与景观用水规划以及湿地的开发与人工湿地规划。

第二阶段：详细设计阶段：

2.1　建筑设计

主要涉及：建筑规模、容积与面积控制，对于体育场馆来说单个观众席的折合面积与造价；结构材料选择；建筑主体节能；室内可能实现的热环境效果；室内自然采光状况；室内可以获得的日照量；隔声与噪声控制设计评价；建筑内自然通风效果分析；对于奥运建设项目还要评价建筑的可适应性，既当要求的功能改变时建筑的适应能力。

2.2　室外工程设计

主要涉及：场地工程的评价；绿化和园林工程评价；道路工程评价以及室外照明和光污染控制分析。

2.3　材料与资源利用

根据所使用的全部建筑材料量定量地计算分析这一新建项目导致的资源消耗数量和生产与运输这些材料所消耗的能源及对环境的影响。检查建筑材料的本地化比例，并评估旧建筑材料利用状况。

2.4　能源消耗及其对环境影响

主要涉及：所采用的冷热源和能量转换系统效率；由风，水循环系统构成的能源输配系统的输配效率；供热空调系统在部分负荷下和只有部分空间使用的条件下的可用性和效率；所采用的新风热回收技术评价；其它用能系统评价；照明系统的节能分析；对用能设备的计量、监测与控制状况；可再生能源的利用；以及能源系统运行对环境影响和空调制冷设备中是否使用了破坏大气臭氧层的工质。

2.5　水环境系统

主要涉及：饮用水安全性评价；污废水处理及资源化评价；再生水回用率与回用方案评价；雨水利用；绿化与景观用水；以及节水设备与节水器材的使用。

2.6　室内空气质量

主要涉及：室内自然通风与空调通风系统对改善室内空气质量的分析评价和装饰装修材料无害化评价

第三阶段：施工阶段评估

3.1　施工的环境影响

包括怎样减少施工对场地土壤环境影响；对大气环境影响；施工噪声；施工造成的水污染；施工造成的光污染；以及施工期间对周边区域的安全影响评价和采取的古树名木与文物保护措施。

3.2　能源利用与管理

降低施工能耗的措施和施工过程用能优化。

3.3　材料与资源

包括对材料节约利用；施工材料的合理选择；资源再利用措施和就地取材情况。

3.4　水资源

施工用水的节约和各种水资源的优化利用

3.5　人员安全与健康

考察现场的安全措施，实现人性化，改善施工人员的工作环境。

第四阶段：调试验收与运行管理

4.1　室外环境

现场考察项目建成后实际对周边生态环境的影响；对原生环境保护和改善；测试并评价室外热舒适与热岛效应；室外风环境；环境噪声；环境振动；室外照明；大气质量；道路工程及交通状况。

4.2　室内环境

测试并评价室内空气质量；室内声环境；光环境；热舒适性。

4.3 能源消耗

通过对系统的详细测试对试运行阶段的系统能耗进行评估。

4.4　水环境

实际使用效果与用量的考核与测试计量。

4.5　绿色管理

考察有无有效的管理体制和激励机制来切实实现有效的绿化管理，固体废弃物收集和处理，空调系统运行的卫生管理，水质管理，节水管理与节能管理。

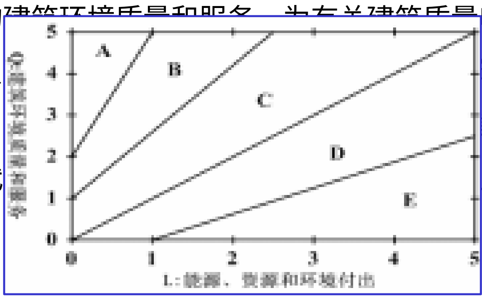
上面简单地列出绿色建筑涉及的内容。“绿色建筑评估纲要”中对其中的每一条的考核目的，原理，建议的做法给出详细说明，可以直接在各阶段的设计施工和管理工作中参考。

四、绿色奥运建筑评估体系

为定量评价绿色建筑，还需要一套科学的评分体系，对上述各项指标逐项打分，最终得到对一个项目符合绿色建筑程度的综合评价。要建立这样的打分体系就需要解决三个问题：1）怎样协调提高建筑环境质量与减少建筑物的环境负荷这两类不同性质的指标；2）怎样对每项指标进行量化，给出定量评价；3）怎样设计一套加权系统，使各项指标的分数能够相加，同时还能客观地反映出各项指标对绿色建筑理念所具有的作用。

（1）Q 与 L 打分体系

如上所述，绿色建筑追求的是用最少的环境代价 L 获取最好的建筑环境质量 Q。简单的把二者的完善程度相加，并不能反映被评价项目绿色程度的实质。例如在废弃的垃圾场上建设住区，属于充分利用废弃的土地资源，在减少环境负荷 L 上作得很好，但获得的建筑环境质量 Q 不一定很好；而在森林中辟一块土地开发住区，获得了很好的居住环境 Q，但也付出很大的环境代价。简单地把 L，Q 相加，会得到这两个项目绿色程度相同的结论。而这绝不是我们想得到的。因此面对 Q，L 这对矛盾，很难用单一指标给出科学评价。为此采用图一所示的 Q，L 两维坐标来评价建筑的绿色程度。横坐标 L 为能源环境资源的付出，涉及评估纲要中有关环境负荷的指标，纵坐标 Q 为所获得的建筑环境质量和服务，为有关建筑质量收益方面的指标。这样，当评价结果位于 A 区时，表示只 筑环境质量和服务，属于出色的绿色建筑。同样，当处于 B 建筑。而当处于 D，或 E 区时，则表明付出了高额的环境代 此从绿色建筑的角度看，应该是坚决避免的。



图一。Q—L 分区判断建筑的绿色性

北京五棵松文化体育中心的原设计方案，结构耗钢量大，外表面电视墙投入高，并造成周边的光污染，建筑能耗高，因此 L 很高，而建筑内交通，人流组织不畅，由于外表的电视墙使建筑的周边房间断绝了与室外的联系，不具有好的室内环境质量，Q 并不高。评价分析的结果是处于 D 区，不符合绿色建筑要求。尽管该方案属国际招标中标方案，经多次论证，现在终于彻底推翻原方案，而代之以简朴，求实的新方案。

（2）各项评价指标的定量化

把上述评估纲要中的各指标分为属于建筑环境质量与服务的 Q 类和属于环境负荷与资源占用的 L 类，对各类中的每一项，都要定量评分。为使其可操作，将各种指标分为两类。对于能定量化分析的指标，例如建筑材料的资源占用，建筑材料生产过程的能源消耗和环境污染，建筑物的运行能耗等，都采用严格计算分析，得到单位建筑面积的消耗量，再与通过对目前大量建筑的调查分析的基础上得到的参考值比较，确定 0~5 分分值。对于无法定量分析的指标，则列出各种可能的做法的菜单，对各种做法直接给出分值。各项指标的具体打分方法和计算方法的说明，见“ 绿色奥运建筑评估体系 ”[1]。

（3）权系数分配体系

通过对每项指标加权相加，可得到最终的综合评价。对上述设计与施工，管理的每个阶段，分别得到 Q 和 L 的总分。根据各项目在绿色建筑中的作用，分级给出权重系数。下面仅列出各阶段

第一级指标的权重。

第一阶段：规划设计阶段

Q 建筑环境质量与服务评价

场地质量：0.15　　　服务与功能：0.45　　　室外物理环境：0.4

L 环境负荷和资源消耗

对周边环境的影响：0.35; 能源消耗：0.35；材料与资源：0.1; 水资源：0.2

第二阶段：详细设计阶段

Q 建筑环境质量与服务评价：

室外环境质量：0.1；室内物理环境：0.3; 室内空气品质：0.35；服务与功能：0.25

L 环境负荷和资源消耗：

对周边环境的影响：0.05; 大气污染：0.1；能源消耗：0.4；材料与资源：0.3; 水资源：0.15

第三阶段：施工过程

Q 人的安全与施工质量：

人员安全与健康：0.7;　　　工程质量：0.3

L 环境负荷与资源消耗：

对周边环境的影响：0.55; 能源消耗：0.15；材料与资源：0.2; 水资源：0.1

第四阶段：调试验收与运行管理

Q 建筑环境质量与服务评价：

室外环境质量：0.1；室内物理环境：0.2; 室内空气品质：0.15；服务与功能：0.2；绿色管理（绿化，服务，垃圾管理）：0.35

L 环境负荷与资源消耗：

对周边环境的影响：0.1; 能源消耗：0.3； 水资源：0.15；绿色管理(节能节水管理)：0.45

以上每个一级指标下，又设有二级指标，部分二级指标下又有三级条目，从而逐步细化与深入。而权系数也是如此分级设计，这样就可以很灵活地根据这类被评对象的具体情况，适当修订底层的某些权系数，使之既适合于各种不同情况，又能在上一层次上得到统一。为了使评估工作简单易行，课题组专门开发了相应的评估软件，内置了各项指标的打分方法和权系数，只要根据被评建筑输入各项指标的具体做法与参数数值，就可自动完成全面的评价分析与打分工作。

五、评估体系的主要特色

目前世界上已相继制定出许多绿色建筑评估体系，如美国的 LEED[2]，加拿大的 GBtool[3]，日本的 CASBEE[4]等，我国的绿色奥运评估体系，除如前所述在分阶段评价，区分 Q，L 两类指标等特色外，还根据我国建设领域的具体情况，尤其是奥运建筑的实际问题，突出了如下特点：

1）在场地选址和总体规划中引入绿色概念和要求，强调要对项目的可行性和规模进行深入论证，避免上无必要的项目，避免盲目扩大规模。同时对奥运建筑，着重考核其赛后利用情况。盲目上马不必要的项目，会造成赛后大部分时间空闲，将是最大的土地和各种资源的浪费，应该坚决避免。盲目地不切实际地扩大规模与标准，也不符合绿色建筑原则。为此，研究制定了土地利用率指

标，单座建筑面积指标等系列评估指标进行引导和评价。

2）从全生命周期考察建筑材料的利用。提出建筑材料资源消耗，能源消耗，环境影响，本地化等 4 个定量指标。对近 20 个实际项目进行了调查，得到每一项的参考数值指标。由于各种型钢和有色金属的回收利用率很高，因此尽管这类材料在生产过程中耗能和污染都比较大，但考虑到回收再利用后，从全生命周期分析的方法研究的话，却会有不同结论。调查分析的结果表明，不同的建筑结构体系所占用的资源与能源环境消耗有较大差别，合理的使用钢结构可以获得资源环境代价最小的结果，但如“鸟巢”那样不合理达钢结构设计，也会导致严重的资源能源浪费的现象。

3）随着“西气东输”项目的完成，北京的能源供应出现多元化。怎样分析比较煤，电，天然气等不同能源构成的建筑能源供应与能量转换系统，也必须认真科学地解决，才能防止误导造成决策上的失误。根据各种能源做功和可利用的程度，这一评估体系采用“能质系数”的方法，同时考虑能源消耗的数量和品质，从而对对各种系统与方式做出科学的判断。分析结果发现，以天然气为一次能源的建筑热电冷三联供方式（BCHP），并非总是节能的。当热电比例不当，建筑以供冷为主，建筑的热电冷负荷不匹配时，BCHP 系统的能源利用率会低于常规系统。直接燃烧天然气产生热水的大规模天然气锅炉也不是太好的能源转换方式。

4）在大规模体育场馆和公共建筑的空调系统中，50~70%的空调能耗是被风机水泵构成的输配系统所消耗。而输配系统的节能又在许多场合被忽视。为此评估体系中专门设计了输配系数 TDC (Transportation and distribution coefficient) 来评价输配系统泵和风机的能耗。这样以鼓励选择更好的输配系统形式，精心选择泵和风机以获较高效率，尽可能采用变频调速的调节手段。

5）同样，各种热回收技术和可再生能源的合理利用也得到了鼓励和科学评价。这类技术措施在设计得当时可产生显著的节能效果，但有时其辅助装置的能耗（尤其是泵与风机）要高于收益。因此也从能质系数的角度出发，提出系列的评价指标，要求对其进行科学评价，避免以使用可再生能源的招牌炒作，而最终并未获得实际的节能效果。

6）在评价对大气环境的污染时，提出同时考察造成当地的大气污染的直接排放和对发电厂所在地区大气造成污染的间接排放。均衡这两个大气污染指标，合理地协调当地污染与外地污染的矛盾。这样就可以科学地看待电力利用的问题，避免了一些认为电力是清洁能源，主张大力发展电采暖，把污染转到其它地区的错误主张。

还有许多类似的评估指标，都是根据当前的实际问题与出现的误区而具体制定。正是这些指标所涉及的内容使这一评估体系不同于国外版本，更清晰地针对于解决我国城市建设中的实际问题。这也是为什么要另行研制我国绿色建筑评估体系的原因。

六、发展现状

003 年秋，这一评估体系已基本完成。为考察其可应用性，选择了一批在建和建成项目，对规划，详细设计，施工以及运行管理阶段分别进行了评估。由于篇幅限制，这里不再详细介绍评估结果。值得指出，在规划阶段与详细设计阶段被评为 B^+的某办公楼项目近日还通过了美国 LEED 绿色建筑评估认证，在白金级，金级，银级中初步认定为金级。某个被评为 A 的绿色施工过程 2004 年作为唯一的施工绿色管理项目，荣获北京市科技进步奖。运行管理被评为 B^+的某个住宅项目最

近也荣获北京市科技进步奖。由于这一评估体系完成时北京奥运场馆的主要项目的方案已基本确定，因此这一评估体系没能在主要场馆招标和方案确定中发挥作用。但是如前文所说，按照这一评估体系分析，发现某些项目目前的方案离绿色建筑相距甚远，某些项目从绿色建筑的角度分析，还有很大的改进空间。目前北京市政府及时认识到这一问题，采取了一系列有效措施，坚持勤俭办奥运的原则，切实落实“ 绿色奥运 ”的承诺。这为推广绿色奥运建筑提供了极好的机遇。我们正在组织力量对各个奥运项目进行绿色建筑评估，为方案的改进和完善提供科学的依据，为真正落实北京的绿色奥运发挥作用。

今后的十年正是我国城市建设关键的十年。发展绿色建筑应是实现我国可持续发展的城市化进程中关键性一环。北京绿色奥运建筑的实践从各种角度为推广绿色建筑提供了经验。上海世博会的建设也会为绿色建筑的推广做出更科学更务实的样板。科技部现在已启动“ 绿色建筑关键技术研究 ”重大攻关项目，全面从理论，标准，技术，示范平台各方面开展研究与推广绿色建筑的工作。相信这一切能有效地推进我国绿色建筑事业，从而健康，科学，平稳地实现我国的城市化过程。

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Promotion of Sustainable Building based on the Concept of Eco-Efficiency

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Abstract New assessment system for green buildings known as CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) have been developed by the JSBC (Japan Sustainable Building Consortium), supported by the Ministry of Land, Infrastructure and Transport. In CASBEE, two environmental aspects i.e. environmental load (L) and quality of building performance (Q) are set as the major assessment targets. There are about 80 items to be assessed in CASBEE, which are categorized into two groups of L and Q. BEE (Building Environmental Efficiency) is defined as Q/L, following the concept of eco-efficiency. Thereby, it becomes possible in CASBEE to assess how much a building can reduce the environmental load, with realizing the high environmental quality. This assessment structure is the most unique point of CASBEE compared with existing assessment tools, in which the main concern is the evaluation of the environmental load, and the aspect of realizing high quality is not expressed clearly. With the increasing BEE value, total environmental performance of buildings is labelled as any of Class C (Poor), Class B- (fairly poor), Class B+ (good), Class A (very good), and Class S (Excellent). CASBEE is going to provide four tools according to the lifecycle of a building, i.e. pre-design stage, design stage and post-design stage.

摘 要 在日本国土交通省的支持下，日本可持续性建筑共同联合体开发了新的绿色建筑评估体系 CASBEE（建筑环境效益的综合性能评价系统）。CASBEE 中，两个主要的评价指标是环境负荷（用 L 代表）和建筑性能（用 Q 代表）。共有约 80 项的内容需进行评估，它们被分作 L 和 Q 两大类。建筑环境效率 BEE 用 Q/L 来定义，它包含了生态效率的概念。因此，CASBEE 可评价建筑物在实现高效环境的同时对环境负荷的减少程度。这种评价结构体现了 CASBEE 的独一无二特点，而现有的其他评价工具主要关注环境负荷，对高效环境的描述不清。随着 BEE 值的变大，建筑物综合环境性能可分为 C（差）、B-（较差）、B+（好）、A（非常好）、S（优异）等多个级别。CASBEE 将提供四个工具，分别针对建筑的前期规划、设计和建造管理等全生命周期的过程。

1. The notion of sustainable building under the paradigm of sustainable ecosystem

With global environmental issues becoming more critical, terms such as ‘sustainable building’ and ‘sustainable city’ have come into widespread use since the principles for “sustainable development” was proposed by the UN’s World Commission for Environment and Development (the so called ‘Brundtland Commission’) in 1987. Nowadays, these words have been used in many different ways, but because of the Brundtland Commission background, the most natural and most basic interpretation is in association with global environmental issues. Today, the largest point of discussion in global environmental issues is the issue of danger to the ecosystem that provides the basic support for our lives. Consequently, the definition of sustainable building is "producing buildings whose loadings on the global environment are manageable enough to maintain the sustainability of the ecosystem". The eco-balance concept has been suggested as a means of assessing the sustainability of the ecosystem, but because eco-balance is very complex and comprehensive, it is difficult to define it accurately at present.

Current sustainable building assessments focus on such items as preventing global warming, saving energy and resources, and conserving the indoor and outdoor environment, etc. They are the major elements that make up eco-balance, but by themselves, these are by no means considered to be sufficient for assessing eco-balance. As the study of the eco-balance progresses, it is quite likely that items for building assessment could be added and modified, and the assessment method itself could be changed.

2. Danger to the ecosystem, and the amount of time left for us

The fact that changes are occurring to the earth's ecosystem that provides the basic support for human life has already been confirmed by a variety of evidence, particularly with regard to global warming, and has been described in detail in several publications. For example, in well-known publications such as "The Limits to Growth" (1972)[1], "Beyond the Limits" (1992)[2], "Factor 4" (1995)[3], "Factor 10" (1994)[4], repeated warnings have been given by Meadows, Weizsacker and Schmidt-Bleek, etc. Their message is that in order to avoid catastrophic changes to the earth's ecosystem, the mass production and mass consumption lifestyles of the developed countries of the North need to be reformed urgently and radically. According to various predictions based on numerical models, the amount of time left for us to achieve that is about 50 years. An example of the simulation that predicts this situation is shown in Figure 1. Drastic

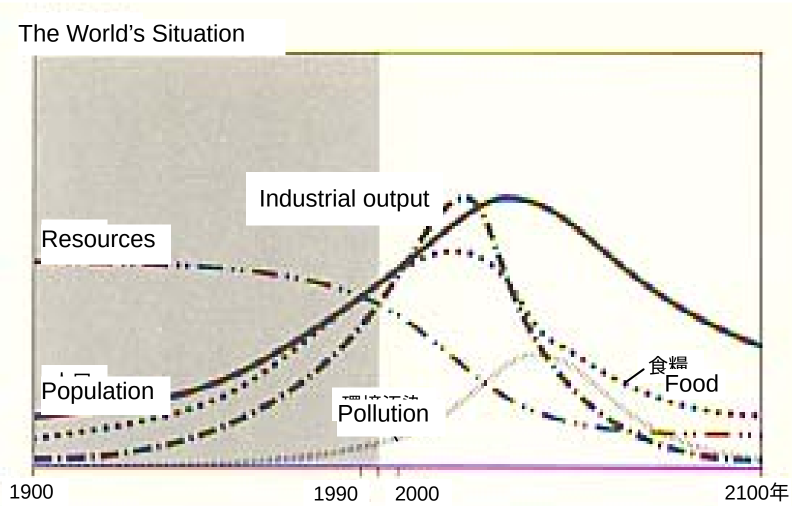

Figure 1 Prediction of global environment by the standard run using the growth model[2)]

This is the prediction result by the standard run of the simulation using the growth model developed by Meadows, etc. Population and industrial output continue to grow until environmental pollution and resource consumption reach limits. Catastrophic changes will break out after that.

changes of various factors related to global environment in near future are clearly predicted. The conference slogan for SB05Tokyo (The 2005 World Sustainable Building Conference in Tokyo) is

“Action for Sustainability,” a slogan chosen because the urgency of the situation requires action. The building sector must reform its position to become properly aware of the critical nature of these urgent global environmental requirements, and must take serious action to provide solutions.

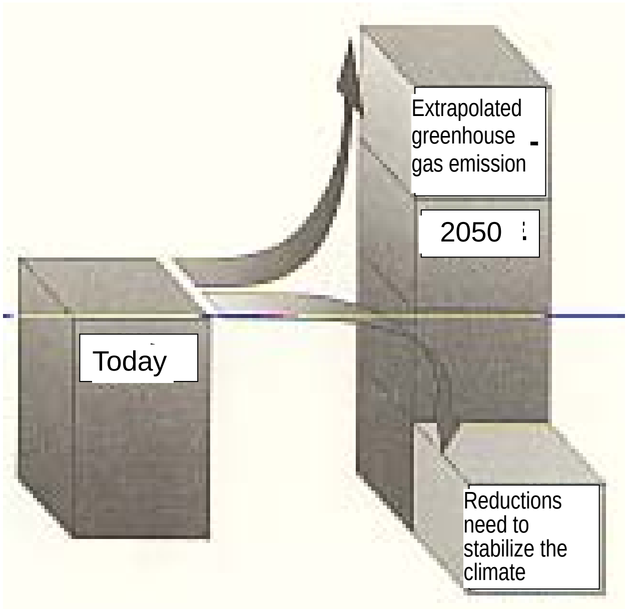

Figure 2 Prediction of energy demand and reduction[3)]

Human beings are already directly facing the risky ‘Factor 4’. In about 50 years time, emissions of greenhouse gases are expected to double. Researchers warn that emissions need to be reduced unconditionally to half the level.

3. Factor 4, Factor 10 and CASBEE

It is well-known that Weizsacker, Schmidt-Bleek and others are advocating concepts such as ‘Factor 4’ and ‘Factor 10’ to proceed reform in the resource productivity of the developed countries, based on their conclusions that the sustainability of the earth’s ecosystem cannot be maintained without an increase by a factor of 4 or a factor of 10 in resource efficiency. An example of this approach applied to reduction of greenhouse gas emissions (cuts in fossil fuels) is shown in Figure 2.

The principle of resource efficiency is expressed in the following formula;

Resource Efficiency =

Asset and Service Production/Resource Input

An index similar to resource efficiency is utilized by organizations such as the WBCSD (World Business Council for Sustainable Development) and the OECD (Organisation for Economic Co-operation and Development) based on the eco-efficiency approach. This is defined as follows;

Eco-Efficiency =

Quality of Life / Impact on the Environment

These approaches are attempts to coordinate and unify the various and different aspects involved in environmental assessment and express them in terms of efficiency. They are excellent approaches for the remarkable clarity and simplicity of the principles.

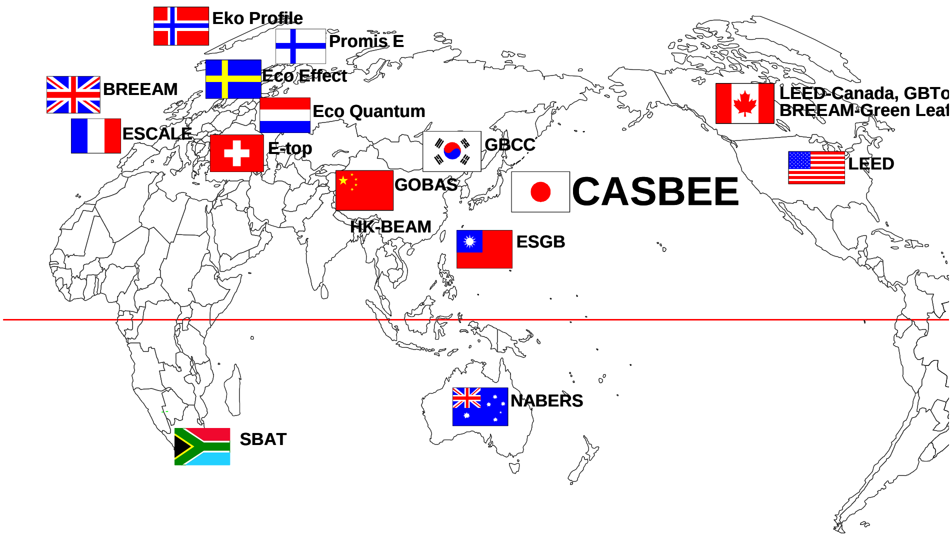

Figure 3 Assessment tools for comprehensive building performance around the world

In recent years, there has been a worldwide boom in attempts to assess the comprehensive environmental performance of buildings from the perspective of global environmental issues, and a number of different assessment tools have been developed with the aim of achieving this objective. Figure 3 shows the comprehensive assessment tools for buildings available at present around the world. In Japan, a new system called CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) has been developed with the support of the Ministry of Land, Infrastructure and Transport, and with the participation of industry, government and academia. Figure 4 shows the covers of the manuals of CASBEE for New Construction and CASBEE for Existing Buildings.

CASBEE is the first attempt in the world to apply the eco-efficiency approach to this sort of system. Specifically, the eco-efficiency approach has been applied to issues of environmental assessment of buildings, producing an index of Building Environmental Efficiency (BEE), defined by the following equation;

Figure 4 Covers of the manuals of CASBEE for New Construction and CASBEE for Existing Buildings

BEE =

Q (Building Environmental Quality and Performance)

/ L (Building Environmental Load)

In order to define the terms Q and L used in the BEE definition, the new concept of hypothetical boundary at the site boundary is introduced as shown in Figure 5. In Figure 5, Category “Q” is assessed as the improvement of environmental quality within the virtual enclosed space. Category “L” is assessed as the negative impact on the environment outside the virtual enclosed space. The method of labeling based on BEE is shown in Figure 6. Trial applications of BEE on buildings constructed by a major company in Japan are illustrated in Figure 7. Here, high-quality buildings are selected as the targets for the assessment. The results of implementation of CASBEE Nagoya on buildings in Nagoya are shown in Figure 8. In this case, common buildings in Nagoya city are assessed, thus almost all labelings belong to the classes of B- and B+. CASBEE is based on the eco-efficiency approach, and its advantage over the many building assessment systems around the world is clear due to its excellent approach . CASBEE has attracted a great deal of attention worldwide for its clear concept.

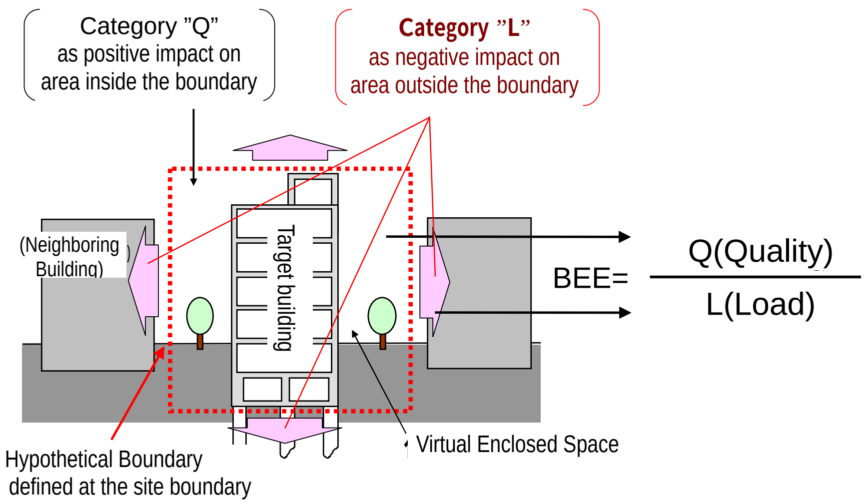

Figure 5 Definitions of Q, L and BEE based on virtual enclosed space

As can be seen from the various prediction results as shown in Figures 1 and 2, the Factor 4 and Factor 10 approaches advocated by Weizsacker and Schmidt-Bleek, etc. are extremely rational indices for the objective of maintaining an ecosystem that provides the basic support for human life. CASBEE and BEE are proposals in line with those principles, and the building sector is recommended to promote sustainable building on the basis of this sort of assessment system.

4. Prospects for the building sector in the dematerialization paradigm in the 21st Century

The paradigm of the 20th Century was mass production and mass consumption. As a result, we now have the risk of the ecosystem collapsing, and face a situation where human existence is in danger. The natural consequence of this is that the paradigm of the 21st Century needs to be dematerialization. In order to achieve dematerialization, there needs to be wide-reaching reform of the current economic systems, social systems and political systems that are based on economic growth.

It goes without saying that dematerialization must also be promoted in the fields of building and urban planning. When promoting dematerialization in the building sector, the BEE principle embedded in CASBEE is a powerful tool. Because Factor 4 and Factor 10 are concepts to promote dematerialization,

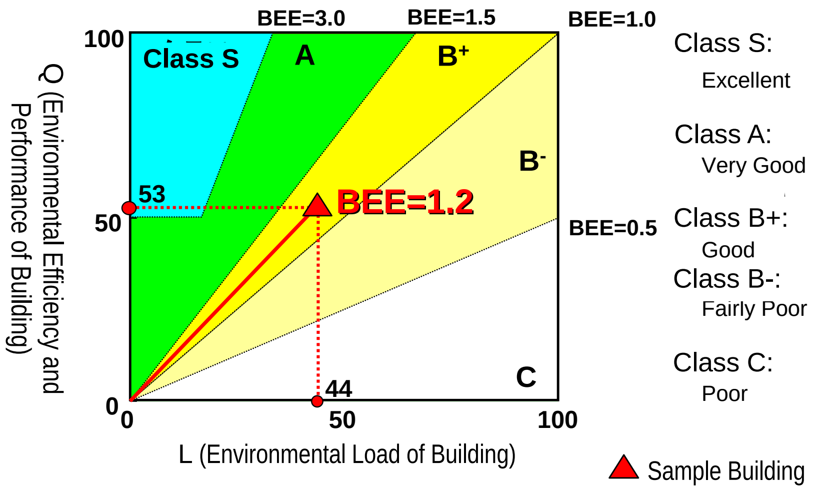

Figure 6　Environmental labeling of buildings utilizing BEE (Example)

and CASBEE is based on principles aligned with these concepts.

Here, several practical aspects that need to be taken into account when promoting dematerialization in the building sector are presented. First one is the need to make efficient use of existing building stock. The massive stock of buildings is a symbolic accumulation of the materialistic civilization of the 20th Century. This huge stock can function as a treasure chest of resources to support dematerialization in the 21st Century.

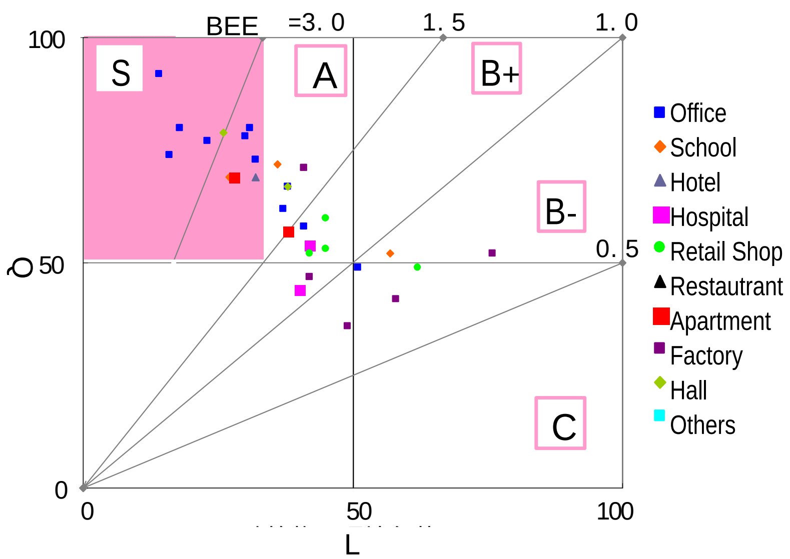

Figure 7　Trial application of BEE on buildings constructed by a major construction company

Another practical issue is achieving high efficiency for the movement of materials and for logistics systems. We know the saying of the 3-ton wedding ring; the eco-rucksack teaching that 3 tons of rock or gravel need to be moved at the gold mine to obtain enough gold for a 10 g wedding ring. Recent research into ecosystem has made it clear that the movement of massive amount of materials around the world in the various processes of industry and agriculture is a big menace to the sustainability of the ecosystem. In the building sector, too, the amount of the materials moved by constructions and logistics is estimated to be huge. The implementation of new principles and the development of new technology are required to achieve dematerialization in this area.

5. Barriers to promoting dematerialization and action aimed at overcoming them

In order to promote this dematerialization, there need to be wide-ranging links between the stakeholders, including countries, regions, industries, etc. In practice, however, there is antagonism between approaches at various levels – economic, political, cultural, etc. Many situations can be seen where we are still a long way from achieving cooperation for dematerialization. At the economic level there is fierce economic

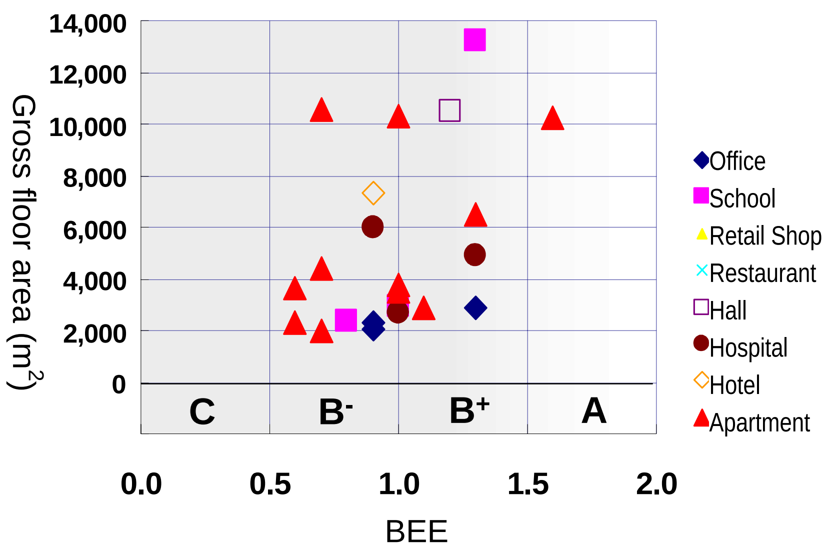

Figure 8 Assessment result of BEE based on CASBEE-Nagoya

opposition between the North and the South, and it is not easy to promote sustainable policies on an international basis. Even though Spaceship Earth looks in danger of being shipwrecked, the attitudes of the stakeholders are still very strongly focused on pursuing short term profits, and it is difficult to achieve a consensus for promoting dematerialization. The truth is that very large barriers still exist. In order to make even a small amount of progress in removing these barriers, the SB05Tokyo will be proposing an Action Plan entitled "Bridging the gaps", an effort to fill in the three most representative types of gaps (differences of opinion). The first type is the gaps between regions (e.g. the North-South divide), the second type is the gaps between environmental sustainability, social sustainability, and economic sustainability. The third one is the gaps between specialists and non-specialists in industry, government, academia, and the general public.

We must ensure that the movement to promote dematerialization is active on a broad basis, both internationally and domestically, and between specialists and non-specialists in industry, government, academia, and the general public. To achieve that, we must continue with our efforts to encourage dialogs with the objective of filling in these gaps, and to nurture cooperative relationships. If SB05Tokyo were able to contribute in that process, it would be a great success.

6. Conclusion

The global environment, which represents our ecosystem, is facing a real risk of collapse. Principles such as Factor 4, Factor 10, eco-efficiency, and CASBEE can be used to provide ways to overcome the problem. This paper demonstrates the need to assess the sustainability of buildings based on the concept of eco-efficiency, and suggests methods and prospects for achieving this by using CASBEE. Next, this paper indicates a paradigm of dematerialization for the 21st Century. In order to make that a reality, this paper describes the importance of filling in the gaps formed by differences of opinion, including the gap of economic opposition between the North and South (developed and developing economies).

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生态建筑室内环境控制关键技术

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摘　要　创造健康、舒适、高效的室内环境是生态建筑体现“以人为本”的主要目标之一。室内环境主要包括室内空气质量、室内热环境、室内声环境和室内光环境。本文详细阐述了在生态建筑规划设计、施工、验收和运行管理各阶段有效控制室内环境质量的关键技术和策略。
关键词　生态建筑；室内环境；室内空气质量；热舒适；室内声环境；室内光环境；预评估
Abstract　Creating a healthy, comfortable and productive indoor environment is one of the most important tasks in Eco-building. Generally indoor environment includes indoor air quality, thermal comfort, indoor acoustic quality and indoor light quality. The paper discusses the important technical Strategies that are applied for Eco- building during layout, design, construct, run and management phase.
Keywords　Eco-building, Indoor Air Quality, Thermal Comfort, Indoor Acoustic Quality, Indoor Light Quality，Predict technique

1　引言

20 世纪 60 年代美国建筑师保罗·索勒瑞 (Paola Soleri)把生态学(Ecology) 和建筑学 (Architecture) 两词合并为“ Arology ”,提出“ 生态建筑学 ”的新理念。“ 生态建筑 ”就是把建筑物的能源、环境与人的生理、心理甚至情感的需求综合起来考虑,在以人为核心的生态系统中达到一种供需平衡的建筑。

室内环境主要考虑的因素包括室内空气质量、室内热环境、室内声环境、室内光环境[1][2]。20 世纪 80 年代，室内环境问题逐渐凸现，不少办公楼存在严重的建筑病综合症（SBS），影响楼内工作人员的身心健康和工作效率。美国每年由 SBS 引起的误工、医疗、保险甚至诉讼所造成的经济损失高达 140 亿美元。我国目前每年仅由于室内空气污染造成的损失,如果按支付意愿价值估计,约为 106 亿美元[3]。

生态建筑是 21 世纪全球建筑发展必然趋势。生态建筑的核心是以人为本。由于现代人平均 80％-90％的时间在室内度过，而室内环境质量的提高可以避免或者降低 SBS(sick building syndrome)，减少医疗损失,降低人员的抱怨和旷工情况，提高人员的健康和工作效率。因此创造健康、舒适、高效的室内环境成为生态建筑的主要目标之一，而如何有效控制室内环境的质量则是目前生态建筑关键技术研发的主要任务之一。

2　室内环境控制的关键技术和策略

（一）室内空气质量控制

目前的研究表明有很多因素影响室内空气质量，包括建筑材料、家具家电、办公设备、新风量和新风质、空调系统、室内湿度等。控制室内空气质量的关键是如何在规划设计阶段提出合理的措

施，施工阶段实施正确的操作，验收阶段发现存在的问题，并在运行和管理阶段得到有效的保证。

1、规划设计阶段

表 1　在规划设计阶段室内空气质量控制关键技术

建筑设计	通风系统	预评估	结果
1 建筑设计： ·建筑物位置 ·周边建筑情况 ·建筑物物理模型 ·房间功能 ·房间位置 ·结构设计 2 装饰设计： ·墙体、天花板、地板装饰材料 3 室内布置： ·家具家电位置和散发强度 ·办公设备位置和散发强度 ·净化设备位置和散发强度 4 室内人员： ·人数 ·活动和工作情况 ·吸烟情况	1 系统形式： ·自然通风：门窗的位置和大小 ·机械通风：风口形式、位置 2 气流组织 3 净化方式和效率 4 新风量和新风采集位置以及新风途径 5 空调系统的形式	1 温度场 2 速度场 3 浓度场 4 湿度场 5 空气年龄场	1 房间功能的重新划分 2 房间位置合理的布置 3 门窗开启度和气密性的确定 4 风口形式和风口的位置 5 防水层和土壤隔断层的确定 6 建筑材料、装饰装修材料的确定 7 房间内的家具家电布置 8 通风系统、新风量、新风采集口位置的确定

2、施工阶段

表 2　在施工阶段室内空气质量控制关键技术

工艺	过程	设备调试
合理施工，不使用或者少使用含有甲醛等	规范施工，洁净施工，避免材料与结构造成的尘埃和湿气的积聚等	系统运行参数于设计参数相符等

3、验收与运行管理阶段

表 3　在验收与运行管理阶段室内空气质量控制关键技术

室内空气品质	通风系统	结果
1 国家国际标准中相关指标体系的建立 2 实际房间的检测 3 室内空气质量评估体系的应用	1 新风途径的检查 2 通风系统的运行和维护	1 污染源和污染途径的整改 2 改善设备的确立 3 通风系统的整改 4 建筑和系统运行维护体系的建立和监督

（二）室内热环境控制

影响人体舒适的参数一般包括空气温度、空气相对湿度、风速、辐射温度等。控制室内热舒适的关键是在满足健康、舒适、节能的基础上合理的热舒适参数的确定和自然通风与空调系统的设计和运行是否合理。

1、规划设计阶段

表 4　在规划设计阶段室内室内热环境控制关键技术

建筑设计	通风系统	预评估	结果
1 建筑设计： ·建筑物位置 ·周边建筑情况 ·建筑物物理模型 ·房间功能 ·房间位置 ·维护结构设计 ·遮阳设计 2 室内布置： ·冷热源位置、形状 ·冷热源强度 3 室内人员： ·人数 ·活动和工作情况 ·衣著情况	1 系统形式： ·自然通风：门窗的位置、大小、风量 ·机械通风：风口形式、位置、参数 2 气流组织 3 采暖空调系统的形式	1 温度场 2 速度场 3 湿度场	1 房间功能的重新划分 2 房间位置合理的布置 3 门窗开启度的确定 4 房间内的冷热源布置 5 采暖空调系统的确定

2、验收与运行管理阶段

表 5　在验收与运行管理阶段室内热环境控制关键技术

室内热环境	采暖空调系统	结果
1 国家国际标准中相关指标体系的建立 2 实际房间的检测	1 采暖空调系统的检测 2 采暖空调系统的运行和维护	1 采暖空调系统的整改 2 风口形式和风口的位置 3 系统运行维护体系的建立和监督

（三）室内声环境控制

影响室内声环境的因素主要包括辅助用房、空调设备、电梯、交通噪声、隔墙和楼板性能等，控制室内声环境的关键是合理布置噪声源和振动源、选用隔噪性能较好的外窗、重视隔墙和楼板的空气隔声性能和楼板的撞击声隔声性能等。

1、规划设计阶段

表 6　在规划设计阶段室内声环境控制关键技术

建筑设计	控制体系	预评估	结果
1 建筑设计： ·周边环境噪声调研 ·平面规划布置调整 ·室外区域降噪方案 ·房间功能及位置 ·与采光通风协调的建筑立面隔声设计 ·墙体楼板隔声设计 ·建筑构件及设备选型建议 2 室内布置： ·噪声源集中布置原则 ·噪声源减振消声处理 ·功能区间声环境控制方案	1 隔声： ·室外声屏障 ·外立面隔声 ·分户墙体楼板隔声 ·设备房隔声 ·管道井、电梯井隔声 2 消声： ·通风空调管道消声 ·大区域公共区间吸声处理 ·会议室吸声处理 ·大型设备消声处理 3 隔振： ·建筑基地隔振 ·设备隔振 ·楼板隔振	1 室外噪声传播 2 建筑隔声性能模拟 3 功能区间声学参数模拟	1 建筑群落的合理布局 2 房间功能的重新划分 3 房间位置的合理布置 3 建筑构件及设备的合理选择 4 建筑构件及设备的合理布置

2、施工阶段

表 7　在施工阶段室内声环境控制关键技术

目的	过程
·减小施工噪声污染 ·保障建筑的隔声性能	·改进施工工艺 ·维护施工机械及设备 ·封闭施工厂界 ·合理安排噪声作业时间 ·避免墙体楼板的不合理施工引入空气声罅隙 ·避免不合理施工引入额外结构传声 ·规范设备的安装及调试

3、验收与运行管理阶段

表 8　在验收与运行管理阶段室内声环境控制关键技术

标准与体系	测试	结果
1 国家国际标准中相关指标体系的建立 2 室内声环境评估体系的应用	1 室内背景噪声测试 2 建筑立面隔声性能测试 3 墙体隔声性能测试 4 楼板隔声性能测试 5 功能区间混响时间等其它参数测试	1 噪声源和声传播途径的整改 2 系统运行维护体系的建立和监督

（四）室内光环境控制

影响室内光环境的因素包括照度、亮度、均匀度、眩光、显色指数等因素，控制室内光环境的关键是自然采光的合理设计和自然采光与人工采光的合理结合。

1、规划设计阶段

表 9　在规划设计阶段室内光环境控制关键技术

建筑设计	采光系统	预评估	结果
1 建筑设计： ·建筑物位置 ·周边建筑情况 ·建筑物物理模型 ·房间功能 ·房间位置 ·外遮阳设计 2 装饰设计： ·墙体、天花板、地板装饰材料 ·内遮阳设计 3 室内布置： ·视频终端位置 ·灯具位置 ·工作平面高度	1 自然采光： ·窗户的位置、大小 ·遮阳系统的形式、规格 2 人工照明： ·灯具位置、功率、色温	1 照度分布 2 日照时数 3 显色指数	1 建筑朝向的确定 2 合理布置窗户和天窗的位置和高度和大小 3 外遮阳系统的合理选择和布置 4 装饰材料反射系数范围的确定 5 灯具选型、配光和安装

1、验收与运行管理阶段

表 10　在验收与运行管理阶段室内光环境控制关键技术

室内光环境	照明系统	结果
1 国家和国际标准中相关指标体系的建立 2 实际房间的检测	1 遮阳系统和自动调光系统的检测 2 遮阳系统和自动调光系统的运行和维护	1 遮阳系统和自动调光系统的调整 2 系统运行维护体系的建立和监督

3　展望

有效控制室内环境质量，在保证健康的前提之下进一步追求舒适和高效是发展生态建筑的一项艰巨的任务。在传统理念中，人们只重视使用后的室内环境问题，而忽略了规划设计、施工等过程的影响。室内环境质量的实现必须参照建筑生命周期方法来分析不同阶段的影响，并注重从源头进行控制。因此围绕本文所述各环节室内环境质量控制的关键技术和策略，进一步深入开展室内环境预评估技术、综合评估体系等方面的研究和工程应用对于创造健康、舒适和高效的生态建筑室内环境将发挥关键作用。

Enriched Virtual Environment:

Application to Building and Environmental Project.

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Abstract For the last several years, the French Scientific and Technical Centre of Building (CSTB) started a transversal research strategy to group the skills available in various disciplines together inside prediction and simulation tools using Virtual Reality. The main idea behind this strategy is to offer the managers of a project the ability to evaluate the project through the perception (visual, audio…) of physical valid displays. They will be able to study and test various choices from a perceptive point of view in the field of materials, lighting, acoustics, safety, electromagnetism, thermology, environmental issue as well as economic and sociology. As an example, an urban planning project will be evaluated by navigating through a numerical 3D model of the site including the display of the associated urban environment as perceived in reality. This can include a visual display (with lighting simulations), an audio display (3D audio restitution of road traffic noise and other common urban noise sources), a representation of air pollution due to road traffic noise and others pollutant emitters, a representation of local climatic comfort (as related to the temperature, sun exposure, humidity or wind). The user will also be able to evaluate using the same type of simulations the quality of a given building as perceived from inside.

Focussed on both the lighting and acoustic fields, the presentation gives an overview on the advanced modelling and restitution tools developed to provide realistic immersion for one or a small group of users. In particular, specific 3D sound simulation techniques of indoor and outdoor environments are presented.

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集成的虚拟环境：

——在建筑及环境工程中的应用

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简　介　过去几年来，法国建筑科学技术研究中心开始了一项横向的研究策略，旨在利用虚拟现实将不同领域的有用技术集成到预测模拟软件中。这一策略的主要想法在于让工程管理者通过有效的物理显示获得感性认识（视觉、听觉……），从而提高对工程的预评估能力。他们可以在材料、照明、声学、安全、电磁学、热学，以及经济社会等环境领域的某些方面找到切入点开展研究和验证。比如，一项城市规划工程可以通过原址的三维数字模型显示出来，让人们实际感知相关的城市环境。这包括一个视觉显示屏（用于光环境模拟）、一套音频播放系统（三维立体声还原马路噪声及其它城市噪声源）、一种空气污染（马路交通及其它污染源引起）的表现手法、一种当地气候舒适度（温湿度、太阳暴露状况、风力风向等）的表现手法。运用同样的模拟工具，使用者还可以到虚拟建筑内部身临其境的感觉并评价建筑环境质量。本次报告重点以光环境和声场为例，概要介绍这种为部分使用者提供虚拟实景而开发的先进的建模、还原工具。报告会特别介绍室内外声环境的 3 维模拟技术。

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Numerical models for building acoustics

Philippe JEAN

Building acoustics has to deal with a large range of problems. Such a list could include: ground-borne vibrations for underground or surface trains, air-borne sound from external sources such as cars, trains or airplanes. Indoor sources are also many: equipment (heating, elevators, piping,..) , neighbours, both generating structure- or airborne sources.

Many models have been developed to deal with these problems ranging from very sophisticated precise but usually time consuming up to very simplified, fast but cruder approaches. Some models developed at CSTB will be exposed, based on Statistical Energy Analysis (SEA), modal analysis, Finite Elements Methods (FEM), integral approaches, or ray tracing. Each approach has distinct advantages and drawbacks; combining them can lead to interesting hybrid approaches. It must be stressed that the models developed for building acoustics are often applicable or inspired from other fields such as transport noise. Some examples will be showed related to railway vibrations, aircraft noise, traffic noise or laboratory testing.

建筑声学的数值模型

Philippe Jean（菲利普·让）

建筑声学需要解决很多问题：比如地铁或地面火车产生的地表振动；汽车、火车、飞机等室外声源引起的空气传播噪声；还有很多室内声源既产生结构振动也产生空气噪声，如建筑设备（取暖系统、电梯、管道等）、邻里噪音等。

为了解决这些问题研究者开发了很多模型，有的相当复杂精确但往往过于耗时，有的则简单快速但结果粗糙。本文介绍了 CSTB 开发的一些模型，他们基于不同的方法，如统计能量分析 SEA、模型分析、有限元、积分逼近或声线追踪。每一种方法都有其特定的优缺点，综合使用某些方法可以得到意想不到的结果。需要强调的是，用于建筑声学的模型往往适用于或启发自其它领域如交通噪声，因此文中介绍的一些实例与铁路振动、飞机噪声、交通噪声或实验室测试相关。

绿色建筑评估中的权重策略研究

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摘　要　权重是绿色建筑评估中不可或缺的一个基本组成部分。通过对一个评估体系上百个不同的评估条款进行加权，权重描述了这些评估条款相互之间的相对重要性，从而产生较为严谨、反映出重要指标的对建筑环境表现评价。在绿色建筑评估领域，现有的研究多是侧重于对于加权系数的研究，而对于更为重要的，如何运用权重于绿色建筑评估这一特殊的评估系统，即权重在这一领域的应用策略和方法论，则一直缺乏系统的研究。本文介绍一项博士论文的研究成果，全面阐述了采用正确的权重策略，对于科学建立绿色建筑评估法的重要性，以及目前绿色建筑评估体系所应采用的权重策略。

一、权重及其特点

随着绿色建筑（也即可持续建筑）运动的深入发展，绿色建筑的规范化和相应的评估也日渐获推广并为人接受。自上个世纪九十年代，许多国家都相继开始建立自己绿色建筑评估体系。对于科学建立绿色建筑评估体系的各项研究方兴未艾，各评估体系也在不断地发展，成熟。权重作为评估体系的基本组成部分之一，一直是绿色建筑评估研究领域中的一个富争议的难点，而且目前现有对于权重问题的研究，大部分也只局限于对于加权系数的研究，而对于更为重要的，原则性的如何运用权重策略的问题，即权重应用的方法论的问题，在这一领域还没有较为系统的研究。

权重表示的是一个评估体系中不同评估指标的相对重要性，一般用加权系数来表示。在绿色建筑评估体系中，权重作为最基本的不可或缺的组成部分之一，有它特殊的作用和重要性。首先，权重对于一个评估体系的评估结果有很强的阐述性，权重系数对于某些相对重要的评估指标的侧重直接影响评估的结果和对评估的综合修正。

其次，权重对于指导绿色建筑实践有鲜明的导向性，权重系数可直观地将更为重要的因素表示出来，从而指导建筑实践的重点放在关键性因素，以取得最大的环境效益。

目前大部分学者对于权重的研究主要集中于如何获得正确的加权系数以应用于不同的评估体系，例如：有些学者提出应采用建筑各项表现对环境的产生的最终值（ Endpoints）（Todd, 1996）来决定评估体系各项评估指标的加权系数。但由于绿色建筑评估领域目前还不具备一个完整的科学基础，以及足够的数据资料，将建筑的设计手段与其最终对环境的各项表现联系起来，这些理论大都缺乏实施性。目前在部分评估体系仍依靠“ 共识 ”（Consensus）的方法来确立加权系数，例如：1998 年的 BREEAM 办公室分册（Baldwin 1998）

加权系数还是一个动态变化的体系，会因时间，地点其至评估自身的评估范围和侧重不同而不断变化，因绿色建筑评估实践本身也是一个动态变化的过程，不同的时间，地点和社会环境下，不论是物质环境还是人文环境对建筑表现都会有不同的侧重和要求，这就决定了对于任何一个绿色

建筑评估体系，其加权系数必须不断地更新。

二、权重策略及其重要性

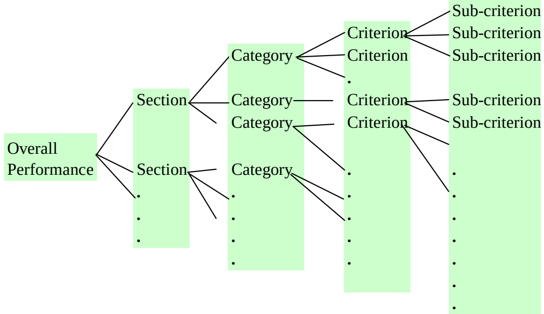
在目前这种状态下，正确地运用恰当的权重策略对的评估体系就更加重要。正确的权重策略可以减少人为确立的权重系数给评估带来的主观性，提高评估的可靠性和严谨性。权重对于绿色建筑评估体系是必需的，而每一个评估法也各自采用某种权重策略。在现有绿色建设评估体系中可以是到大致两种采用权重的方法：一种为隐含权重的“简单评价”(Simple Rating)式，另一种为明确使用权重的“明确权重”（Explicit Weighting）

“简单评价”式的权重方法，在绿色建筑评估系统的初期被较多地采用，例如最早的 BREEAM 版本(Baldwin 1990)，香港的 HK-BEAM 等，利用每个评估条款的评分来表示条款本身的相对重要性。“明确权重”在评估系统发展到一定程度才开始出现，即是在评估条款评分系统之外，另外赋予评估条款不同的加权系数来表明其相对重要性。较早的采用明确权重的是加拿大的“BEPAC”（Cole et al 1993)，其后 BREEAM 98 办公式分册和加拿大的 GBTOOL 也都是采用了明确权重来给评估系统加权。“简单评价”的权重方法具有简单直接、易于理解的优点，但也同时因其不能更为深入地表达不同评估条款的重要性，而不适应绿色评估的发展。“明确权重”与“简单评价”相比，具有将评分系统与权重系统明确分开，从而使评估系统更为严谨。评估更为明确的优点，随着绿色评估的发展和成熟，权重及权重方法更加受到重视，目前的绿色建筑评估法大部分都采用明确的权重系统。

即使采用相同的权重方法，不同的评估体系都各自采用不同的权重策略，例如美国的 LEED 和香港的 HK-BEAM（BEC 1996-2003）都是采用的“简单评价”的权重方法，但它们的权重策略各自不同。LEED 给予大部分评估条款相同的评分/权重，只对少数明显重要的评估条款大幅增加评分/权重；HK-BEAM 则是给不同的层级评估条款加以不同评分，并通过对关键的评估条款增加其下级条款及评分的方法，达到提高此评估条款总评分和权重的目的。

随着绿色评估的实践的推广和对评估体系统研究的深入，评估体系的架构和条款内容都日趋定型，大部分评估体系都采用“层级归纳”的方法，从建筑的整个生命周期的过程把建筑对物理环境及人文社会的影响因素加以归纳、评分，再赋予权重体系，组成个体完整的绿色建筑评估法（如图1）。 较为典型的是加拿大的 GBTOOL 系统（Larsson & Cole 1998-2002)。这样的评估体系，评估条款往往超过上百个，较之早期的评估系统远为复杂，如何采取适当的权重策略成为这些评估体系能否科学、严谨地对绿色建筑的表现进行评估的关键。

图1. The Heriarchical Structure of GBTool98



三、个案研究

本项研究选择了在评估架构和权重策略较为具代表 GBTOOL 对绿色评估的权重策略进行了深入研究。GBTOOL 是由加拿大发起的“绿色建筑挑战”（Green Building Challenge）运动建立和发展的。自其问世以来，成为国际绿色评估领域研究讨论的平台。其清析的架构和明确的权重系统更成为不少地区性绿色建筑评估体系的样板。但由于在 GBTOOL 的发展和建立过程中缺乏对于权重系统的系统的深入研究（Cole 2001），GBTOOL 一直未有一套成熟适当的权重策略。1998 年 GBTOOL 刚刚问世时采用的是给其所有的四级评估条款加权的权重策略（如图 2），其结构及权重方法非常类似 Saaty 的分析层进法（AHP） (Saaty 1990)，一种多因素决策方法(Multi-Criteria Decision-Making Process)。但是，经过一轮的使用和测试，许多学者指出 GBTOOL 的权重系统存在严重的问题：过分复杂，过多地以主观的加权系数影响评估的分数和最终结果，并使评程过程变得难以直接被人理解，评估结果变得不可信。

为了解决第一轮测试反馈出来的权重系统的问题，GBTOOL 的开发者决定在第二轮的 GBTOOL 2000 减少两级加权，即第一级“环境表现小节” 和第二级“环境表现类别”，只保留第三级和最后一级详细评估条款的权重。然而这项决定并非是经过深入的研究得来的，这个权重策略是否是正确没有任何研究基础来确证。

本项研究因此将研究的焦点放在对 GBTOOL 的权重策略的研究上。对于这样一个较为典型的评估架构体系，找到其正确的权重策略不仅直接有利于其本身评估系统的发展，更对其他地方性绿色评估系统的建立和发展起到重要的参考作用。

本文作者以香港为背景，选择了三幢建筑用 GBTOOL 的第二轮版本 GBT2K 进行了详细的个案研究，并将其中一个办公室的个案与用 HK-BEAM 的评估进行权重系统和策略的比较。研究结果显示：GBTOOL 中第二级评估条款，即环境表现类别（Category）一级评估条款在评估中是至关要的一级，也是评估架构中的关键一环，代表了建筑每一大类项中的环境综合表现。对这一层级的评估条款进行加权则可以通过权衡建筑在不同综合类项的环境表现达到对绿色建筑的准确的综合性评价，现有的研究也发现（Cole, 2001），各个国家在发展地方性评估系统时，在这个级别所采用的共识性加权系数非常接近，说明在全球化影响之下，各个国家和地区的环境现状是相似的，也因此使等各个不同的评估方法较为容易在这一级别的加权系数达到全球性的共识。

而第二轮的 GBTOOL 版本 GBT2K 却恰恰去掉了这一层级的权重。个案研究表明，没有这一级的加权，GBT2K 的评估过程明显被中断，虽然有较低的两级的权重系统，但各“环境表现类别”之下下的评估条款无与其他“类别”下的条款相比较，实际上造成了整个评估权重系统的瘫痪。一些处于“类别”层级的重要条款也未能收到足够的加权。没有了对“环境表现类别”的权衡比较，整个评估也不能达到对建筑表现的最终的综合评价。研究证明，GBTOOL 为解决权重系统过于复杂的问题而解除对“环境表现类别”这一关键层级评估条款的加权是错误的。

个案研究还发现，权重明显地影响评估过程和评估结果，甚至可以超过人们可以接受的程度，在绿色评估系统中越高级别的权重对评估影响越大，而经多重主观性的加权积累以后，每项评估条款对于评估体系最终的取重值变得难以理解和接受，也降低了评估价评估的透明性和评估过程的可

靠性，因此，在绿色建设评估目前这个阶段，应用权重应非常慎重。

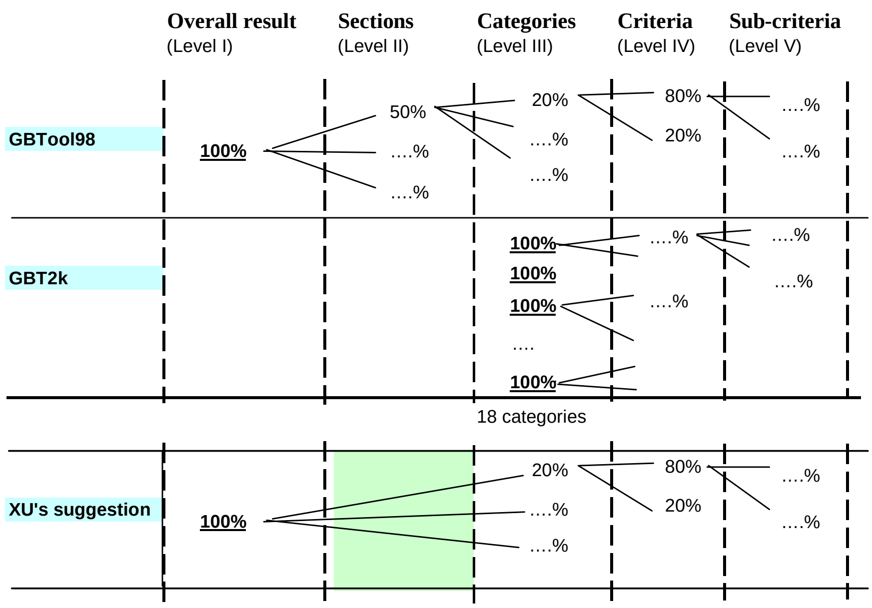
四、建议权重策略性

在进一步的研究中，作者试图给 GBTOOL 的权重系统所面对的困境提出解决办法。首先，必须把“ 环境表现类别 ”这级条款重新加入权重体系，并可参考“ 共识 ”的加权方法进行加权。前面的研究已经证明了这一级权重的重要性，在 GBTOOL 中给“ 类别 ”以共识的方法加权，可以使重要的评估条款在这一级别获得足够的强调，并可使相对不重要、甚至不适用的条款从评估中完全剔除。“ 共识 ”的加权值可减少主观性，提高权重和评估系统的可靠性。但是，单纯恢复“ 环境表现类别 ”的加权还不能完全解决 GBTOOL 所面对的权重系统过于复杂的问题。

研究中发现，GBTOOL 第一级评估条款，即“ 环境表现小节 ”（Sections）在 GBTOOL 的评估架构中只是起到传递权重的作用，对于评估本身并无实质性的参与。减少这一级别的权重不仅可以使对“ 类别 ”的比较加权更加直接、清晰，还可以大大降低权重系统的复杂性，和由于多一层加权可能带来的主观性。因此建议去掉的这一层级别的权重。

绿色建筑评估系统低层的评估条款在绿色评估体系中是最基础的详细评估条目和具体的要求，由于各个地区之间环境和建筑实践的差异，各个地区的评估法在这一层评估条款的规定和要求大不相同。又由于通常这一级别的条款数量较大，给这些条款的加权应采用较为慎重的态度。过多的加权可能会因过多的主观性令评估失去控制，导致评估结果的不可信。因此研究建议参考 BEEAM98 办公室版本，对这一层级的加权采用“ 温和 ”加权的策略，即除特别需要强调的评估条款之外，其他评估条款都采取等值加权的策略，即“ 简单评价 ” 的方法。这样，建议的权重策略将加权的重点放在了“ 环境表现类别 ”这一级别的评估条款，解除了这一层级以上“ 环境表现小节 ”的加权，同时放松对低级评估条款的加权，形成了一套严谨的权重系统（图 2）。

图 2　Suggested Weighting Strategy for GBTool



经过进一步深入的研究测试和个案分析，证实上述权重策略可大大提高 GBTOOL 评估系统的权重系统的严谨性，评估过程的透明性以及评估结果的可靠性，证明所建议的权重策略能够解决原本 GBTOOL 的权重系统的大部分问题，是可靠而且适用的。

结论

本项研究第一次明确提出权重策略对于绿色建筑评估体系的重要性，尤其在目前绿色建筑评估和环境影响研究还不是很成熟的阶段，采用恰当的权重策略对于建立和发展科学严谨的评估系统至关主要。GBTOOL 后来的发展也证明了此项研究建议的权重策略是正确的，在香港政府最新研究的 GEPAS 绿色建筑综合评估体系也采用了作者建议的权重体系。绿色建筑评估仍属于一个较新的领域，权重也仍是这一领域最富争议课题，有许多问题仍待大量深入的研究。

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利用区域网络模型对室内环境的研究

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摘 要 本文介绍了用于研究建筑物内部气体流动情况及污染物传递的多区域网络模型、及其使用条件和理论基础，并针对不同条件下室内污染物的传递情况进行分析。以一幢高层住宅楼为原型，利用多区域模型划分成不同的气流途径，内部的空气流量和污染物浓度与风速、风向、室内外温差及不同的通风方案有关，通过模拟得出污染物浓度随季节的变化趋势、迎风面及背风面窗户的启闭对污染物传递的影响、当室外风速不变而室内外温差的变化时，房间是否采用机械排风对室内污染物浓度的影响。
关键词 区域网络模型； 室内空气品质；中性压力面；烟囱效应

Study on the indoor environment by using multizone modeling

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Abstract Multizone modeling used to study airflow and contaminant transport in building, was described. Assumptions and basic theory were also introduced and indoor contaminant transport in different conditions were analyzed. A tall building was modeled by using multizone method in order to develop different airflow paths. The results show that interior airflow rates and contaminant concentration are related to wind direction, wind speed, indoor-outdoor temperatures differences and various ventilation strategies. Effects of different seasons and side window states would influence the contaminant concentration. Furthermore, When outdoor wind speed is constant and the indoor-outdoor temperatures differences are variable, the effect of mechanical exhaust would affect the pollutant concentration.
Keyword multizone model, indoor air quality, neutral pressure plane, stack effect

0 引言

建筑物内部气体的流动及污染物的传递是由于压差的存在而使气流经过外墙的孔洞或不同区域的分隔间而引起的。压差由以下因素造成：风、热浮力、机械通风系统产生的气流。对于一幢建筑物来说，只要是知道气体渗漏特性、通风系统的气流量、天气情况、污染源强度，多区域气流及污染物传递模型就能预计气流、污染物在每一个区域的传递情况及污染物浓度水平。

多区域气流及污染物扩散模型用于研究多层建筑物内部气体流动情况、预计气流图形及污染物浓度水平，评价不同情况下建筑物通风系统的性能[1]。模型在质量守恒的基础上得到一系列非线形方程[2]，每个节点上在 New-Raphson 方程基础上用迭代的方法求得压力，再用这些压力值在给定的渗漏值的基础上计算稳态的气流量，最后再把气流量、污染物强度用于其他的污染物传递机制

中，通过它可以计算建筑物内每个区域的污染物浓度。

本文的目的就是利用多区域模型来模拟高层建筑物内污染物传递及氡气扩散情况，从而分析高层建筑内部的空气品质。

1 区域网络模型的建立

多区域网络模拟把整个建筑物作为一个系统,而其中的每个房间为一个控制体(或称网络节点),各个网络节点之间通过各种空气流通路径相连,利用质量、能量守恒等方程对整个建筑物的空气流动、压力分布和污染物的传播情况进行研究。分析在不同的通风条件下室内污染物对人体的影响。区域模型使用的前提条件是：

1）各区域内空气混合均匀：将各区域分别视为单一的节点,区域内温度、压力和污染物均匀一致。不考虑区域内的局部影响。

2）满足质量守恒：在稳态模拟过程中，每一个区域内根据质量平衡原理建立非线性代数方程,从而在多区域内构造非线性方程组,并最终求得各区域内压力和区域间流量。而在瞬态模拟中，由于区域的空气密度、压力或污染物的量产生变化致使总的质量增加或降低，但严格地说,其瞬态模拟也是一种准稳态流动，因为在模拟过程中认为区域内的空气质量并不随时间发生变化视为定值。

多区域模型是在质量及能量守恒的基础上来研究区域之间的压力及气流量的分布情况，从区域 i 到区域 j 的气体流量为 $F_{i,,j}$，它是沿气流途径的压力差($\Delta P_{i,j}=P_j-P_i$)的函数，压力差的存在由浓度、高度、风速及风量的大小所造成的。

房间的污染物分布是一个复杂的过程，主要取决于气流性质、传热、通风换气、空调系统、流体的流入和流出、化学反应以及吸附沉降等的影响。我们可以选择一个房间、房间的一部分或多个房间作为一个区域，区域内的温度保持一致，污染物在区域 i 的质量为：

$$m_{\alpha i}=m_i C_{\alpha i} \tag{1}$$

式中：m_i——区域的空气质量

$C_{\alpha i}$——污染物的质量百分比

假定该区域的通风效果很好，因此区域内的污染物浓度一致，且房间的污染物的浓度很低，不足以改变室内空气中的污染物混合浓度。

污染物方程：

$$\frac{dm_{\alpha i}}{dt}=-R_{\alpha i}C_{\alpha i}-\sum_j F_{ij}C_{\alpha i}+\sum_j F_{ji}(1-\eta_{\alpha ji})C_{\alpha j}+m_i\sum_\beta K_{\alpha\beta}C_{\beta i}+G_{\alpha i} \tag{2}$$

式中 R_{ai} 一—排出系数 R_{ai} C_{ai}——污染物排出量

F_{ij}——从 i 到 j 的气流量 $\Sigma_j F_{ij}C_{aj}$——从区域内流出污染物的量

$\eta_{\alpha ji}$——从区域 j 到 i 的过滤效率 $G_{\alpha i}$——污染物产生量

$\Sigma_j(1-\eta_{\alpha ji})F_{ji}C_{\alpha j}$——进入的气流量

$m_i\Sigma_\beta K_{\alpha\beta}C_{\beta i}$——与其他污染物 $C_{\beta i}$ 一次化学反应量

上述微分方程也可以写成差分形式：

$$m^{*}_{\alpha j}=m_{\alpha j}+\Delta t(\sum_{j}F_{ji}(1-\eta_{\alpha ji})C_{\alpha j}+m_{i}\sum_{\beta}k_{\alpha\beta}C_{\beta i}+G_{\alpha i}-(R_{\alpha i}+\sum_{j}F_{ij})C_{\alpha i}) \qquad (3)$$

式中*表示时间为 t+Δt 时的值

上述方程存在两方面的局限，第一：所研究区域的气体满足质量守恒，这是建立在区域温度不变和污染物质量浓度很低的基础上。第二：由于使用的是线性分析的方法限定了各种动力学模型的建立。

多年来，为了进行污染物的分析，人们一直致力于研究室内气体流动的情况，已发表了多篇针对多区域气体流动的计算程序[1]。而多区域模型中的气流计算是在 AIRNET[3] 的基础上发展起来的。

基本方程：

从区域 j 到 i 的气流量为 $F_{j.i}$(kg/s)，沿空气流通途径的压力降为 P_j-P_i，通过房间过滤器的气流量为 f，则有：$F_{j.i}=f(P_j-P_i)$ （4）

空气的质量为 m_i(kg)，在区域中用理想气体状态方程表示为：

$$m_i=\rho_i V_i=\frac{P_i V_i}{R\ T_i} \qquad (5)$$

式中： V_i——区域的容积　　P_i——区域的压力　　T_i——区域温度

R——空气的气体常数 R=287.055(J/kg.K)

对于瞬时解亦遵循质量守恒：

$$\frac{\partial m_i}{\partial t}=\rho_i\frac{\partial V_i}{\partial t}+V_i\frac{\partial \rho_i}{\partial t}=\sum_j F_{j.i}+F_i \qquad (6)$$

$$\frac{\partial m_i}{\partial t}\approx\frac{1}{\Delta t}\left[(\frac{P_i V_i}{RT_i})-(m_i)_{t-\Delta t}\right] \qquad (7)$$

式中：m_i——区域中的空气质量　　$F_{j.i}$——区域之间的气流量（从 j 到 i 为正）

F_i——没有气体流动的情况下进入或排出区域的气体量

假定准稳态条件下 $\Sigma_j F_{j.i}=0$，由于方程（4）中的函数可能是非线性的，因此可以使用 New-Raphson 方程通过一系列线性的迭代而解非线性方程，新的区域估计压力为：

$\{P\}^{*}=\{P\}-\{C\}$ （8）

式中：{P} ——当前估计压力；

{C} ——修正项的值可以由下式求得：

$[J]\{C\}=\{B\}$ （9）

式中：{B} ——列向量　　$B_i=\Sigma_j F_{j.i}$ （10）

[J] —— N×N 矩阵　　$J_{i,j}=\sum\frac{\partial F_{j,i}}{\partial P_i}$ （11）

对线性方程（9）进行迭代求解，直到产生收敛值即求得压力值，计算的过程中使用了高斯消元法

和稀疏矩阵法，并采用了对称的 Jacobian 矩阵。

模拟中允许区域有已知和未知的压力，在解系统方程和方程（9）时，区域的压力保持不变，周围或外界的压力也是定值。

质量守恒使 New-Raphson 方程迭代产生收敛的解，如果针对当前所有区域压力 $\Sigma F_{j,i}=0$，则解是收敛的。当 $\dfrac{\left|\sum_j F_{j,i}\right|}{\sum_j \left|F_{j,i}\right|}<\varepsilon$ 会使收敛更加迅速和准确，ε 的选取需要考虑计算流体的运用条件，如能量守恒。为了加速收敛的过程，常采用引入松弛因子ω的方法，方程（8）变换为：

$$\{P\}^{*}=\{P\}-\omega\{C\} \tag{12}$$

其中松弛因子ω=0.75 即能满足要求，虽然此值实际上并不是最优值，但是效果却很好。

满足质量守恒的各区域的线性方程用如下形式表示为：

$$[A]\{P\}=\{B\} \tag{13}$$

式中：[A] 与方程（9）中的 [J] 同样都是稀疏矩阵

当解一系列相似的问题或连续的稳态后出现瞬时变化时，用前一个解的值作为下一个的初始值。

2 区域模型进行污染物扩散研究实例

2.1 固定污染源的模拟

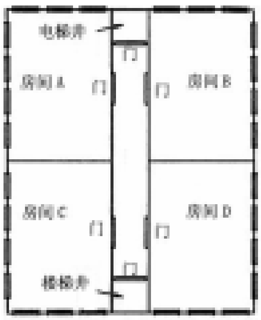

图 1 楼面布置图

一幢高层的住宅楼包括一个地下室，水平方向为 30×22.5 米，每层高度为 2.5 米，地下室高 2 米，楼面布置图见图 1。

建筑物每层有四个房间（一边两间），中间有中央大厅，大厅的尽头是楼梯井和电梯井，楼梯井和电梯井从地下室到顶水平面积为 2.5m×5m，大厅为 26m×2.5m。地下室除了楼梯和电梯的外墙没有内部分隔，关闭所有的大厅到房间、地下室到楼梯或电梯的门。竖井被模拟为单层垂直区域。

建筑物的主要渗透面积：

外墙 $3.0cm^2/m^2$，入口门 58 cm^2，房间门 75 cm^2，房间窗户 7.5 cm^2，内墙 2.0 cm^2/m^2，内部楼层 0.5 cm^2/m^2，电梯及楼梯门 150 cm^2。

所有的渗透值建立在参考压力为 $4P_a$、扩散系数为 1.0 的基础上，且所有的渗透途径的压力幂指数为 0.6。假定室内温度为 22℃，送风温度为 15℃。表 1 列出了室外温度及风况。室外进气量占整个送风量的 25%（$82.4m^3/s$），室外气体交换量为 0.94ACH。

表 1 室外气体温度及风况

	室外气温（℃）	风速 km/h（风向）
冬季	-13	13.5（西）
夏季	27	12.1（东）

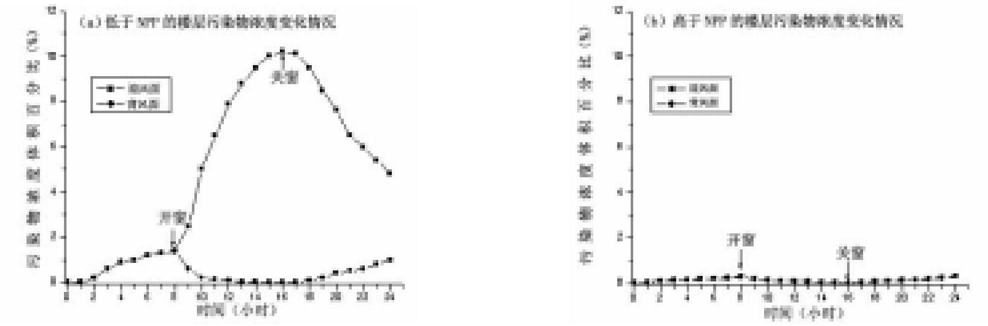

图 2　冬季窗户的启闭对污染物浓度的影响

假定楼内具有持续的污染源，最初的测量浓度为 0%。图 2、3 所示污染物冬、夏浓度变化情况（这里采用了切断污染源部分的回风）。可以看出，对于所有的高于或低于 NPP（中性压力面 neutral pressure plane，即室内外压力相等的表面）的楼面来说，冬季打开位于污染区背风面的窗户是很有效的降低污染物浓度的方法。当楼层低于 NPP 时，如图 2（a）所示，由于烟囱作用、HVAC 系统的送风及风况的影响，楼层背压面的复合压差为负值，因此当窗户打开时，能够有效的阻止污染物的进入，而打开迎风面窗户会使房间内的污染物浓度增高。但是当楼层高于 NPP 时如图 2（b），这种现象几乎不存在，这是因为烟囱效应及风的影响所造成的。

夏季，打开背风面窗户仍不失为一种有效的方法。从图 3（a）可以看出，当楼层 NPP 以下时，夏季开启背风面窗户的效果与冬季几乎相同；当楼层在 NPP 以上时，如图 3（b），由于楼层的背风面的复合压差有时为正值，从而导致了通过窗户有两路气流：从上部进入的气流及从下部流出气流，因此当窗户打开时污染物会进入房间。从图中也可以看出，夏季的污染物浓度大于冬季。

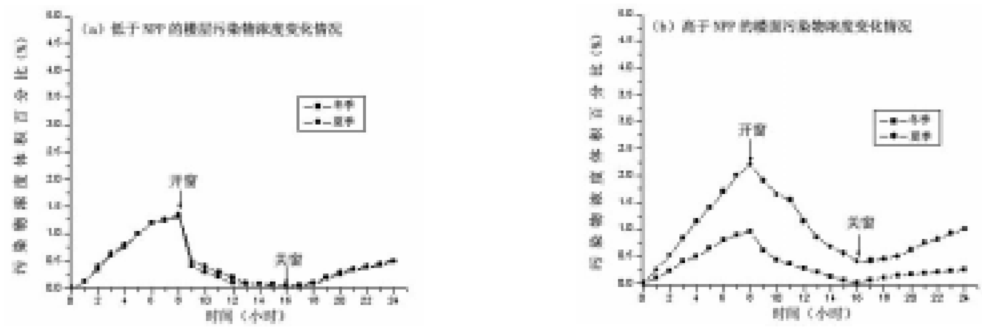

图 3　冬、夏季开启背风面窗户时，污染物浓度变化情况

2.2　室内氡气扩散的模拟研究

还是利用上例中的大厦模型，在这里我们研究氡气的进入和传递，为了模拟大厦内氡气的进入，在基础部分使用氡气发生源模型，模型假定氡气的产生量与地下室和室外的压力差有关，即氡气的进入量等于氡气系数乘以压力差 n 次幂，地下室的氡气系数假定为 0.02Bq/s.P_a/m^2，压力的幂指数假定为 1.0。氡气发生源模型也需要一个地下室内通过土壤和室外的气流途径的气体渗透系数。模拟中：参考压力为 4P_a，地下室渗透区域为 0.0085 cm^2/m^2，压力幂指数为 1.0。

进行的模拟在建筑物最底层区域增加了所谓的土壤层区域。土壤区与最底层的连接有最小的气流阻力，与外界的连接的阻力为地下室的面积乘以 0.0085 cm^2/m^2，所有模拟过程中室外的氡气浓

度假定为 10Bq/m^3。建筑物内稳态区域的氡气浓度是根据给定的气象条件和通风系统的气流量所计算的气流量的基础上得出的。

图 4 所示在无风的条件下，室内外的温差从-10℃~30℃变化时，氡气的平均浓度在地下室、第 2 层和顶层的变化情况。从图中可以看出，当温差小于或等于 0℃时，没有氡气从土壤进入地下室。当温差为正值时，地下室的压力下降，氡气的浓度逐渐增加，随着温差的进一步增大氡气的浓度不断上升，这主要是由于烟囱效应所造成。顶层及整幢建筑的氡气平均浓度都相应的增大。但是第 2 层内的氡气浓度并没有增加。这是因为从地下室或更低层来的烟囱驱动气流直接进入了电梯井或楼梯井，通过它们把氡气带入了更高的楼层。第 2 层内氡气的浓度在温差为-10℃时，略大于室外浓度 10Bq/m^3，而当温差为正时却略低于 10Bq/m^3，这是由于温差不同时，室内外气体密度不同所造成的。

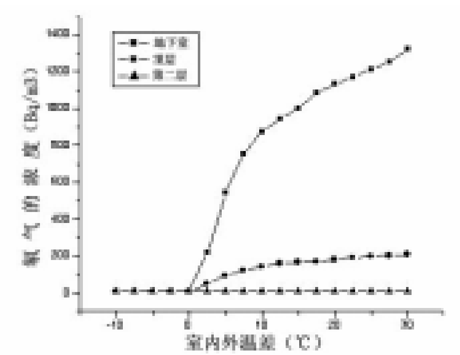

图 4　风速=0m/s，室内氡气的模拟结果

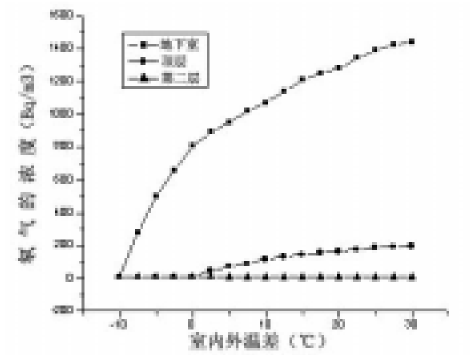

图 5　风速=0m/s 且有机械排风，室内氡气的模拟结果

图 5 所示，当室外风速为 0，排气扇气流量为 47L/S 时，氡气的浓度随室内外温差变化的情况。从图中可以看出当温差为负值时，没有氡气从土壤进入建筑物内，当温差为正值时，地下室的压力下降，随着温差的进一步增大氡气的浓度不断上升，这主要是由于烟囱效应所造成。顶层及整幢建筑的氡气平均浓度都相应的增大。但是无论温差怎么变化，2 层内的氡气浓度均变化不大，这主要是因为烟囱驱动气流的作用。比较图 4 和图 5 可以看出：若房间装有排气扇，则氡气的进入量比没有排气扇时高，但是由于排气扇的操作相应的增加了室外气体交换量，因此建筑物中总的氡气的浓度反而会下降。

3　结论

本文通过采用多区域网络模型来研究大厦内污染物在冬季、夏季的浓度变化情况及室内外温差、机械排风对氡气产生量的影响得出：建筑物中，使污染物最小化而采用的措施与不同的通风方案及所研究区域的位置有关，结果表明采用下列方法可以阻止污染物的扩散：

1.关闭污染源部分的回风，如果可能的话，关闭其送风。

2.冬季，打开背风面通往外界的窗户对降低所有的楼层污染物浓度都有用。夏季，这种方法只适用于低于 NPP 的楼层，高于 NPP 的楼层则仍会受到影响。

3.当室内外温差增大时，靠近地下室楼层中氡气的浓度不变，，而顶层楼内的氡气浓度不断上升，可以采用机械排风降低氡气的浓度。

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住宅内空气品质的维护

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摘　要　引用世界卫生组织的定义，指出健康住宅的宗旨是为了使居住在其中的人们获得幸福和安康，分析了造成住宅内空气污染的主要原因是污染源的散发和不充分的通风，介绍了五个基本的控制策略。
关键词　空调病；健康住宅；室内空气品质；控制策略

The maintenance of the residence inside air quality

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Abstract　Quoting the definition of World Health Organization, aim that point out the health residence lives in for the sake of people who make among them the winning is happy with the peace and health; Analyzing to result in the main reasons of the air pollution in the house are the distribution of the contaminated sources and deficient ventilation; introducing five basic control strategies.
Keywords　disease by air-condition，　healthy residence, indoor air quality, control strategy

1　引言

随着人们生活水平的提高，越来越多的居民家里安装了空调，鳞次栉比的现代化写字楼和办公室更是空调、冷气一应俱全。人们的夏日似乎过得很清凉、惬意。正如世间万物利弊共存，它在给现代家庭带来舒适与欢乐的同时也有可能给人们的健康带来危害。研究人员调查发现，在有中央空调的办公楼内工作的人员中，有 98%在上班过程中发生不同程度的疲惫、乏力、头痛、头晕、耳鸣、胸闷与味觉异常等症状。追踪观察还发现，此类人的感冒、支气管炎、肺炎、高血压发病率明显高于其他人群。长时间呆在恒温室内，使他们对室外气候的变化过分敏感或不适应，一旦离开空调环境，会比一般人更容易患呼吸道疾病、感冒、眼睛与皮肤感染、皮肤过敏及中枢神经系统功能紊乱等。这种不适综合症就是人们常说的“ 空调病 ”。同时还会使人已患有的病情加重，像冠心病、高血压、哮喘、感冒等症状，严重威胁人们的身体健康。

由于室内空气质量与人们的健康息息相关，所以人们便提出了健康住宅的概念。根据世界卫生组织的定义[1]，“ 健康住宅 ” 就是指能使居住者 “ 在身体上、精神上、社会上完全处于良好的状态的住宅 ”，其宗旨就是为了使居住在其中的人们获得幸福和安康。近几年来大量的科学实验表明，居住建筑和其他建筑物内的空气污染可能比在超大工业化城市的室外的空气污染更为严重。另一些研究表明人们大约 90%的时间停留在室内。因此，对绝大多数人来说，健康危险可能很大程度上归因于室内空气污染而不是室外的。

2　造成室内空气品质恶化的原因

室内污染源散发的气体和颗粒物是造成室内空气品质问题的首要的原因。随着能源危机的加重，建筑物热耗越来越受到重视，现有建筑被加强改造，建筑管理人员也开始减少新风量，这样不充分的通风，既不能引入足够的新风来稀释室内污染源的散发，也不能带走室内污染物，所以可能增加室内污染水平。另外，高温高湿的环境也可能加快某些污染物质的散发，增加污染物浓度水平。

2.1　污染源

在每个居住建筑内都有许多污染源，这些污染源主要包括室内和室外两部分[2]，流动空气可使空调房间内悬浮的颗粒物质增加，过敏因子明显大于传统建筑。现代建筑的装饰，也会使建筑表面在空调送风的影响下，散发更多的刺激性气体，如高档家具、壁纸、化纤地毯中散发的有毒气体甲醛，直接影响人的健康。具体的污染源有：

室内来源主要有消费品和化学品的使用、建筑和装饰材料以及个人活动，如

①各种燃料燃烧、烹调油烟及吸烟产生的 CO_2、NO_2、SO_2、可吸入颗粒物、甲醛、多环芳香烃（苯并[a]芘）等。

②建筑装饰材料、家具和家用化学品释放的甲醛和挥发性化合物、氡及其子体等。

③家用电器和某些办公用具导致的电磁辐射等物理污染和臭氧等化学污染。

④通过人体呼出气、汗液、大小便等排出的 CO_2、氨类化合物、硫化氢等内源性化学污染物，呼出气中排出的苯、甲苯、苯乙烯、氯仿等外源性污染物；通过咳嗽、打喷嚏等喷出的流感病毒、结核杆菌、链球菌等生物污染物。

⑤室内用具产生的生物性污染，如在床褥、地毯中孳生的尘螨等。

室外来源主要有

①室外空气中的各种污染物包括工业废气和汽车尾气通过门窗、孔隙等进入室内。

②人为带入室内的污染物，如干洗后带回家的衣服，可释放出残留的干洗剂四氯乙烯和三氯乙烯；将工作服带回家中，可使工作环境的苯进入室内等。

任何单个来源的相对重要性取决于它散发了多少规定的污染物以及这些散发物有多危险。

2.2　通风量

如果室外新风量太少，污染物可能累积到引起健康或舒适度问题的水平。考虑到室内的污染物会“渗透”到其他房子而按最小新风量设计和建造的房子，其污染物水平可能比其他房子的要高。

3　如何控制室内的污染水平

室外空气进入室内的方式：渗透、自然通风和机械通风。在一个已知的渗透程序中，室外空气主要通过缺口，结合处以及墙壁、地板和天花板以及窗户和门的周围的裂缝等进入室内。在自然通风中，空气通过开放的窗户和门进入室内。由于室内外的温差以及风的作用造成了与渗透和自然通风有关的空气运动。最后，还有许多机械通风装置，例如浴室和厨房的排风扇。当只有少量的渗透、自然通风或者机械通风，且换气效率很低时，污染物水平可能会增加。

这里介绍五个基本的控制策略。

3.1　源头控制

通常改善室内空气品质最有效的方法是消除单个的污染源或减少它们的排放。有些污染源，像

石棉，能够被密封起来，其他的，像煤气炉，可以重新校准以减少其散发。在许多案例中，在保护室内空气品质上，源头控制比增大通风量还要合算，因为增大通风可能增大能量消耗。选择和开发绿色建筑装饰材料能有效控制室内空气污染 [3]。自德国使用环境标志“ 蓝天天使 ”以来，世界上已有 20 多个国家和地区对建筑装饰材料实行环境标志制度。我国 1993 年开始实行环境标志制度，1997 年上海市首先公布了“ 健康型建筑涂料 ”标准。目前，我国应制定“ 健康建材 ”的国家标准，积极开发绿色建材产品，借鉴日、美等国家经验，将光催化技术应用到新型建筑装饰材料中，加大环境自净材料的开发与应用。

3.2　改善通风

在降低室内空气污染浓度方面，室内污染源的控制也并不总是最有效的方法[4]，彻底稀释尘粒，增大通风量往往被认为是很有效的。大多数供热制冷系统，包括电加热空气系统，并没有机械地引入新风。当天气允许或者运行带有通风控制开关的窗式空调的时候，打开窗户和门，开动窗户或顶楼的风扇以便增大通风换气率。浴室和厨房的排风扇也可以直接将室内的污染物转移到室外，并且也增大了通风换气率。建筑设计人员在建筑设计阶段应选择合理的自然通风以改善室内环境。如利用门窗对位，促进水平穿堂风的形成；利用风管、风塔或高层建筑的中庭进行灌风或抽风，以促进垂直通风等。增大通风换气次数，特别是新装修好的房间一定要注意长时间的通风。

增大室外新风量相应会增大能源花费，而能源使用需求量越大，则污染物水平越高，全球不可再生能源越少，因此必须在能源利用上建立平衡，增大室外新风的同时充分利用热回收装置。国内外关于住宅内通风换气次数标准见表 1。

表 1　国内外关于住宅内通风换气次数

建筑类型	中国(次/h)	德国(次/h)	英联邦(次/h)	日本(次/h)	美国(cfm)
居室	1	3-6	4-6	6	50
厨房	3	6-8	20-60	15	100
浴室	0.5-1	4-6	6	6	50
卫生间	1-3	4-6	6-8	10	-

注：1.国内通风标准选用的是《简明通风设计手册》[5]规定的民用建筑的换气次数；
2.美国的标准选用的是 ASHRAE Standard 62.2-2003[6]规定的住宅的通风标准。

由表 1 我们可以看出，国内的换气次数远远低于国外的换气次数，这可能与国内的建筑结构，生活水平有关。

3.3　重视厨房卫生

住宅的厨房、卫生间可设置烟道通风道，以利于有害物向室外排放。采用变压式公用排气道以及与其配套运行的深筒油烟机组成排气系统是解决住宅厨房排气通畅、排除油烟污染、防止串烟串味的有效措施。灶具所处位置宜二面靠墙，以减少进入油烟机的空气量，提高排油烟效率。操作中尽量使用精制食物油，多使用微波炉烧烤食物，烹调时不要让油加热冒烟，烹调结束后至少延长排气 10 分钟。与厅、室相联的开厂式厨房要有间隔，采取柜或玻璃隔断，装设玻璃推拉门等，应尽量使油烟不溢入其它房间。

3.4　加强室内空气的净化处理措施

吸附技术是目前去除室内挥发性有机物最常用的控制技术，常用的吸附剂有颗粒活性炭、活性炭纤维、沸石、分子筛、多孔粘土矿石、活性氧化铝及硅胶等，其中又以颗粒活性炭、含高锰酸钾的活性氧化铝最为常用。结合家庭装饰，可将吸附剂放置于适当位置且考虑定期更换，能有效净化室内空气。还可使用空气清洁机，市场上有许多型号和尺寸的空气清洁机，价格不等。有些空气清洁机在颗粒物的去除上有很高的效率，然而其他的，包括大多数的桌面式其效率却很低。通常空气清洁机不能去除气体污染物。

3.5　加强居住小区的环境建设

加强居住小区的绿化与生态建设，推行室内养花种草，也是减少环境污染的一种方法。室内环境与室外环境是统一的整体，当室内环境中的污染物浓度高于室外时，室内中污染物就向外扩散，室外绿化好的居民区，由于绿色植物对扩散进入室外大气中的污染物具有吸附吸收和净化作用，促进了室内污染物向外转移、扩散，加快室内环境中污染物浓度的降低。室内养花种草在陶冶人的情操美化居室的同时还可吸收室内产生的一些污染物。研究表明,在含有甲醛的密闭房间内，放 1～2 盆吊兰或长青藤，半天内可使甲醛的含量降低约一半。

4　结论

由于我国目前存在的现状，维护室内空气品质不是短期内就可快速解决的简单问题，但是如果我们从基础工作做起也非难事。这里提出几点预防措施以供参考：

·使室内空气清新，保持流通。空调开启切忌连续，至少保持 3-4 小时定时通风换气，以保证空气中有足够的新鲜氧气含量；

·合理地调整室内外温差。我国夏季一般室内舒适温度为 26-29℃，冬季 20-22℃，相对湿度 40-60%，室内外温差以不超过 5-8℃为宜；

·使用空调器的房间应保持清洁卫生。定期清洁打扫空调器，定期清洗空气过滤网，减少疾病的污染源；

·长期在空调下工作的人员，尤其是长期使用空调的家庭，应增加每天户外活动的时间，锻炼身体，提高机体抵抗力，要注意增减衣物，同时多喝开水，加速体内新陈代谢。

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合理通风与空气品质的改善

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摘　要　气品质问题已经逐渐成为室内环境的焦点问题，而通风是改善空气品质的重要手段。但是新风量的提高导致能耗的增长。本文通过对于空气品质问题造成的经济损失和通风能耗的论述，基于经济效益的角度考虑，阐明了合理通风的重要意义，并提出新风量的确定方法和影响新风量大小的因素。
关键词　空气品质；新风量；通风效率
Abstract　Indoor air quality becomes the focus problem of indoor environment at present. Ventilation is one important method to improve indoor air quality. However increasing the outdoor air flow rate increases the energy consumption. The paper discusses the economic loss due to indoor air quality and energy consumption due to fresh air. Based on the viewpoint of economical benefit, the paper clarifies the important significance of reasonable ventilation and put forwards the method to determine the outdoor air flow rate and the factors which affect the fresh air flow rate.
Keywords　Indoor Air Quality, outdoor air flow rate, ventilation efficiency

1　空气品质及由于空气品质问题造成的经济损失

室内空气品质定义在这二十几年中经历了许多变化。最初，人们把室内空气品质几乎完全等价为一系列污染物浓度的指标。近年来，人们逐渐认识到这种纯客观的定义已不能完全涵盖 IAQ 的内容。

在 89 室内空气品质讨论会上，丹麦哥本哈根大学教授 P.O.Fanger 提出：品质反应了满足人们要求的程度，如果人们对空气满意，就是高品质 ;反之，就是低品质。英国的 CIBES（Chartered Institute of Building Services Engineers）认为如果室内少于 50%的人能察觉到任何气味，少于 20%的人感觉不舒服，少于 10%的人感觉到黏膜刺激，并且少于 2%的人在不足 5%的时间内感觉到烦躁，则可认为室内空气品质是可接受的。这两个定义的共同点是都将室内空气品质完全变成了人们的主观感受[35]。

近年来，ASHRAE 标准 62-89R 中，首次提出了可接受的室内空气品质（acceptable indoor air quality）和可接受的可感知室内空气品质（acceptable perceived indoor air quality）等概念。ASHRAE 标准 62-1999 中的《达到可接受室内空气品质的通风标准》又对这两个概念进行了补充[5][6][24]。其中，可接受的室内空气品质就是空气中没有已知的污染物达到了权威机构规定的可能对人体健康产生严重威胁的浓度，并且空调房间中绝大多数人（80%或更多）没有对室内空气品质感到不满。可接受的可感知室内空气品质就是房间中绝大多数人没
有因为气味和刺激性而表示不满。它是达到可接受的室内空气品质的必要而非充分条件。由于有些气体，如氡、CO 等没有气味，对人体也没有刺激作用，不会被人体感受到，但却对人体危害很大，

因而仅用可感知室内空气品质是不够的，必须同时引用可接受的室内空气品质。

目前空气品质问题已经逐渐成为室内环境的焦点问题。由于空气品质问题造成了巨大的经济损失。Dorgan[16,19]估计美国商业建筑由于空气品质问题使工人劳动力的下降造成的损失如表 1 所示。NEMI[20,23]对美国由于 IAQ 问题造成的损失进行了统计，结果如表 2 所示。

表 1　人员降低劳动力造成的损失

建筑种类	商业建筑损失/年（10^9US$）	损失/人（US$）	办公建筑损失/年（10^9US$）	损失/人（US$）	劳动力下降（%）
健康	0.0	0	0	0	0
一般健康	12.5	520	6.1	610	1.5
不健康，原因不祥	18.8	1270	7.6	1440	3.5
不健康，原因知道	10.7	1270	4.8	1440	3.5
SBS/BRI	12.8	2200	4.8	2465	6.0
合计	54.8		23.3		14.5

表 2　医疗损失

种类	严重的呼吸病	军团病、HF、人员哮喘	SBS 相关的病	合计
花费/年（10^9US$）	1.2	0.8	6.0	8.0

2　建筑能耗和建筑中通风能耗

改善空气品质的措施通常有三种措施：①消除或控制室内污染源；②提高新风量③提高新风的利用性能，就是使新风充分利用。对于方法 2，不可避免地涉及到能耗问题。

随着人类的发展，能耗高速度增加，建筑能耗相应的或更快的增加。Joseph C. Lam[8,11,12,17]统计香港的耗电量基本上每年增长 10.1%。如图 1 所示。Hidetoshi Nakagami[4]统计日本的能耗量如图 2，增长率也大约 10%。Robert Cohen[7]调查发现英国 48%的二氧化碳是由建筑物释放的。在中国，建筑能耗目前占国民经济总能耗的 25%左右，且呈递增趋势[32]。进入 90 年代，人们发现，酸雨的出现频率和覆盖范围在增加，地球臭氧层空洞在不断扩大，全球温暖化进程在加速，异常气候出现的周期在缩短。严酷的现实使使人们认识到，工业革命之后短短一二百年间的建筑发展历程，实际上是人类在以不可再生的能源作为武器试图征服大自然的过程。其结果是人与自然两败俱伤。在可持续发展成为全世界所追求的目标时，建筑行业也在关注能源以及环保。无论从环境角度还是商业角度来看，如何降低能耗是必须解决的问题。

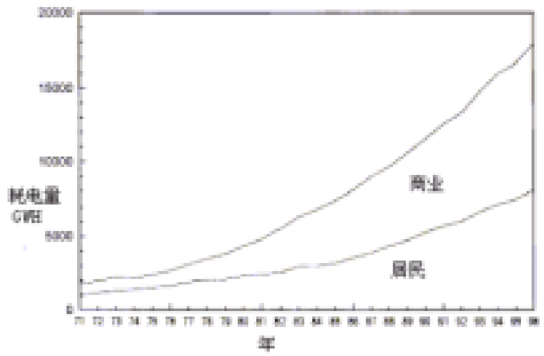

图 1 从 1971 年到 1996 年香港建筑耗电量

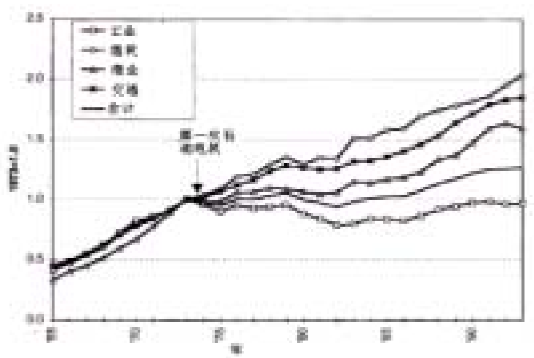

图 2 日本从 1965 年到 1993 年的能耗

在建筑空调中，通风所占能耗是相当大的，M. Orme[13,14,25]1994年对比利时、加拿大 、丹麦、芬兰 、法国、德国、荷兰、 新西兰、挪威、瑞典、瑞士、英格兰、 美国能源进行了调查，如图3、4、5。得出通过加热空气使状态改变的能耗大约9.3 EJ。而通过提供根据新陈代谢需要和污染负荷需要的新风来降低，这种能耗可以充分地降低。在建筑空调相关能耗中空气状态改变相关的能耗与热传导损失、设备损失一样重要。

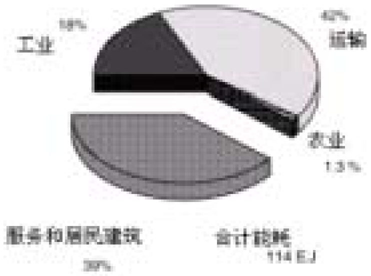

图 3 总能耗和各项比例

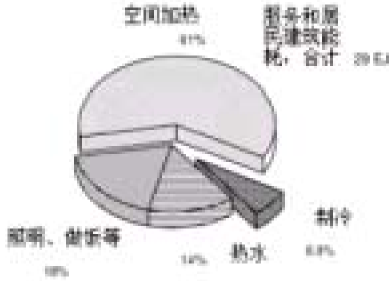

图 4 建筑能耗和各项比例

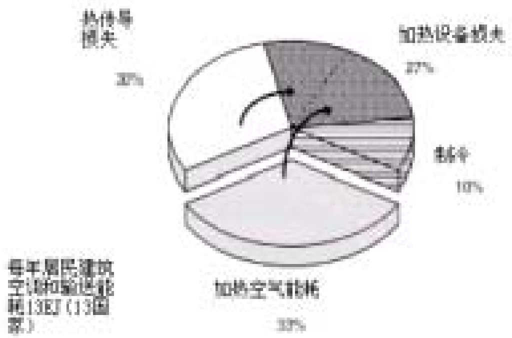

图 5 空调总能耗和各项比例

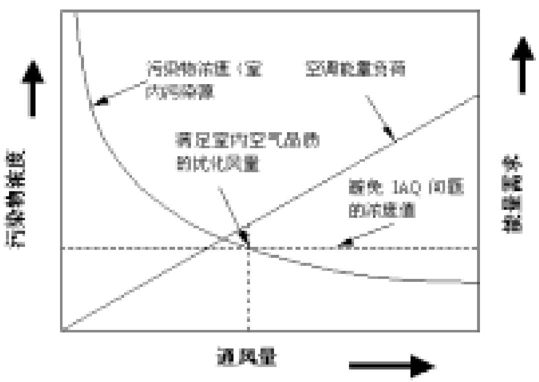

图 6 通风的特点

3 合理通风的经济效益

通常提高新风量来提高室内空气品质和将能耗降到最小是矛盾的。在高温、高湿的地区提高新风量，使其降温减湿能量的消耗是相当大的。而按最小新风量设计则可以降低运行能耗和低容量系统的初期投资[3]。Liddament M.W[2]认为新风量的合适选择应该按图6所示的方法进行选择。当新风量提高时候，那么相应的室内污染物的浓度降低。但是同时导致能耗的增高，包括空气调节能量和风机的运行费用等。MILTON D.K[26]在600个办公室和一个大的美国制造厂调查了3,720名雇员，结果是提高新风量到11.8L/s/人（25cfmp），那么对于每100名兼职工作人员每年可以纯节省$39,950，对于每100名全职工作人员每年可以纯节省$16,394。WARGOCKI P[37]研究结果是在室外风量为3L/人与30L/人之间时，每提高风量2cfm，整个平均劳动力提高1.7%。需求通风对于室内污染负荷不是定值的场所，是节省能耗的办法[33,38]。

如果从经济和商业的运作来看，那么也就是投入和产出问题。理论上来看，新风量的多少归根结底决定于经济规律。新风量的增加一方面可以降低由于新风不足而带来的空气品质问题导致的经济损失。但同时又增加了设备投入和运行费用。随着风量的增加，其边际效用越来越小。那么从经济的角度来看，选择合适的新风量就是寻找一个满足如图7中的点。

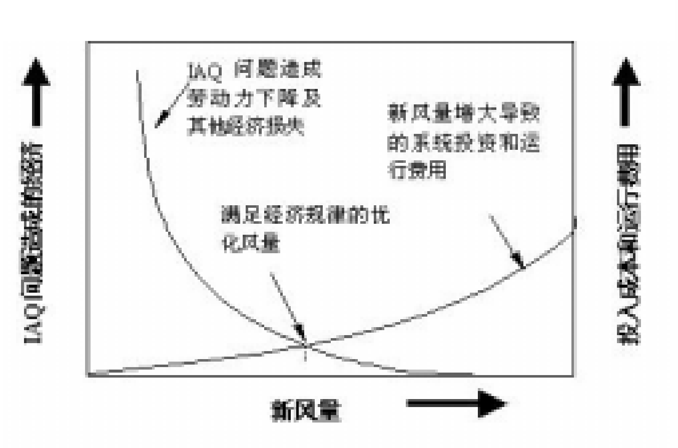

图 7 新风量的选择

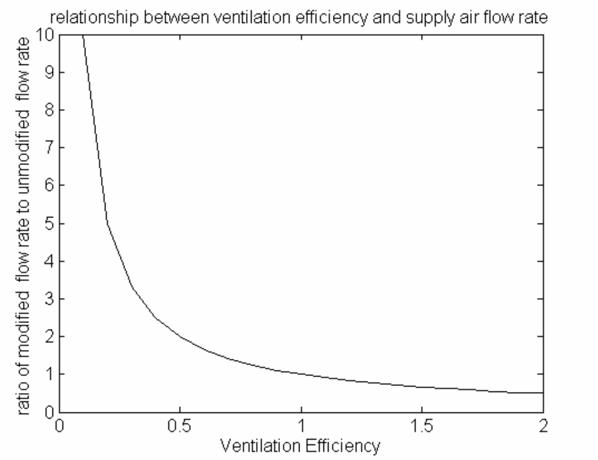

图 8 通风效率和风量的关系

由于国家和地区经济发展水平的差异，人员工资以及医疗成本等也不相同，发达国家人员成本相对要高，因此由于IAQ问题导致劳动力下降等损失相对要高。相比而言，能耗费用在不同国家地区相比相差不是很大。如果简单的以经济规律作为唯一的确定基准，以达到卫生标准为下限，那么地区之间的新风量的标准也不相同。

4　新风量确定考虑的因素

以上讨论的新风量的前提是室外风是足够“ 干净 ”，并且新风量可以进入人员的工作区域。然而实际系统中由于新风“ 质 ”和通风效率等的影响，新风量的确定需考虑这些因素。Liddament M.W[1]认为提高室内空气质量应该包括以下两个方面：

①室外气体的处理。包括污染释放控制、新风采集位置、过滤、密封问题；

②室内问题的处理。包括污染源和污染释放控制、局部处理、通风、过滤、系统维护。

那么对于新风而言，新风的预处理和气流在室内的有效性是解决空气品质的重要部分。R. Menzies[36]曾对两座办公大楼做问卷调查，结果表明：在新风量为34m^3/（H·人）时有症状显示者有7.12%~14.9%，而当新风量为85 m^3/（H·人），有11%~14.5%的人有症状表现。Mendell[21]认为在机械通风建筑中没有特定的BRS与比较低的每人新风量的变化有特定的关系。Menzies D[15,28]认为提高混合通风的新风量一般不会降低人员的症状是因为没有降低相关的暴露因素。面对新风量的提高而效果没有提高的事例，值得引起注意的是应该注意新风的量的同时也应该注意新风的质[22,27,31]。由于往往新风过滤器效率不高，又无净化气体的功能，大气中的有机化学物质不能被清除[29]，那么在保证新风量的同时，如何提高新风的有效性越来越被重视。

以通风效率为例，由于通风效率不相同，那么呼吸区域CO_2的浓度在达到相同值时候需要的新风量就不完全相同。考虑绝对通风效率$E=\dfrac{G/Q}{\overline{C}-C_s}$和相对通风效率$E_r=\dfrac{\overline{C}-C_s}{C_p-C_s}$的对于风量的影响，假设$C_s=0$，其与完全混合模型对比的关系见图8，其中设完全混合模型$Q=1$。

对于舒适性空调房间而言，在满足舒适的基础上，呼吸区域CO_2的浓度达到要求是通风的目的。

基于保证空气的新鲜度和节能方面的考虑，近年来空调技术出现了一些新的技术，如置换通风、工位调节、刺激空调[9,10,18]。正如赵荣义[30]、John W. Mitchell[3]在文献中提到的，减少能耗和环境污染，提供健康、舒适和可承受的居住和工作环境是空调的发展和趋势。

5 结论

综上所述，通过合理的通风来改善空气品质有着重大的经济意义。合理的通风应该包括提供合适的新风量和提高新风的利用程度。

1、合适的新风量是指提供一定量的符合要求的新风，它必须考虑地区经济、地区环境、法律法规等的约束，而不是一个固定的量。

2、提高新风的利用程度需要考虑新风采集、新风途径、新风净化以及室内气流组织，尤其是通风效率的影响必须考虑

本文中所用的符号的解释

$\overline{C}$ ：室内污染物平均浓度（千克/立方米）；

C_p ：室内点污染物浓度（千克/立方米）；

C_s ：送风污染物浓度（千克/立方米）；

E：绝对通风效率；

E_r：通风相对效率；

G ：房间内污染物发生量（千克/秒）；

Q：送风量（立方米/秒）；

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个性化送风下的局部热环境和空气品质改善研究

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摘　要　本文通过人体模型测试和示踪气体测量，研究了一种个性化送风系统中风速、风温和污染物浓度随送风参数的变化状况，并预估了此系统微环境（人员呼吸区）中空气参数的改变程度。结果表明，个性化送风的灵活控制有助于改善局部热环境和空气品质，且呼吸区空气品质的改善程度跟送风量、送风距离和人体周围的热羽流均紧密相关。

关键词　个性化送风；热环境；空气品质；示踪气体；人体模型

Impact of a personalized ventilation system on local thermal and air quality improvement

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Abstract　Measurements were conducted to study the influence of a personalized ventilation system on the air velocity, temperature and contaminant concentration in the microenvironment. The air parameters in the human breathing zone were analyzed using a breathing thermal manikin together with tracer gas measurement. Results show that the flexible control of this system creates a more comfortable indoor environment by improving local thermal comfort and air quality. It's also observed that the degree of air quality improvements is closely related with the airflow rate, air blowing distance and thermal plume around human body.

Keywords　personalized ventilation, thermal environment, air quality, tracer gas, thermal manikin

1　引言

长期以来，人们主要采用全空气的混合通风或置换通风方式来控制室内环境参数。对于混合通风的系统，送入的新风在达到人员呼吸区之前已经在房间内受到污染；同时，为了保证人员的热舒适而使得全房间的空气温度降低，也造成了无谓的冷量耗费。相对而言，置换通风房间内的空气分层使得靠近地面区域的空气较洁净，温度也较低。然而由于人体下半部对空气流动比较敏感，置换通风环境下人们易产生冷吹风感的抱怨[1]，并且当污染源集中在房间下部时，这种送风甚至会恶化空气品质[2]。跟以上两种系统不同，个性化送风将风口放置在人员工作台周围，在赋予使用者自由调节的同时，改善了局部热环境，并提高了人们吸入空气的质量[3~5]，因此成为当前研究和应用的一个重点。

根据系统末端风口的不同布置，个性化送风系统包含多种形式。鉴于放置在桌下的风口吹风会造成使用者不舒适[6]，当前更多的是将风口放置在人体呼吸区的高度位置上。一些测试表明，个性化送风的应用使得呼吸区空气温度和浓度都有所降低[7，8]，但该实验中风口送风量远远高于当前标准中低于 15 L/s 的推荐值[9, 10]，因此在应用中主要为了改善局部热状况。也有实验在固定送风距离

的情况下比较了各自系统对空气品质的影响，但忽视了系统的个性化调节，也未能给出不同送风距离和送风速度下的环境改善效果[11, 12]。

本课题对一种个性化送风系统的性能进行了测试。在不同的背景温度下，通过调整个性化送风的温度、风量和送风距离，结合一个可呼吸的模拟人体测量，对使用者呼吸区内的热环境和空气品质改善效果进行了研究。

2　实验方法

整个测试过程在一个环境室中进行（如图 1 所示）。环境室中安装了一个个性化送风系统，送风末端经可移动的软管跟送风道相连，风口位置和送风角度能够随意变动，该末端对应的小风机也可通过调速来改变送风量。该环境室的背景空气参数由单独系统控制，房间内垂直方向的空气速度为 0.05 m/s（房间换气次数 58 次/小时），空气温度的控制精度为±0.1 ºC。在送风道上设置有示踪气体（SF_6）的送入口，可以保持环境室内均匀的背景浓度。个性化送风参数通过在送风口前端的管道内采样进行调控，从而实现不同的个性化送风温度和环境室背景温度的组合。

本实验借助一个可呼吸的人体模型（Manikin）对局部空气环境进行研究。该 Manikin 以跟人体相近的肺活量进行呼吸，呼吸频率为 6 秒钟一次。Manikin 整个身体被分成 23 个部分，每部分的皮肤温度根据热舒适状况下人体相应部位的温度单独控制，而体内的核心温度为 36.5 ºC。在不同的热环境下通过记录其皮肤温度和散热量，可以预估所在环境中实际人体的热感觉，其详细描述可见相应文献[12, 13]。在测试中，该 Manikin 的着装热阻值约为 0.5 clo（1 clo = 0.155 m^2· ºC/W）。在不同的温度、风量和送风距离下，分别对 Manikin 吸入气体的浓度、温度进行了测量，测点设在吸入气流所经过的 Manikin 嘴巴内。除此之外，还对房间和个性化送风的浓度和温度进行监测。

实验中示踪气体浓度的测试仪器为 INNOVA Multi-gas Monitor 1302，Manikin 吸入空气的温度由传感器 Thermobead sensor series B07 测量，采样频率为 10Hz。不同送风距离和风量组合下的风速由热球风速仪测量。

3　实验结果

3.1　送风气流测量

图 2 为等温送风时，不同工况下呼吸区的空气流速，图 3 为测量所得的气流湍流强度。可看出本系统中湍流强度比较稳定，但风速可在较大范围内变化（可通过调高送风量或减小送风距离获得）。在送风距离 30~40cm、风量低至 3 L/s 时，呼吸区风速在 0.2 m/s 以下，而当个性化送风量为 15 L/s 时，呼吸区风速可高达 1.0 m/s。在 ASHRAE 规范中，送风标准为 8~15 L/s.person[9]，该系统中对应的呼吸区风速可提高到 0.6~1.0 m/s，为此具有改善人体局部热感觉的较大潜力。同时风速可通过送风量和送风距离两方面随意调节，在实际使用中有可能提高人们的满意程度。

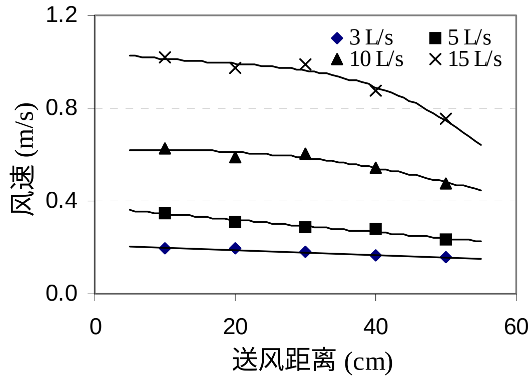

图 2　个性化送风的风速变化

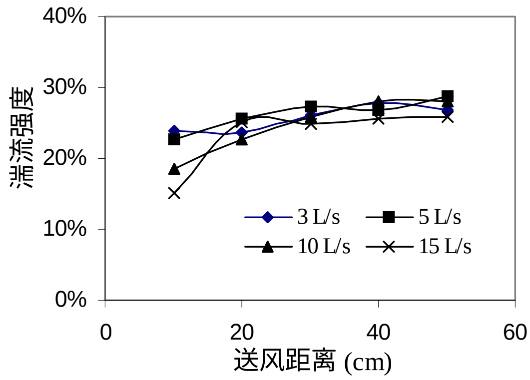

图 3　个性化送风的湍流强度

3.2　模拟热感觉

本实验中测试了 Manikin 身体各部位的散热量，以观察个性化送风对身体各部分热感觉的可能影响。图 4 显示室温 26 ºC 的等温送风（送风量 10 L/s，送风距离 40cm）时，Manikin 各个部分散热量相对于不存在局部吹风时发生了变化，但身体各部位散热量的变化幅度有所不同。对于个性化送风直接吹向的 Manikin 头部，散热量有较大程度的提高；而在下肢、躯干和上肢等部位，局部吹风的影响较小，为此这些部位的散热量改变幅度不大。从这个结果可以预测，实际使用中个性化送风对人体局部热感觉的影响较大，而对全身热感觉的影响有限。当送风量（风速）进一步加大时，换热的强化将能够使局部热感觉得到更明显的改善。

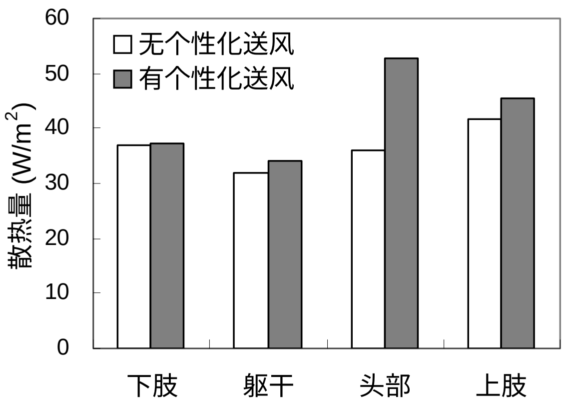

图 4 个性化送风对 Manikin 各部位散热量的影响

3.2　吸入空气的温度

根据丹麦的 Fang 等人的研究结果，吸入的空气温度影响着人们对空气的评价[14]。图 5 为测试 Manikin 一个呼吸周期内所测的空气温度变化。可以看出在吸气过程的约 3 秒钟内，虽然送风温度为 23 ºC，但 Manikin 吸入的空气温度已经升高至 25 ºC，表明个性化送风气流在到达使用者呼吸区之前已经跟房间内的背景空气进行掺混，这也预示着实际使用者吸入的空气温度已经较送风温度有一定程度的提高。

当 Manikin 处于呼气阶段时，主动吸入过程的停止使得具有较低温度的个性化送风很难到达传感器所在的嘴巴位置，另一方面鼻孔呼出的气流也一定程度上削弱了个性化送风气流的影响，因此测得的为紧贴 Manikin 表面的空气温度。虽然

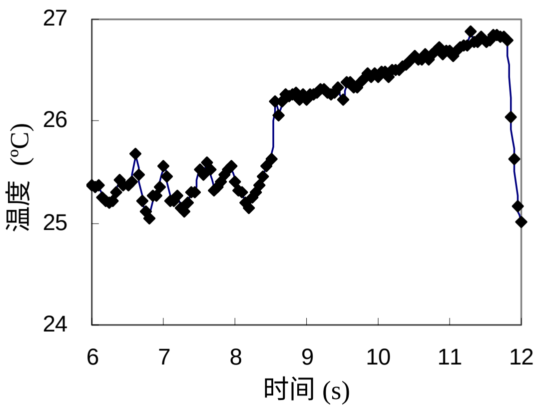

图 5 呼吸周期内 Manikin 吸入空气的温度变化
(送风温度 23ºC，背景温度 26ºC)

室内空气温度为 26 ℃，但由于 Manikin 本身发热而在周围产生热羽流，使得紧贴身体的空气温度高于背景温度，同时 Manikin 身体的温度也逐渐产生辐射作用，因此测量温度逐渐升高，直至下一个吸气过程开始，由于较冷空气的吸入而再次降低。

3.3　吸入的空气质量

个性化送风的一个目的是将新鲜空气直接送往人员呼吸区，从而在房间背景空气被污染的情况下，呼吸区的空气品质能够保持在较高的水平。送风效率可通过使用者吸入空气中来自个性化送风风口的空气比例来量化。此比例的定义如式（1）[12]：

$$\varepsilon_p = \frac{C_r - C_{in}}{C_r - C_{PV}} \tag{1}$$

其中 ε_p 为吸入空气中来自个性化送风的比例，C_r 为房间背景浓度，C_{in} 为吸入空气的浓度，C_{pv} 为个性化送风中的浓度。若使用者吸入的空气全部来自未跟背景空气污染的个性化送风气流，则此比例为 100%；对传统的混合通风，可认为吸入的空气中直接来自个性化送风风口的比例为 0。在系统送入全新风情况下，该比例越高，表明使用者吸入的空气越清洁。

图 6 显示了等温送风（室温 26 ℃）时，Manikin 自身发热对吸入空气中来自个性化送风的比例的影响。风量低至 3 L/s 的情况下，送风速度低于 0.2 m/s，当 Manikin 未加热时，送风不受热羽流的影响，即使较低的风速也能够被 Manikin 吸入；而当 Manikin 被加热时，如此较低的风速使得个性化送风难以穿透 Manikin 周围的热羽流，从而吸入的空气中包含较多沿身体周围上升的空气，个性化送风效率较低。当风量增大为 5 L/s 后，送风风速相应增大，较强的气流能够冲开身体周围的热羽流，从而热羽流的影响不再明显。当风量在更大范围变化时，图 7 所示的测试结果表明，送风量（风速）加大在一定程度上也强化了跟背景空气的掺混，使得送风效率的难以得到更大程度的提高。在各种风量下送风距离的缩短均能够大幅减少掺混过程，从而使送风效率得到提高。在本系统中，当送风距离在 40cm 和 20cm 时，新风吸入比例最高可分别达到 38%和 55%。

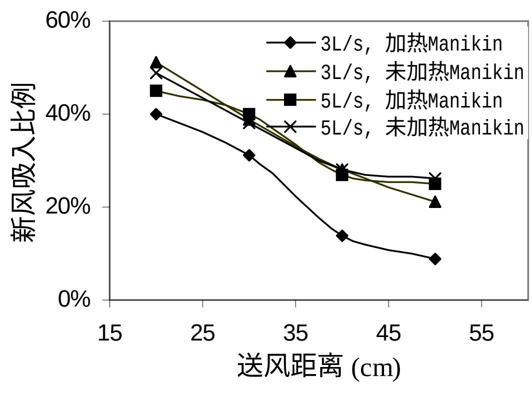

图 6　热羽流影响下的个性化送风效率

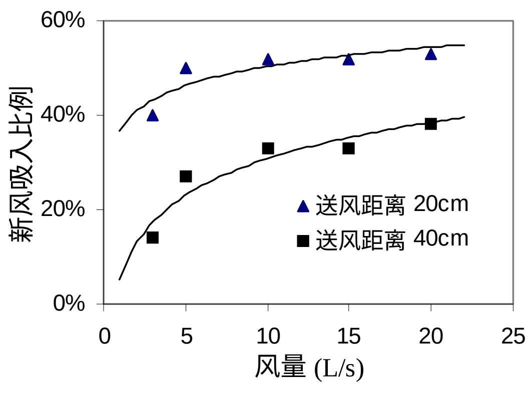

图 7　送风参数对个性化送风效率的影响

4　结论

通过风速、温度和示踪气体浓度的测量，在环境室中对一个个性化送风系统的性能进行了测试，并使用可呼吸的人体模型（Manikin）研究了个性化送风对局部环境的改善效果。实验结果表明，

1、个性化送风系统给予使用者对送风量、送风距离和送风角度等多方面调节的手段，具有提高使用者满意程度的较大潜力。

2、个性化送风产生的局部吹风能够强化人员局部区域的换热，从而改善局部热环境。

3、呼吸区的空气品质跟人体周围的热羽流和送风状况均相关，其改善程度跟送风量和送风距离紧密相关。

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INDOOR ENVIRONMENTAL DESIGN CRITERIA AND CONTROL STRATEGIES IN ECO-BUILDING

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Abstract The paper will illustrate our approach to design eco-building criteria such as GB50325-2001. At the same time, to demonstrate the applicability of the advanced technology approach, an indoor air quality (IAQ) comprehensive assessment software tool named IAQ-SRIBS of the eco-building has been undertaken. It includes the assessment of comprehensive environmental impacts and the database of Shanghai local meteorology, building materials and construction properties. The simulation results have been compared with in-situ measurements monitored in the building. The IAQ will be controlled through strategic planting. Some environmental control strategies such as material sourcing control are also implemented.

Key words Design criteria; Indoor air quality (IAQ); IAQ-SRIBS software tool; environmental control strategies;

1 Introduction

It is a common consensus within the “ eco-building ”activities that indoor-environment issue has to be an essential part of the global sustainability. Asia’s economic development asks for sustainable development. The sustainable development of buildings is a key part of the sustainable Development strategy in cities and the whole country. And what are design criteria to develop an eco-building and how to fulfill the eco-building is our impending task in china now.

2 Design criteria

The main objectives of eco-buildings are to provide a comfort and health indoor environment whilst minimize the reliance on conventional mechanical equipment to achieve it. So the approach eco-building criteria is as the followings :(1) trying to use the healthier green building materials, creating a higher standard of air quality. (2) Increasing the "energy efficiency" of their home, reducing the carbon dioxide emissions, control its emission concentration under 1000ppm. (3) Control the concentration of Particulates under0.15mg/m^3. (4) The humidity would cause mold and growth, and the rains would eventually enter the structure and cause problems. So Design the ventilation system to maintain the indoor relative humidity between 40% and 70%; temperature should be controlled between 17-27^{O}C,and different standard in winter from in summer; Medium efficiency pleated air filter with minimum 10% ASHRAE average dust spot test.（5）noise is controlled under 50dB.（6）When the sun shines, you take advantage of it; otherwise, the added insulation will only make the house more efficient in both cooling and heating. So sun shines/per day is above 3 hours.（7）having sufficient lighting apparatus.

Among these seven items, the most important item is the first one. Referring to how to use the healthier green building materials, creating a higher standard of air quality, the Ministry of Construction and the China State Quality Supervision-Inspection-Quarantine Administration (SQSIQA) have promulgated and enacted the code for indoor environmental pollution control of civil building engineering (GB

50325-2001). When we design an eco-building in China. The indoor pollutants such as Radon, benzene, ammonia, TVOC and so on should meet standards listed in table 1.

Table 1 Concentration limits of indoor pollutants for civil building engineering

Pollutant	Civil Building Engineering Group I a	Civil Building Engineering Group II b
Radon (Bq/m^3) c	≤200 d	≤400
Released formaldehyde (mg/ m^3)	≤0.08	≤0.12
Benzene (mg/ m^3)	≤0.09	≤0.09
Ammonia (mg/ m^3)	≤0.2	≤0.5
TVOC (mg/ m^3) e	≤0.5	≤0.6

Note: a. Group I - residential apartments and houses, hospitals, old age homes, kindergartens, schools and, b. Group II - office buildings, shops, hotels, entertainment halls, bookstores, libraries, galleries, gymnasiums, public transportation waiting rooms, restaurants, barber shops. c. Bq (becquerel): One Bq corresponds to one disintegration per second. d. Except for radon, background concentration of the other outdoor air pollutants shall be measured. e. TVOC: total volatile organic compounds.

The other Chemical pollutants such as CO, CO_2, O_3, PM10 and Microorganism pollutant: total bacterium counter (cfu) should be 100% up to the standard GB/T18883-2002, which listed in table 2:

Table 2 Concentration limits for indoor air pollutants (GB/T18883-2002)

Name of Pollutant	Unit	Concentration	Remark a
Sulfur dioxide (SO_2)	mg/m^3	0.5	Hourly average
Nitrogen dioxide (NO_2)	mg/m^3	0.24	Hourly average
Carbon monoxide (CO)	mg/m^3	10	Hourly average
Carbon dioxide (CO_2)	ppm	1000	
Ozone	mg/m^3	0.16	Hourly average
Inhalable particulate matter	mg/m^3	0.15	
Bacterial total	cfu/m^3	2500	

Note: a. Daily concentrations if not specified otherwise.

About the item 4, that is, Physical pollutants is also important, temperature, RH, air velocity in eco-building design should be according to the criteria in the following table 3:

Table 3 Parameters for air-conditioned or heated indoor environment

Temperature (ºC)	Winter	16-24
	Summer	22-28
Relative humidity (%) a	Winter	30-60
	Summer	40-80
Air velocity (m/s)		<0.3

Note: a No limits for the humidity of the sites without air conditioners.

The last but not the least is to control the indoor acoustics under 50 dB. Controlling the indoor lighting above 300 lux. The following we mainly talk about the indoor environment pollutant.

3 Strategies

Under the guidance of the design criteria, we should find control strategies to fulfill the eco-building. The most important strategy is using the comprehensive assessment software tool to evaluate the main influence factors and its impact on human health, comfort and productivity in indoor environment, to predict the concentration and exposure rules in certain times, to conduct a performance analysis about how efficient its pollutants emission control, how efficient the control and improve measurements are. If we find the assessment result isn't as good as we wanted. We will find another important strategy, which is source control to fulfill the eco-building.

3.1 Mode Control

We use indoor air quality (IAQ) comprehensive assessment software tool named IAQ-SRIBS of the eco-building to analyze whether a building is a real eco-building or not. It includes the assessment of comprehensive environmental impacts and the database of Shanghai local meteorology, building materials and construction properties, as shown in Fig.1. This mode control strategies combines the use of round-predict and improve measurements, as shown in Fig.2.

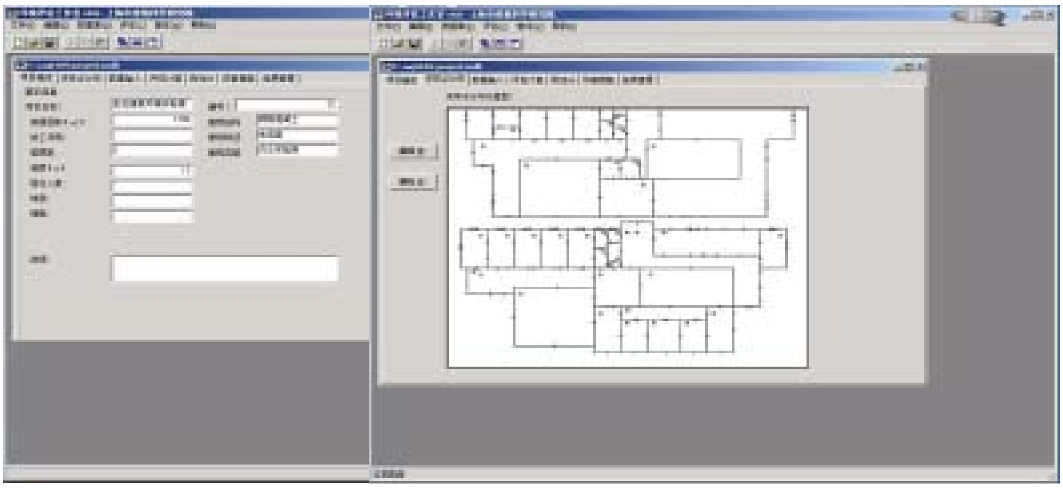

Fig.1 The mainly Assessment Sheet

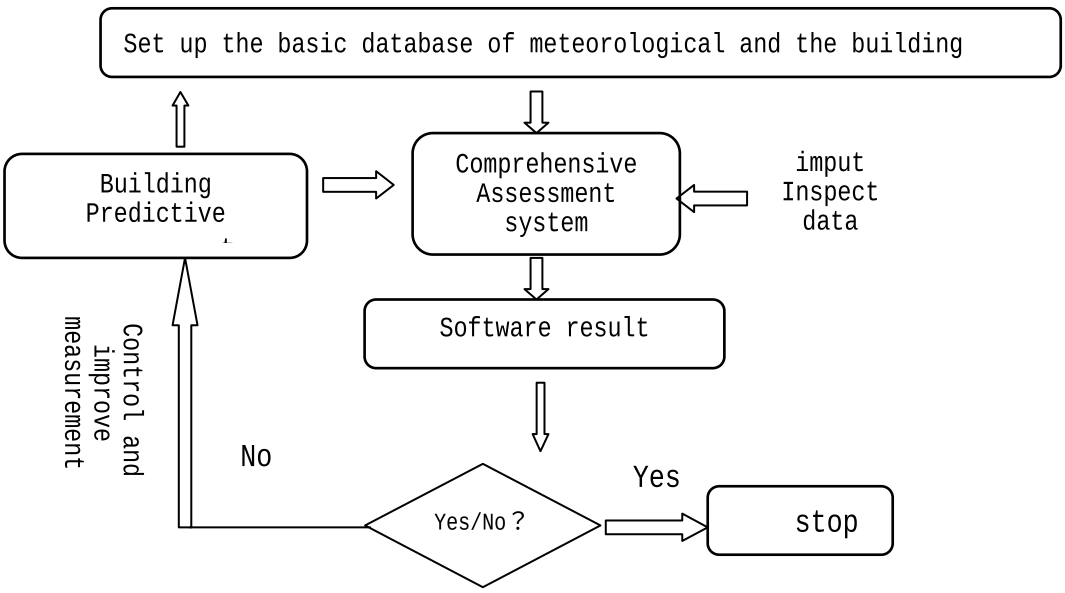

Fig.2 The process of software tool assessment

In the software tool, we also consider eco-building's local cite, the climate and meteorological, basic characteristic description of the building (build age, building scale, building direction, materials of construction, the numbers of the room or office, ventilation system and maintenance, hygienic facility, heating and cooling system, outside environmental condition around the building) and high and the use of environmental design principles. The Assessment Result Sheet mainly displays the result of the assessment of a eco-building using IAQ-SRIBS software tool, as shown in Fig.3.

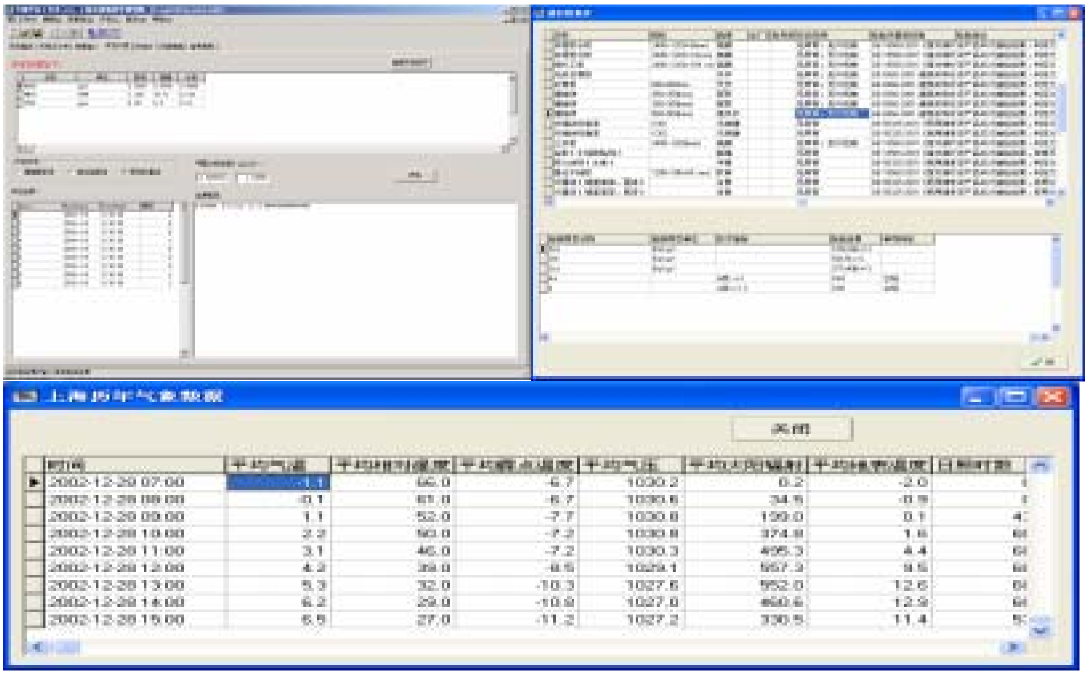

Fig.3 The meteorological Database and the building materials' s database and result sheet

If the assessment result isn't obey the standard, we will do some improving measurement and assess again until its got a high score.

3.2 source control

However from a rational perspective, contaminant source control is the most effective general means to improve IAQ. As we known, many building

Material such as wood-based panel and finishing products, solvent coatings for woodenware, interior architectural coatings, adhesives, wood based furniture, wallpapers, polyvinyl chloride floor coverings, carpets, carpet cushions and adhesives, concrete admixtures, and radio nuclides are all having harmful substances, TVOC, HCHO and so on. Now SQSIQA(Ministry of Construction and the China State Quality Supervision Inspection Quarantine Administration enacted compulsory national standards for limiting harmful substances in those ten kinds of indoor decorative materials(GB18580～18588- 2001, GB6566-2001). So we can control contaminant source according to those standard.

3.3 Other control strategic

Above is the most efficient ways to fulfill the eco-building. There is some other control strategic. The following is some of them:

- Developing environment functional material and technology. We can use some environment functional materials and technology such as electromagnetic shielding materials, green electronic joining materials, eco-building materials etc.

- Medium efficiency pleated air filter with minimum 10% ASHRAE average dust spot test.
- Control building’s humidity and temperature. Walls need to be protected by wide eaves, foundations need to be high and dry, and the walls should be breathable so they don't gain moisture and hold it. Incorporates as much thermal mass material (tile, brick, rock, etc.) as possible inside the house to help stabilize temperatures.
- Natural ventilation. We’d like to build using those figures to capture as much wind as I can to flow through the house. Wind catching towers can be employed, to direct the wind into the house.
- Balance the amount of sunlight that is allowed to enter the house and be stored in the thermal mass with the particular climate where you are. Orient the house to catch some of the winter sun, but with shades to exclude the summer sun.

4 Conclusions

When we want to design a eco-building, especially we want to fulfill the high quality of indoor environment, to decrease indoor pollutant ’s impact on human health, to improve comfort and productivity, it’s very important for us to choose the materials according to our enacted related criteria , such as GB/T18883-2002,GB50325-2001, GB18580～18588- 2001, GB6566-2001 and so on. The most important thing is we should chose a software tool such as IAQ-SRIBS to evaluate the whole situation of the eco-building pre-construction, constructing and after-construction, in order to modify the design and material choosing at any moment, of course, we should consider local climate and meteorological, basic characteristic description of the building into software.

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生态建筑中室内环境设计规范和控制措施

袁静　叶剑军　李景广　谢晓东

摘　要　本文探讨了，在建造生态楼时，在中国地区应遵循的室内环境设计标准，同时，在标准的指导下，为了更好地按标准来建造生态建筑，引入上海市建筑科学研究院自己开发的室内空气质量评估体系 IAQ-SRIBS 对生态楼的建造进行跟踪评估，该评估体系软件分析其室内空气质量的主要影响因素和危害程度，并结合软件中的上海地区的气象条件、建筑物特征和材料污染数据库对生态楼进行指导，预测其在一定时期内的变化趋势及规律，确定其可能造成的危害程度，并提出科学、合理、经济技术可行的控制改善措施，如，建材污染源的控制措施等。

关键词　设计标准；室内空气质量；IAQ-SRIBS 评估软件；环境控制措施

上海市生态办公示范楼的声环境综合控制策略

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摘　要　生态建筑的声环境控制是一个从建筑选址到使用进程的全周期的控制策略，必须兼顾通风、采光、经济性等多方面因素。本文以上海市首栋生态办公示范楼为例，介绍如何综合室外噪声控制、建筑物隔声设计、建筑设备噪声控制及功能区间特殊声学设计等手段提高生态建筑的室内声环境。

关键词　生态建筑；建筑声环境；自然通风；ABC 原则

Abstract　Controlling the acoustic environment in an eco-building is a life cycle strategy from the site selection to the usage of the building. Different strategies were used in the first demonstration eco-building in Shanghai to improve indoor acoustic environment quality, including the outdoor noise attenuation, indoor noise insulation, equipment noise control and functional acoustic design.

Key words　Eco-building, Building Acoustic Environment, Natural Ventilation, ABC Rule.

引言

半个世纪以来，人们对生态建筑严格的定义和具体范围界定尚无一致意见，但是作为建筑的两个主体，建筑师和使用者彼此达成了共识，即在建筑选址、建造、使用和拆除全过程节约能源和资源、实现建筑与环境的协调共生，同时为使用者提供一个健康、舒适、高效的建筑环境[1,2]。

建筑环境的控制因素包括室内空气质量、热环境、声环境、光环境等。作为建筑环境的一个分支，声环境往往在生态建筑整体控制方案中受到忽略或挑战。一方面，声环境的控制有别于自然通风、自然采光等措施，不会因附加的建筑节能效应带来可观的经济效益；另一方面，声环境控制措施与自然通风等存在矛盾，比如建筑物开窗通风时会引入室外噪声，很多时候人们往往忽视甚至牺牲声环境来保障其它技术的实施。但是声学研究表明，长期的噪声作用会对人员造成耳部不适、心血管损伤、神经系统功能紊乱等健康影响，并会降低人员工作效率、干扰休息和睡眠等[3]。声环境控制不当的“生态建筑”将背离其“以人为本” 的主旨，无法创造健康舒适高效的建筑环境。

近年来许多国家发展的绿色建筑标准和评估体系都考虑了声环境因素，将室内外区域的背景噪声及建筑隔声性能作为考核指标加以评分，典型的如英国的 BREEAM、美国的 LEED 以及中国的生态住宅技术评估手册。另外一些地方性的研究成果在评分基础上给出实施指南，如上海市生态住宅小区技术实施细则[4]和绿色奥运建筑实施指南[5]。国外很多生态建筑的实例也充分考虑了声环境因素，可资借鉴[1]。如荷兰戴尔福特的中央图书馆在建筑布局上考虑将电脑工作站这样的“闹区”集中配置，并与其他阅览室、自习室、办公室相分离；加拿大多伦多约克大学的计算机大楼兼顾外

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墙的通风、隔声与保温性能，避免在空气流速较大的地方产生高分贝的噪音。

本文以上海市首栋生态办公示范楼为例，介绍如何遵循“选址分析→控制指标选择→软件模拟→控制方案及选材建议→测试评估”的工作流程，综合室外噪声控制、建筑物隔声设计、建筑设备噪声控制及功能区间特殊声学设计等手段提高生态建筑的室内声环境。

1 选址分析

上海市首栋生态办公示范楼位于上海建科院莘庄园区西南角，比邻中春路、申富路十字路口，如图 1。建筑功能定义为实验办公楼，即室内部分空间将用做建筑环境实验室，其中对声学有特殊要求的包括混响室及建筑环境综合测试舱。

先期调研显示，建筑原址的背景噪声主要来源于附近的交通噪声及临近的幕墙检测实验室。选址西侧的中春路为四车道交通干道，与园区边界之间有非机动车道、人行道及 14m 宽的草皮灌木绿化带隔离。该马路的车流量 1000 辆/小时，重型车比例高达 46%，因而噪声和振动非常严重。采用 B&K2260 声学分析仪测试的结果显示，该马路的等效 A 声级 L_{Aeq} 高达 78.8dB，严重超过城市 5 类环境噪声标准中道路交通干线两侧区域昼间等效声级 70dB 的限值[6]。并且，目前中春路向北延伸段即将竣工，建成后与沪杭高速公路下匝道连通，经高速前往闵行的很多客货车辆都将经由此路，预计近年的交通流量还会激增。比较而言，图示申富路的车流量和噪声都较小。但两条马路红绿灯十字路口的车辆噪声不容忽视。

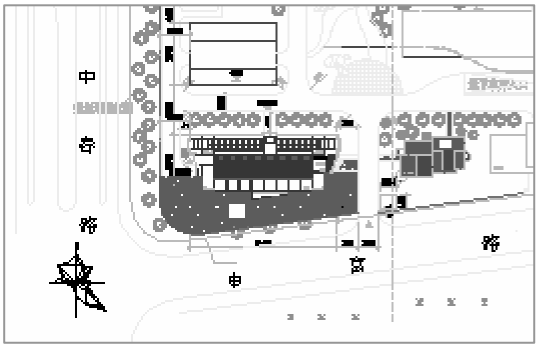

图 1 生态办公示范楼选址示意图

经测，建筑地基边界不同测点的日间平均背景噪声等效 A 声级为 57.6dB。而按照 GB3096-93《城市区域环境噪声标准》[6]的规定，办公建筑所在区域需符合环境噪声 1 类标准，即等效声级 L_{Aeq} 昼间 55dB，夜间 45dB。

因此，单纯的从声学角度考虑，该生态楼的建筑选址存在“先天不足”，给噪声和振动控制带来额外的压力。并且由于建筑布局等方案事先已定，很难改变建筑选址。针对这一状况，我们提出了如下三条措施：

1、原定建于楼内的混响室改建至园区内部远离马路的另一幢楼内。这样可以大大简化混响室的地基构造（隔绝地面振动以达到足够低的背景噪声），节约成本。

2、在园区边界修建隔声屏障衰减马路噪声。考虑到生态楼的选址非常临近马路，我们没有办法通过足够宽度的绿化带隔离噪声，因此考虑建造隔声屏障。

3、提高建筑立面的隔声效果。

2 室外噪声控制：声屏障

声屏障的材料和构造形式多种多样，有传统的砖石砌墙、密实的木质隔板、透明钢化玻璃、与地势相结合的堤坝，以及近年来多在高架道路沿线使用的有机板材或穿孔吸声板。作为生态技术集成的一个子项，声屏障的设计方案不仅仅是简单的声学考虑。起初，设计师希望采用别具一格的材

料和风格，曾提出竹制围篱屏障，但显然难以保证其良好的密封性，隔声性能较差。绿化土坡的设想也因地表面积的限制被迫中止。通风部门则反对在自然通风的主导风向东南向采用任何形式的围墙，并要求尽量减小其它方向围墙的长度和高度。但是，由于围墙距离车道中心线较远，如果高度太低，其隔声效果将非常有限。运用室外噪声模拟软件 CadanA 对区域噪声的传播及衰减进行模拟，可得到最优的声屏障设计方案，

首先根据设计平面图布置相应的道路、绿化带、建筑等，根据现场调研数据设置道路的车流量、车型比例、路面材料等参数，根据园区内选址附近的实测背景噪声校准模拟结果，在此基础上添加不同长度、高度的声屏障，计算由此带来的建筑区域平面、立面的声衰减。软件建模见图 2，部分模拟分析结果见图 3。

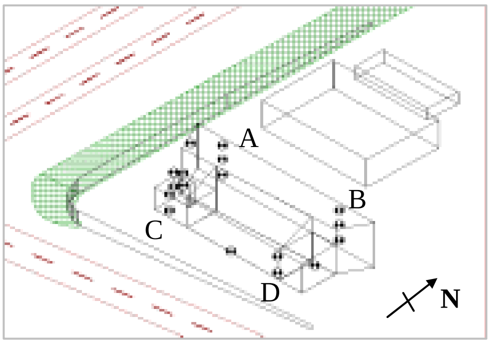

图 2 室外声屏障模拟模型图

由于软件忽略屏障材料的吸声特性，模拟中假设所选垂直屏障为全反射性声学材料。考虑到减小它对东南主导风向的影响，将屏障设计成图 2 所示的三段式结构：拐角处及向北延伸段为等高声屏障，长度 54 米——图 3 结果中表述的屏障高度即这一段的高度；南北向渐降式声屏障，长度 40 米；东西向渐降式声屏障，长度 60 米。渐降式声屏障的初始高度与拐角处声屏障一致，最低处高度为 1 米。

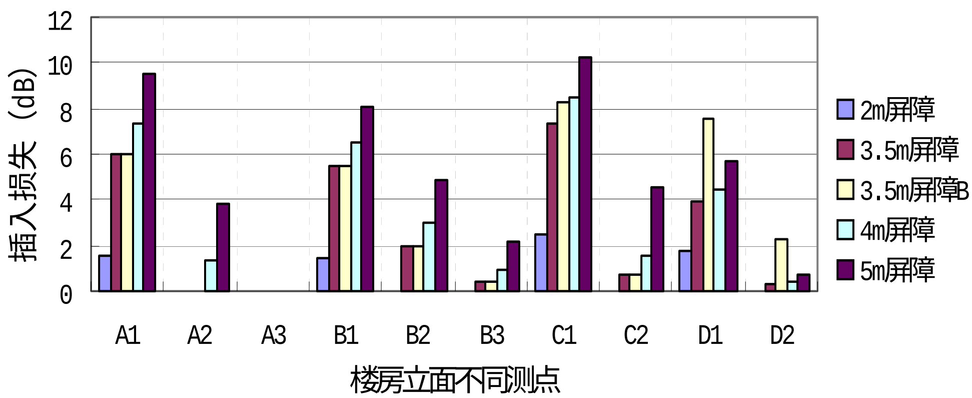

图 3 不同声屏障对应不同测点的插入损失

计算考察了建筑立面上一些具有代表性的测点在加入声屏障前后的声级差，图 3 结果中的 ABCD 测点均位于南北墙面上，分别对应北西、北东、南西、南东四个方向，1、2、3 则对应不同的楼层窗口高度，分别为 1.8m、5.8m、9.3m。另外，建筑的屋顶花园及亲水楼台等等人员观赏区也布置了相应测点。

结果显示：(1) 3.5m 以上的声屏障对底楼测点会有比较明显的隔声效果（4-10dB），屏障越高，隔声效果越好；(2) 5m 以下声屏障对二楼以上测点的保护作用很小；(3) 声屏障对近屏障测点 AC 的保护作用要优于 BD 测点。鉴于过高的屏障会影响视觉和通风，对 3.5m 屏障做优化计算，将南

北渐降段的声屏障改为等高屏障，以提高它的插入损失，即图 3 中的“ 3.5m 屏障 B ”。 可以看到，修改后的方案使部分区域的隔声性能提高了 2-4dB，效果较好。

参考软件模拟结果，后期声屏障方案选择“ 3.5m 屏障 B ”，以铝合金框架的钢化玻璃砌筑围墙，以满足建筑师通透美观的要求；墙基采用舒布洛克的吸声砌块，以吸收路面的低频噪声。但是英国著名建筑师 Geoffery Broadbent 教授在该方案论证时提出：铝合金和玻璃这两种材料的“ Embody Energy ”非常高，即其生产制作过程耗费了相当多的能量，从生态的角度考虑，这样的材料是很不“ 绿色 ”的。鉴于此，并考虑铝合金玻璃墙体工程造价很高，项目组最终放弃了建造声屏障的方案。虽然最终方案未被采纳，但是这一论证过程却提醒我们：(1) 生态建筑的选址必须综合考虑通风、噪声、采光等多项因素，否则将造成方案实施过程不必要的麻烦和额外的经济投入；(2) 生态建筑的噪声控制不单纯是声学方法的运用，而要与自然通风、绿色建材、就地取材等其它生态理念相协调，以期得到最优的方案。

3　室内噪声控制

考虑到室内噪声的来源主要有室外噪声、设备噪声、人员噪声等，室内噪声控制的重点定位于：提高建筑的隔声性能、减小设备的噪声振动、控制功能区的混响。

3.1　建筑隔声设计

民用建筑隔声设计规范将建筑的隔声性能分为三部分：立面的空气声隔声、内墙及楼板的空气声隔声、楼板的敲击声隔声[8]。考虑到实际噪声源及不同区间的功能分布，经分析，生态示范楼的隔声重点定位在以下几个方面：

一是提高外立面的隔声。由于室外噪声比较严重，为想达到室内背景噪声 40dB(A)的预期目标，外立面的隔声性能需优于 35dB。由于该生态项目实施过程相当重视外维护结构的节能特性，建筑采用了双层保温砌块外墙，并选用双层中空玻璃窗，严格控制外窗的气密性。这样的考虑在隔热的同时也保障了立面的隔声性能。但是，作为保障“ 自然通风 ”的必要措施，建筑南北立面外窗在春秋两季是敞开通风的，这无疑是将室内区域直接暴露于临近的马路噪声之中。近年来在高架沿线楼宇逐渐普及的自然通风隔声窗可以改善这一状况，即采用交错开启的内外两层窗户取代双层玻璃窗，室外的噪声和空气都通过曲折的吸声罅隙进入室内。当然，这样的结构对通风效率有一定程度的影响，但可以比完全开敞状况提高 6-10dB 的隔声效果。另外，同样厚度的玻璃构成的内外双层窗户，其密闭状况下的隔声量要比中空双层玻璃窗提高十多分贝，如图 4。如果适当改变内窗的倾角或玻璃厚度，还可以避免双玻窗户隔声的耦合低谷效应。

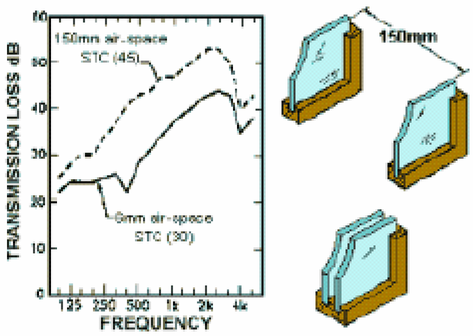

图 4 内外双层窗户与中空双层玻璃窗的隔声性能比较

二是分析建筑室内布局，有针对性的提高电梯间、设备间等区域的墙体楼板隔声性能，减小对相邻房间的影响。为了论证不同材料及施工措施对隔声效果的影响，采用法国建筑科学研究院 CSTB

开发的隔声软件 Acoubat 对部分房间进行了模拟。软件可以自行组合不同的建筑材料及构件，如不同的承重墙、分户墙、楼板、楼板面层、吊顶、门窗、通风口、卷帘设备等等。图 5 比较了采用不同楼板（楼板覆层）时上下楼层间的敲击声隔声性能。6 条曲线由上到下分别代表 14cm 混凝土基底楼板（Rough）、基底楼板加贴面瓷砖（Tiling）、贴面瓷砖下衬很薄的弹性垫层（Tiling-underlay）、木地板、地毯（Carpet）及浮筑地板（Floating）。每条注释后的两个数字分别代表材料本身的计权标准化撞击声压级（实验室测试）和加上楼板覆层后整个楼板层的撞击声压级。可以看到，在基地楼板上铺设木地板或地毯可以有效的提高楼层间的隔声效果；而浮筑楼板的砌筑不但提高了计权隔声性能，而且很明显的改善了中低频（小于 1000Hz）的隔声性能，因而适宜在设备房等低频振动严重的区域使用。

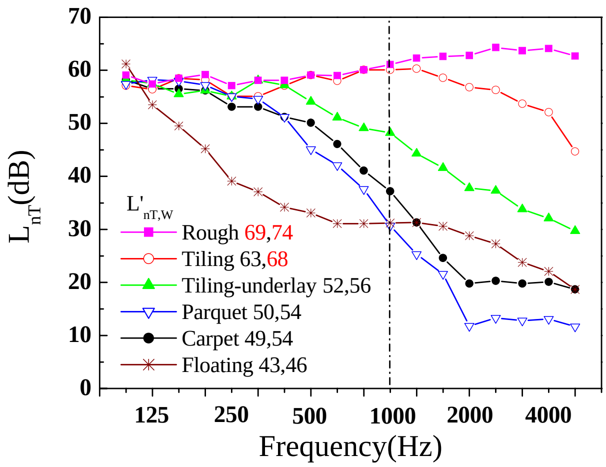

图 5 不同楼板及楼板面层组合的敲击声隔声性能比较

3.2　建筑设备噪声控制

对可能影响声环境的建筑设备，如水管、电梯、水泵、风机等设备提出选材建议，并对其施工安装过程中的隔音隔振措施提出相应方案。典型的如建议选择无机房电梯、内螺旋双壁落水管等，建议安放风机水泵等的设备空间采用浮筑楼板，根据设备的固有频率选择相应的减振垫，强调所有的管道与建筑采取弹性连接，避免因施工不当造成墙体孔隙传声等。

3.3　功能区间声学设计

参考楼层不同区间的功能分布，以下两个区间的声学性能需要进行重点分析和控制。

一是底楼西部的展览区间。为了展示生态建筑的高新技术及产品，建筑师将底楼西部的开敞空间辟为参观展览区。该空间的高度为 3.9m，中部与十多米高的采光中庭相连，总平面面积接近 350m^2。如果不对这一空间进行吸声处理以控制中庭混响，日后参观人员的嘈杂声将严重影响参观者本身的听觉感受和二楼办公区间人员的注意力。该区间的顶棚吸声处理放弃了常规的矿棉板或玻璃棉穿孔吸声板吊顶，而采用植物纤维吸声喷涂，以保持建筑原貌，避免因繁复的吊顶而减弱混凝土结构楼板的蓄冷蓄热性能。该吸声喷涂以天然植物纤维为原料，是阻燃吸声、保温隔热性能良好的绿色环保材料。从声学角度考虑，10-20mm 厚度的喷涂材料 500Hz 以上吸声系数均可达到 0.85 以上。由于直接喷涂在基地楼板上，它的低频吸声系数稍低，但是对于主要噪声源为人员噪声的展示中庭来讲，这样的吸声材料是非常适用的。

另一个是二层办公区的开放式办公室。开放式办公室的设计近年来逐渐普及，因为它可以节约空间、增加人员间的交流。但同时，开放的空间也带来了声环境的诸多问题。比如与传统的隔墙相比，工作区间的隔板隔声性能减低很多，不可避免的会引入人员间的相互干扰，从而影响员工的注意力和工作效率。研究人员称，语音噪声干扰成为开放式办公室最严重的问题，人员受干扰后 15

分钟才能重新集中注意力。另外，空调风口、电脑机箱等设备的低频噪声也会引起人员烦躁。为优化该区域的声学环境，减小人员干扰，提高工作效率，参考国外该领域的研究结果，以“ABC 原则”指导开放式办公室的声学设计。所谓 ABC 原则，即综合利用吸声（Absorption）、阻隔（Block）和掩蔽（Covering）效应来改善空间的声环境[9]。其设计要点在于：

（1）吸声。在开敞式办公室内尽可能多的设置吸声材料至关重要，它可以防止声音传播到远处导致人员注意力分散。在房间内的各个表面中，顶棚的吸声处理最重要。这是因为顶棚的声反射会衰减工作区隔板（本来隔声能力就有限）的隔声效果。顶棚吸声处理应该保证 0.85 以上的降噪系数（NRC）。鉴于 2000Hz 频段的噪声对语言清晰度贡献最大，该频段的吸声系数应当得到充分保证，应不小于 0.8。

另外，工作隔间内表面的吸声处理也很重要，否则这些墙面会将声音从一个隔间反射到另一个隔间。铺设地毯或软性地板可以有效控制撞击声（如脚步声、高跟鞋的点击声、物体落地声等）对室内人员的干扰，这比吸收它们的反射声效果更好。

（2）阻隔。开敞式办公室利用方格屏障隔离工作区间。为了能起到更好的隔声作用，这些屏障的设计必须使声绕射降低到最小。由此考虑，屏障至少应该高 1.5m，传声等级 STC≥25dB。隔间屏障的设置应当能够阻断工作人员的视线并且与地板、窗台和侧墙相接。

（3）掩蔽。利用电声掩蔽系统适当提高背景噪声级，可以减小人员间的语音干扰。该系统的扬声器可以安装在顶棚通风排气口处，或布置在工作隔间。对办公室内的职员而言，正确安置后的声音听起来就像标准的空调噪声一样。

考虑到通过建筑传递的噪声大多是低频声，传统隔声方法衰减高频噪声比较有效，因此设计中有意识提高频率范围在 500Hz 以下的掩蔽背景噪声。

总结

文章以上海市首栋生态办公示范楼为例，通过室内外噪声的综合控制提高建筑物的声环境质量，具体包括：结合选址分析及室外噪声传播的软件模拟确定合适的声屏障设计方案，同时对建筑立面、隔墙及楼板隔声设计、建筑设备噪声控制、展示区混响控制及开放式办公室声学装修设计等提出建议方案。部分结论可作为生态建筑声环境的控制参考：

1、生态建筑的声环境控制是一个贯穿建筑全生命周期的过程，“选址分析→控制指标选择→软件模拟→控制方案及选材建议→测试评估→改善优化”的工作流程可资借鉴；

2、生态建筑的噪声控制不单纯是声学方法的运用，而要与自然通风、绿色建材、就地取材等其它生态理念相协调，以期得到最优的方案；

3、生态建筑的选址必须综合考虑通风、噪声、采光等多项因素，否则将造成方案实施过程不必要的麻烦和额外的经济投入；

4、建筑隔声设计需要根据噪声状况及房间功能分布，着力改善隔声的薄弱环节。建议室外噪声严重的建筑采用立面通风隔声窗；风机、水泵等强振动设备集中放置并采用浮筑楼板隔振；

5、室内大开间区域采取足够的吸声处理改善混响时间，减小室内噪声及语音干扰。对近年普及的大开间办公室可结合使用吸声、阻隔和声掩蔽来改善区域声环境质量、提高人员工作效率。

该项目实施过程中得到生态项目组其它同事的配合及英国 WSPE 公司同仁的合作与帮助，在此致谢。

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建筑系统环境性能评价方法研究

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摘　要　建筑系统环境性能评价是建筑系统环境性能改善的基础，是绿色建筑从哲学理念进入操作层次的重要环节。任何事物的评价必须根据相应的条件进行，由于世界各地的发展程度大不相同，本文提出了根据当地工程技术实际发展状况对建筑系统环境性能进行评价的方法，并由此定义了可以表示被评价建筑系统环境性能相对优劣程度的环境性能指标值。该方法具有可以准确反映对象的实际状况、不需要经常调整标准和可以更好地应用于建筑可持续发展性能研究的优点。
关键词　建筑系统；环境性能；评价方法；基于技术背景评价法；环境性能指标值

Research on Assessment Method of Environmental Performance of Building Systems

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Abstract The assessment is the basis of improvement of environmental performance of building systems, and is a key procedure in the implementation of green building from theory to practice. As an assessment should be carried out in certain range and on certain basis, this paper proposed an assessment method which is based on actual development level of building technology, and defined an objective concept of Environment Index (EI), which can figure the comparative performance of environmental performance of building systems. Compared with traditional assessment methods, this method expresses the status of environmental performance of building systems more precisely, needs not rectify the benchmark frequently in different situations, and is more suitable for the research of building sustainable development.
Keywords building system, environmental performance, assessment method, assessment based on development status, environmental performance index

评价是指“根据明确的目标、结构及属性，用有效的标准测定出被评价对象的性质和状态，然后与一定的评价准则相比较并做出判断的活动”[1]。在建筑系统环境性能[2]研究中，建筑系统环境性能评价是建筑系统环境性能改善的基础，是绿色建筑从哲学理念进入操作层次的至关重要环节。

1　建筑系统环境性能评价

1.1　建筑系统环境性能评价的意义

近年来，随着建筑系统环境性能逐步被人们重视，绿色建筑作为一种新的建筑概念得到了迅速的发展。绿色建筑实践是一项高度复杂的系统工程，这不仅需要规划师、建筑师、结构师、设备师等设计人员具有环境的概念，而且还需要所有者、管理者、施工者、使用者等也具有较强的环境意识。这种多专业多层次多阶段合作关系的介入，需要在整个绿色建筑的实践过程中（包括规划、设计、施工、调试、运行和拆除等阶段）建立明确的评价体系，以定量的方式来衡量建筑系统的环境

性能。这就是建筑系统环境性能评价，即采用数量化或等级化的手段对建筑系统的环境性能进行定量的描述。

建筑系统的环境性能应该建立在建筑系统的社会性能和经济性能的基础上，如果只片面地强调建筑系统的环境性能，而忽视了建筑系统的社会性能和经济性能，也不可能达到可持续发展的目的。因此，建筑系统环境性能的评价首先应该满足安全性、耐久性、适用性和经济性等基本性能，即满足建筑系统社会性能和经济性能的需要，在此基础上再对建筑系统的环境性能进行强调[3]。本文以国家颁布的各项相关规范和标准为平台，在此基础上对建筑系统的环境性能进行评价，即建筑系统首先应满足各项标准和规范后，也即满足用户要求的各项功能后，再进行环境性能评价。

建筑系统环境性能评价是随着人们对建筑环境性能重要性的认识不断加深而提出的新概念。建筑系统环境性能的研究可以概括为两个方面，一是建筑系统环境性能的基础研究，包括建筑系统环境影响的范围、作用机理、危害性等，二是建筑系统环境性能的改善途径。前者是理论问题，后者是现实问题。这两方面的问题紧密地联系在一起，其联系的纽带就是建筑系统环境性能评价。建筑系统环境性能评价是绿色建筑从哲学理念进入操作层次的至关重要的环节，如果没有建筑系统环境性能的评价指标体系、评价方法和模型，绿色建筑的思想就只能停留在定义上，即无法给出科学的界定，也无法指导实际操作。另一方面，绿色建筑作为发展方向必然涉及到实践方案的提出、制定、论证与评估等问题，尤其是对实践方案是否满足绿色建筑的要求做出判断，显得尤为重要。总之，在建筑系统环境性能研究方面，必须把环境性能评价放在首位。另外，从系统的角度来看，建筑系统环境性能评价是绿色建筑的管理、控制和设计的基础工作。

1.2　建筑系统环境性能评价的特点

由于建筑系统自身具有鲜明的特性，因此，与一般的环境性能评价相比，建筑系统环境性能评价具有以下的特点：

（1）多学科性

建筑系统环境性能评价工作涉及到现代科学技术的方方面面，不但包括建筑、环境、能源、材料、生态和设备等各技术学科，还包括美学、艺术、哲学、心理学等人文学科，如图 1 所示[3]，因此它要求各领域的专家通力合作，才能制定出一套科学的评价体系或标准。

（2）要求使用简单

建筑系统环境性能评价的实施一般要求跨学科进行，因此制定的评价体系和标准在实际操作中必须简单易行，这样才能方便各学科专业人员的使用，才能在实际工作中得到广泛推广和发挥作用。

（3）客观性要求高

建筑量大面广，因此需要进行的环境性能评价非常频繁，且参入的评价人员也必然很多，这就要求所建立的评价体系和标准的客观性较好，即评价结果不会因为评价人员的不同而发生变化。

对建筑系统环境性能进行评价是一项非常重要而又复杂艰巨的工作。只有从建筑系统环境性能评价的特点出发，才能制定出科学的评价体系和标准，从而有利于建筑系统的可持续发展。

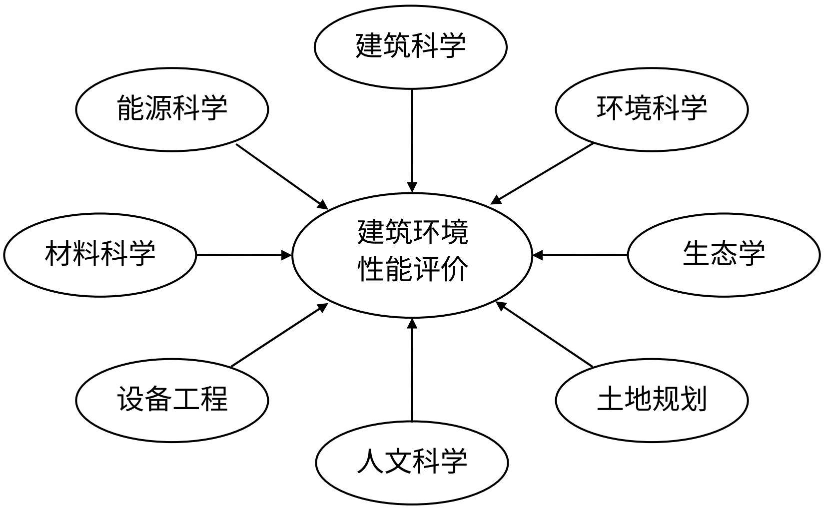

图 1 建筑系统环境性能评价的多学科性

2 等级化评价方法

建筑系统环境性能评价研究起源于 20 世纪 90 年代[4]。到目前为止，西方发达国家和地区相继开发了一大批建筑系统环境性能评价体系。虽然各国和地区的具体情况都不一样，各个评价体系的开发者对建筑系统环境性能的理解也不尽相同，但是大多数建筑系统环境性能评价体系都是以基准法集成模拟[5]得到的环境性能值为基础，然后再采用等级化评价方法对建筑系统环境性能进行评价，即将利用基准法集成模拟得到的环境性能值与一个（或一系列）基准值进行比较，从而得到最后的评价结果。以下为国际上现阶段常用的两种绿色建筑评价体系 BREEAM[6]和 LEED[7]的具体评价过程：

BREEAM 评价的内容包括全局问题和资源的使用、局部问题、室内问题等三个方面的多个子项目（建筑系统的类型不同，或评价体系的版本不同，则评价的子项目也不同）。BREEAM 首先将建筑系统各个子项的表现分别与一定的标准进行比较，根据比较结果得到相应的分数，最后，将各个子项的分数相加，即可得到代表建筑系统环境性能的总分数。这个过程本文称为基准法集成模拟。根据建筑系统最后得到的总分数，分别给予建筑系统“ 通过、好、很好、优秀 ”四个级别的评定。BREEAM 的总评价得分最高为 42 分，其具体评价标准等级见表 1[6]。

表 1 BREEAM 的评价标准等级

评价得分	绿色建筑证书类型
10 分	通过（Fair）
19 分	好（Good）
27 分	很好（Very Good）
36 分	优秀（Excellent）

LEED 的评价内容包括建设场地的选用、水的使用、能源和大气环境的影响、材料和资源的管理、室内环境质量控制、设计过程和创新等 6 个方面的一系列子项目，同 BREEAM 一样，LEED 也采用基准法集成模拟得到代表建筑系统环境性能的总分数。根据最后得到的总分数，被评价建筑

系统可以获得不同的认证等级：一般认证、银质认证、金质认证和白金认证。LEED 总评价得分最高为 69 分，其具体分级标准等级见表 2[7]。

表 2　LEED 认证评价等级

评价得分	绿色建筑证书类型
26－32 分	LEED 认证
33－38 分	LEED 银质认证
39－51 分	LEED 金质认证
52+ 分	LEED 白金认证

从这两种常用的评价体系可以看出，等级化评价方法具有以下局限性：

（1）基准制定困难

在等级化的评价方法中，基准的合理性是一个关键的问题，由于建筑系统环境性能不能直接进行测量，且现阶段的资料非常少，因此很难制定出合理的基准。

（2）需不断对基准进行调整

建筑系统的环境性能评价应该是一个动态的过程，因此在等级化的评价方法中必须不断地对基准进行调整，才能保证评价结果的合理性。

（3）不利于后续工作的开展

采用等级化的评价方式进行评价时，其评价结果为一个定性值，因此不利于后续研究工作的顺利进行。

3　本文提出的评价方法

3.1　环境性能评价方法制定的原则

在制定环境性能评价体系或标准时，一般应遵循以下原则：

（1）科学性原则

科学性原则是指制定环境性能评价标准时，首要考虑的是保障人体健康，生态环境系统和生产系统安全。这是环境性能评价的核心内容。环境性能评价不是终极目的，终极目的是通过对环境性能的评价，找出改善环境性能的途径和可能的方向。

（2）技术合理性原则

环境性能评价必须与当前一段时期内的科学技术发展水平相适应。如果标准制定得过高，超出了现实的技术条件所能达到的范围，则无法实现，再好的标准也只能是一纸空文。反之，如果标准定得太低，一味迁就现有的技术条件，则会失去环境性能评价的积极意义，因此，一定要根据被评价对象当时所处的技术背景进行评价。

（3）动态原则

环境性能评价标准是一个相对性的标准，是一个动态的标准，它应该随科学技术的进步而变化。例如，若对 A 与 B 进行相对比较时，如果 A 的环境影响值为 10，而 B 的环境影响值为 8，则相对而言，可以认为 B 对环境的影响较小，属于环境性能较好的对象。但经过改造后，A 的环境影响值降到 5，则又可认为，相对于 B 而言，A 对环境的影响较小，属于环境性能较好的对象。

正是由于这 3 大基本原则，使得环境性能评价体系或标准具有科学性、时间性、相对性、现实性和地区差异性等特征[8]。

3.2　本文提出的评价方法

通过以上对建筑系统环境性能评价特点和等级化评价方法的分析，并根据环境性能评价方法制定的三大原则，本文提出了一种数量化评价方法——根据技术背景进行评价的方法，即通过对被评价建筑系统的环境性能进行计算机模拟后，再根据其在现阶段技术条件下的相对表现进行数量化评价。

计算机模拟是指利用计算机技术对被研究对象的性能进行分析和预测。在发达国家，计算机模拟技术早已渗透到了各个科学领域，并已取得了非常好的效果。计算机模拟在建筑系统性能研究中也得到了广泛的应用，已经成功地解决了许多重点和难点问题。由于计算机模拟具有科学、公正、客观的优点，因此可以避免人为的臆断和片面性[9]。

根据技术背景进行评价是指根据当前技术发展的实际水平进行评价，即确定出被评价对象的性能在现阶段所有同类对象中的相对优劣程度。在本文中，技术背景是指当前技术发展的实际状况，即现阶段市场上所有已经成熟使用的技术，而一些已经淘汰或规定不准使用的技术，或者尚处于研究中，但未开始推广的技术，均不进行考虑。技术背景是一个动态的概念，它会随着时间的发展而不断变化，因此每隔一段时间需对其进行调整。

3.3　根据技术背景进行评价的步骤

本文提出的根据技术背景进行评价的主要步骤如下：

（1）选定进行环境性能评价的对象

被评价的对象可以是建筑系统的整体，也可以是建筑系统的一个子系统，或是建筑系统的一个构件；被评价的阶段可以是建筑系统的全寿命周期，也可以是建筑系统的建造、运行和拆除阶段中的一个或多个。这就是建筑系统环境性能的全过程评价。

（2）对建筑系统环境性能进行计算机模拟

通过计算机模拟，利用文献[5]提出的直接集成式模拟方法，可以客观地计算出被评价对象的环境性能，从而保证了评价基础的客观性，并大大降低了建筑系统环境性能评价应用的复杂性。

（3）根据技术背景对对象的环境性能进行评价

对于同一个被评价对象，如果所处的技术背景不一样，则它的环境性能在所有同类对象中所处的相对状况可能也不同，因此必须根据当时的技术条件进行评价，才能正确衡量被评价对象环境性能的优劣。

（4）对评价结果进行分析，并提出改善的方法

根据评价结果和目标要求的差距，对被评价对象的各种要素进行改进分析。由于采用了计算机模拟，因此可以很快地模拟出各种参数改变后评价结果的变化，这就使得使用者可以很方便地找到改善的方法。

4　根据技术背景进行评价的关键内容

4.1　评价范围的确定

任何对象的评价都应该限制在一个具体的范围之内，不可能脱离一定的范围进行。因此，在进行建筑系统环境性能评价之前，也必须确定一个评价范围，即确定相互进行比较的对象。

由于多方面的原因，现阶段的建筑设计中“ 垒墙式 ”设计[10]依然占据着重要的地位，另外，现阶段人们对建筑环境性能的重视还不够，很多时候以经济性能和社会性能为主要评价目标。因此，为了提高本文研究成果的实用性和可行性，本文认为在现阶段的设计过程中，建筑的外形设计依然处于一定优先的地位，即对于给定位置和用途的建筑，建筑师先根据各方面的因素（如场地的限制、使用的要求，用户的喜爱等）确定建筑的外形，然后再利用本文的研究成果确定围护结构的材料和各种附属子系统的形式。

根据以上理念，本文定义的评价范围如下：评价是在相同位置、相同功能和相同外形（以下简称为“ 三同 ”）的所有可能的建筑系统之间进行。即将建筑师设计的建筑系统与所有位于同一位置、有着同样功能和外形，但围护结构材料和附属子系统形式不同的建筑系统的环境性能进行比较，从而确定被评价建筑系统的环境性能在这些所有可能的建筑系统中的相对优劣程度。

4.2　技术背景的确定

在本文提出的根据技术背景进行评价的方法中，和等级化评价方法最大的不同是根据技术背景进行评价。本文采用被评价建筑系统的“ 三同 ”建筑系统中最好和最差的环境性能代表被评价建筑系统所处的技术背景。

“ 三同 ”建筑系统是指与被评价建筑系统位置相同、功能相同和外形相同的建筑系统，它们其实是被评价建筑系统在位置、功能和外形确定后所有可能出现的具体实现形式。“ 三同 ” 建筑系统最好环境性能就是指所有这些具体形式中的最好环境性能，而“ 三同 ”建筑最差环境性能就是指所有这些具体形式中的最差环境性能。

在被评价建筑系统的“ 三同 ”建筑中，所有具体实现形式采用的技术均是现阶段已经成熟使用的技术，因此，一些尚处于试验阶段和已经淘汰的技术都不在使用之列。这就保证了技术背景真正能够反映时代的进步，从而使得评价结果随着社会的发展而在不断地变化，因而具有很好的时效性。

在本文中，“ 三同 ” 建筑系统最好和最差环境性能根据基本数据库计算得到。本文的基本数据库借鉴股市中指标股的概念建成，即首先建立各种材料和技术数据库（数据库的容量足够大，因而可以代表这些材料和技术的实际发展程度），然后每隔一段时间（如一年左右）对市场上同类材料和技术进行调查，去掉已经淘汰或规定不准使用的材料和技术，加入在实践中已经得到推广使用的新材料和技术，这就使得基本数据库可以充分反映当今技术的发展和变化。

4.3　环境性能指标

为了更好地描述建筑系统环境性能的评价结果，本文引进了一个新概念——环境性能指标（Environment Index, *EI*）。*EI* 是一个直接反映建筑系统环境性能好坏的定义，无量纲，在 0~100 之间，数值越大，表示被评价建筑系统的环境性能越好。*EI* 为 0，表示被评价建筑系统的环境性能在所有“ 三同 ”的建筑系统中最差，相反地，*EI* 为 100 表示建筑系统的环境性能为最好。

环境性能指标可以根据式(1)进行计算。

$$EI = \frac{EP_{\max} - EP}{EP_{\max} - EP_{\min}} \times 100 \qquad (1)$$

式中：EI 为被评价建筑系统的环境性能指标；EP 为被评价对象的环境性能模拟值；$EP_{\max}$ 为在现有技术背景下“三同”建筑系统中的最差环境性能值；$EP_{\min}$ 为在现有技术背景下“三同”建筑系统中的最好环境性能值。

根据式(1)可以知道，EI 是一个反映建筑系统环境性能相对优劣的无量纲值，它表示被评价建筑系统的环境性能在所有“三同”建筑系统中所处的相对优劣程度。例如，如果某建筑系统的 EI 为 80，则表示该建筑系统的环境性能与其“三同”建筑系统中的最优环境性能存在着 20%幅度的差距（此处幅度是指“三同”建筑系统中最差环境性能值与最好环境性能值间的差别）。

5 结论

本文在建筑系统环境性能模拟研究的基础上，通过对等级化评价方法的分析，提出了基于技术背景的建筑系统环境性能评价方法，并由此定义了建筑系统环境性能指标的概念，用来表示被评价建筑系统的环境性能在“三同”建筑系统中的相对优劣程度。由于根据技术背景对建筑系统进行评价后，可以知道该建筑系统环境性能在所有“三同”建筑系统中所处的相对水平，因此，与现阶段建筑系统环境性能评价相比，根据技术背景进行的环境性能评价具有以下优点：

（1）可以准确反映对象的实际状况

采用本文提出的评价方法，其评价结果就是被评价建筑系统环境性能在“三同”建筑系统中所处的相对水平，这就明确地显示出了被评价对象环境性能的提高潜力。例如，某建筑系统的 EI 值为 60，则表示该建筑系统环境性能的提高潜力是 EI 为 80 的建筑系统环境性能的提高潜力的 2 倍。

（2）不需要经常调整标准

采用根据技术背景进行评价的方法，不需要每隔一段时间对评价基准重新进行研究，只需要根据相关技术的成熟状况对基准数据库进行调整，加入一些新出现的材料和技术，剔除一些已经淘汰或禁止使用的材料和技术，就可以使得评价结果跟上社会的发展。

（3）可以更好地应用于建筑可持续发展性能的研究

对于可持续发展来说，环境性能只是其中的一个指标，它同样也是一个多指标的集成，如经济性能、社会性能等，由于采用本文提出方法得到的评价结果为定量化指标，因此可以直接用于可持续发展性能的综合。

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交通主干道旁室内外空气污染物分析研究

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摘　要　针对上海城市二条交通主干道旁室内外 TSP、PM_{10}、CO、CO_2、NO_2、甲醛（HCHO）、苯、甲苯和二甲苯等空气污染物浓度，进行现场监测，分析研究室内外主要空气污染物及其 I/O 比值，以及日变化规律。结果表明：城市交通主干道旁室内空气污染程度主要取决于室外机动车交通流量及其所使用的燃料。
关键词　交通主干道；室内外（I/O）；空气污染物
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Analysis and Study of Indoor and Outdoor Air Pollutants beside the Trunk Road

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Abstract　The indoor and outdoor air pollutant concentrations beside two trunk roads in Shanghai were measured in this paper. The air pollutants measured were TSP, PM_{10}, CO, CO_2, NO_2, formaldehyde (HCHO), benzene, toluene and xylene. The indoor and outdoor air pollutants and the correlation between them were analyzed. Then study on the diurnal cycles of outdoor and indoor concentrations. It is shown that: the level of indoor pollution beside the trunk road lies on the flow and the type of vehicles.

Keywords　the trunk road; indoor/ outdoor (I/O); air pollutants

随着城市经济的发展，现代人们生活生活水平和工作条件得到不断改善，人们越来越关注室内空气污染的状况。希腊、韩国等国外专家学者的有关研究显示：室内空气污染物浓度与室外存在一定的相关性[1,2]；原采用室外空气污染物浓度值来表示的人体接触总量，并不能准确地反应人体的实际接触量，尤其是短期平均接触量，为此不仅应对室外空气污染物浓度进行监测分析，而且还应分析室内的空气污染状况[3~5]；含有大量对人体有害物质的机动车排放尾气，严重污染位于城市交通主干道旁的建筑物室内空气[6]。我国台湾和香港地区的专家学者对一些典型场所室内的主要空气污染物浓度进行现场监测，并初步分析室内外主要空气污染物的相关性[7-9]，如地铁及地下场所、商场、交通主干道两侧建筑物、住宅区和大学校园等。此外，我国室内空气污染的研究多数集中在建筑和装饰材料对室内甲醛、氨、苯系物（BTEX）、氡浓度的监测统计[10-11]。

上海作为我国最大的经济中心城市，其日益严峻的交通问题和不断增加的机动车加重了城市环境污染负荷，致使如交通主干道旁等局部地区的空气环境质量不断恶化。但是，上海城市的气候特征、建筑物结构、建筑物的通风方式及居民生活习惯与欧美等国家，以及我国台湾和香港地

区有所不同。因此，本文选取二条上海城市交通主干道旁室内外的主要空气污染物，作为研究对象，探讨上海城市交通主干道旁室内外空气污染的特性及其变化规律。

2 监测部分

2.1 监测地点及交通流量

监测地点 1＃，室外点位于军工路与控江路交叉口，室内点为邻近的启明楼客房内，清洁对照室外点位于上海理工大学校园内机械楼三楼平台，对照室内点为机械楼 311 室内。军工路是上海市的交通主干道，所行驶的车型多为重型集卡，车流量约为 1500 辆/时。

监测地点 2＃，室外点位于杨浦大桥浦西引桥段两侧，室内点为毗邻的上海市杨浦建设集团大楼平台。杨浦大桥的车流量约为 7000 辆/时。

2.2 监测时间及气象参数

监测时间选择的五个双休日和五个工作日，以及监测期间的气象参数，如表 1 所示。

表 1 监测期间的气象参数

日期（年/月/日）	温度(℃)	大气压强(kPa)	风速（m/s）	风向	相对湿度（%）
2004 / 03 / 27	15－18	102.2	3.4－7.9	东北	83
2004 / 03 / 28	16－18	102.0	3.4－7.9	东北	88
2004 / 03 / 31	15－20	102.1	5.5－10.7	东南	54
2004 / 04 / 04	17－24	102.3	5.5－10.7	偏北	50
2004 / 04 / 05	13－21	101.6	5.5－10.7	偏北	55
2004 / 05 / 10	17－29	101.0	5.5－10.7	偏西	5 0
2004 / 05 / 22	15－24	100.7	3.4－7.9	偏东	67
2004 / 05 / 23	17－25	101.1	3.4－7.9	东南	70
2004 / 05 / 25	18－27	101.1	3.4－7.9	东南	67
2004 / 05 / 26	22－31	100.9	3.4－7.9	偏南	73

2.3 监测方法

（1） TSP：重量法，KC-12GH 型智能中流量 TSP 采样器，流量 100mL/min；

（2） PM_{10}：重量法，KC-12GH 型智能中流量 TSP 采样器及旋风 PM_{10} 切割器，流量 100mL/min；

（3） 甲醛：酚试剂分光光度法，KC-6D 型大气采样器，流量 0.5mL/min；

（4） NO_2：盐酸萘乙二胺分光光度法，KC-6D 型大气采样器，流量 0.5mL/min；

（5） CO、CO_2：气相色谱法，双链橡皮球及铝膜复合薄膜采气袋；

（6） 苯、甲苯、二甲苯：气相色谱法，KC-6D 型大气采样器及 Tenax 管，流量 0.5mL/min。

3 结果分析与讨论

3.1 空气污染物室内外浓度监测结果与分析

实验监测得到的两条交通主干道旁空气污染物室内外浓度的监测结果如表 2、3 所示。

监测地点 1＃的 TSP 和 PM_{10} 的平均室外浓度超过了环境空气质量标准（GB3095-1996）中的二级标准。其它污染物的室内外平均浓度均未超标。

室内/外，即 I/O 是衡量空气污染物室内外浓度相关性的指标之一，可通过其来分析室内空气

污染物的来源。由表 2、3 可看出：两条交通主干道旁的 TSP、PM_{10}、NO_2 和 CO 的 I/O 大于 1，这说明它们的污染源主要存在于室外。上述污染物的室外污染源主要是交通主干道上所行驶的机动车，其尾气中含有大量的 TSP、PM_{10}、NO_2 和 CO 等空气污染物。甲苯的 I/O 接近于 1，说明甲苯既有室外污染源，又有室内污染源。甲醛、CO_2、苯和二甲苯的 I/O 大于 1，说明它们的污染源主要存在于室内。甲醛、苯和二甲苯的室内污染源主要是装修、装饰材料，而 CO_2 主要是人群活动。

由表 2、3 的对比可以看出：(1) 监测点 1＃的 CO 的室内外平均浓度都要小于监测点 2＃，这可能是由于监测点 1＃旁的交通主干道的车流量要小于监测点 2＃。这说明交通主干道旁的空气污染物室内外浓度与机动车的流量有关。(2) 监测点 1＃的 TSP 和 PM_{10} 的室内外平均浓度都要大于监测点 2＃。这可能是由于监测点 1＃旁的交通主干道上所行驶的车辆多为柴油车，而监测点 2＃旁的交通主干道上所行驶的多为汽油车。且柴油车排放的尾气中 PM_{10} 含量要远远大于汽油车[12]。这说明交通主干道旁的空气污染物室内外浓度还与机动车所用的燃料有关。综上所述，交通主干道旁的空气污染物室内外浓度主要取决于机动车的流量及其所使用的燃料。

表 2　监测点 1＃空气污染物室内外浓度的监测结果

污染物	室内		室外		I/O	对照点室内		对照点室外		I/O	国标
	平均浓度	标准偏差 SD	平均浓度	标准偏差 SD		平均浓度	标准偏差 SD	平均浓度	标准偏差 SD		室内/室外
$TSP^{*}\times10^{-3}$	0.30	0.14	0.53	0.27	0.57	0.09	0.04	0.34	0.16	0.26	一 / 0.30
$PM_{10}{}^{*}\times10^{-3}$	0.10	0.02	0.26	0.05	0.38	0.03	0.01	0.09	0.03	0.33	0.15 / 0.15
$NO_2{}^{**}\times10^{-3}$	0.06	0.01	0.07	0.01	0.86	0.03	0.01	0.04	0.01	0.75	0.24 / 0.24
$HCHO^{**}\times10^{-3}$	0.05	0.02	0.03	0.01	1.67	0.09	0.03	0.04	0.02	2.25	0.10 / 一
$CO^{**}\times10^{-3}$	0.80	0.35	1.14	0.33	0.70	0.56	0.12	0.65	0.12	0.86	10.0 / 10.0
$CO_2{}^{*}$ (%)	0.10	0.02	0.07	0.02	1.43	0.10	0.01	0.07	0.02	1.43	0.10%/一
苯**	6.05	2.27	4.92	2.05	1.23	8.74	2.99	5.44	1.23	1.61	110 / 一
甲苯**	18.50	5.64	19.66	9.83	0.94	16.56	4.80	13.20	3.84	1.25	200 / 一
二甲苯**	22.08	11.04	14.46	7.23	1.53	13.58	6.63	9.94	4.70	1.37	200 / 一

表 3　监测点 2＃空气污染物室内外浓度的监测结果

污染物	室内		室外		I/O	国标
	平均浓度	标准偏差 SD	平均浓度	标准偏差 SD		室内/室外
$TSP^{*}\times10^{-3}$	0.17	0.05	0.20	0.08	0.85	一 / 0.30
$PM_{10}{}^{*}\times10^{-3}$	0.08	0.05	0.11	0.04	0.73	0.15 / 0.15
$NO_2{}^{**}\times10^{-3}$	0.06	0.02	0.07	0.02	0.85	0.24 / 0.24
$HCHO^{**}\times10^{-3}$	0.08	0.03	0.03	0.01	2.67	0.10 / 一
$CO^{**}\times10^{-3}$	0.85	0.14	1.57	0.68	0.54	10.0 / 10.0
$CO_2{}^{*}$ (%)	0.09	0.02	0.07	0.01	1.29	0.10%/一
苯**	8.36	2.09	4.97	1.70	1.68	110 / 一
甲苯**	22.00	5.94	22.81	6.84	0.96	200 / 一
二甲苯**	9.94	4.84	7.80	2.55	1.27	200 / 一

注：(1) 室内空气污染物浓度采用室内空气质量标准（GB/T 18883-2002）；室外空气污染物浓度采用环境空气质量标准（GB3095-1996）中的二级标准。

(2) *表示日平均值，**表示 1 小时平均值。

3.2　室内外浓度的日变化规律

机动车排放的主要污染物是 TSP、PM_{10}、NO_2、CO、苯、甲苯和二甲苯。由于实验条件的限制，无法分析 TSP 和 PM_{10} 的日变化情况。苯——甲苯、苯——二甲苯和甲苯——二甲苯之间的相关系数，由计算可获得 0.937、0.993 和 0.743，说明苯、甲苯和二甲苯之间的相关性较强，因此它们的日变化规律相似。为此，监测点 1# 的室内外 CO、NO_2 和苯的浓度的日变化曲线，如图 1-9 所示。

从图 1-3 中可以看出，室外 CO 浓度的日变化曲线呈现四个较为明显的峰值。其中两个峰值出现在早晨 8：30，其浓度为 2.39mg/m^3，该值也是一天中室外 CO 浓度的最高值。该时段是早晨人们外出上班的车流高峰段，且早晨的气象条件不利于污染物的扩散。另一个峰值出现在傍晚 18：30 左右，这恰好是人们下班回家的时候。还有一个峰值出现在深夜 22：30 左右，这可能是由于外出娱乐的人们回家所造成的车流量增多所引起的，还可能是因为夜间稳定的气象条件不利于污染物的扩散所导致的。从中午到傍晚，室外 CO 浓度始终维持在一个较低的水平，这可能是因为：（1）车流量，中午到傍晚这段时间内，军工路上的车流量较少；(2）气象条件，中午气温较高，且监测点周围的地形开阔，无高大建筑物，地面散热快，

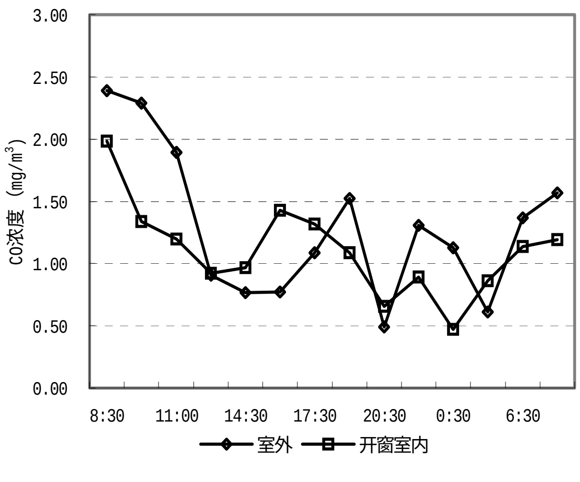

图 1　开窗条件下室内外 C0 浓度的日变化曲线

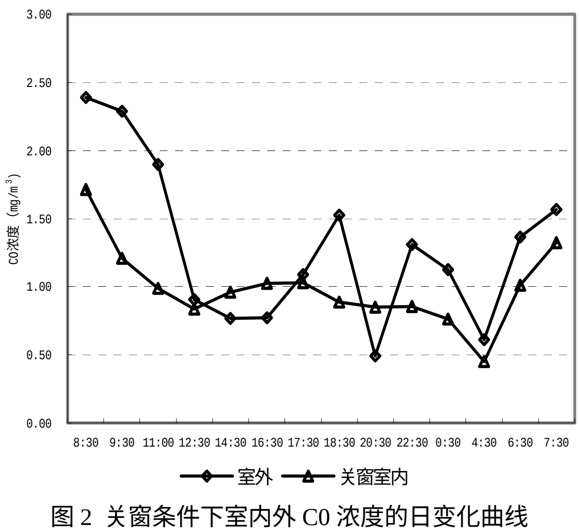

图 2 关窗条件下室内外 C0 浓度的日变化曲线

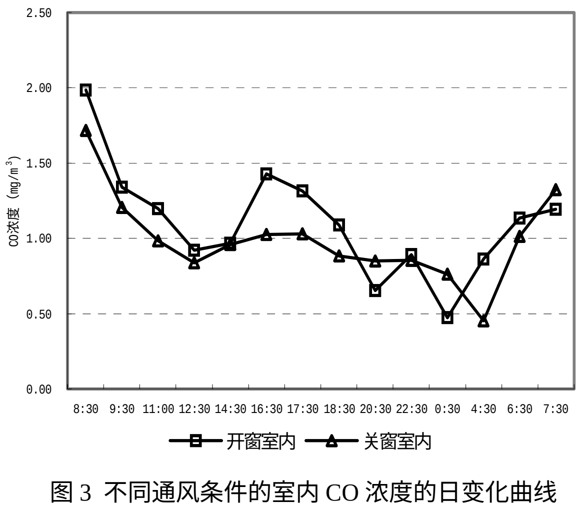

图 3 不同通风条件的室内 CO 浓度的日变化曲线

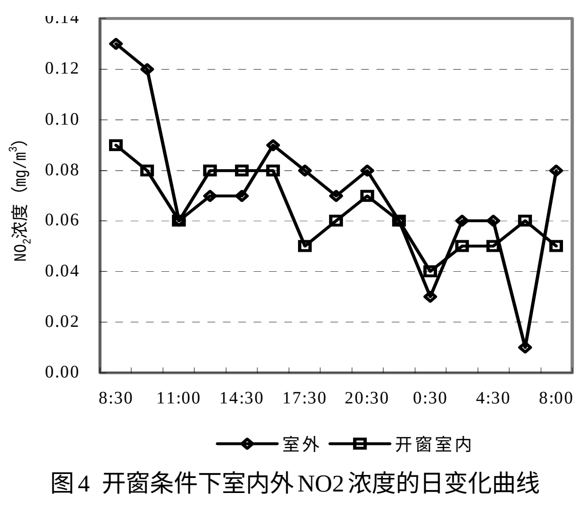

图 4 开窗条件下室内外 NO2 浓度的日变化曲线

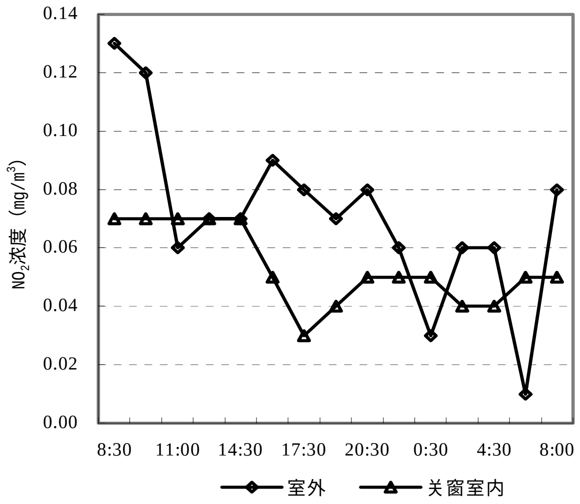

图 5 关窗条件下室内外 NO2 浓度的日变化曲线

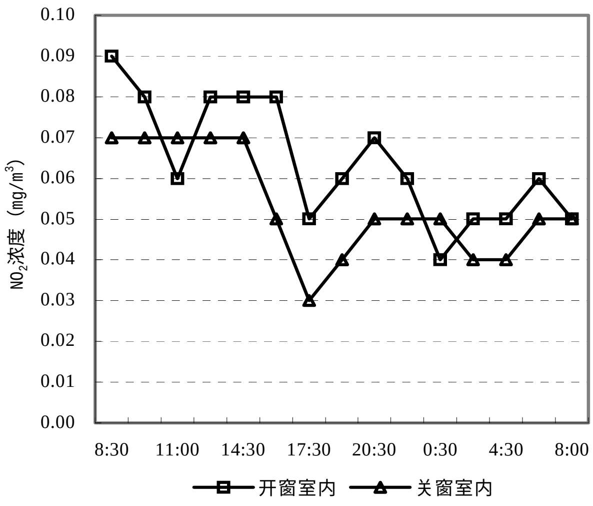

图 6 不同通风条件的室内 NO2 浓度的日变化曲线

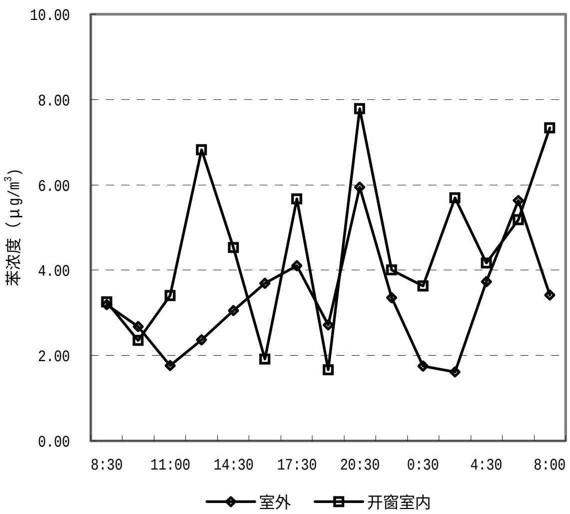

图 7 开窗条件下室内外苯浓度的日变化规律

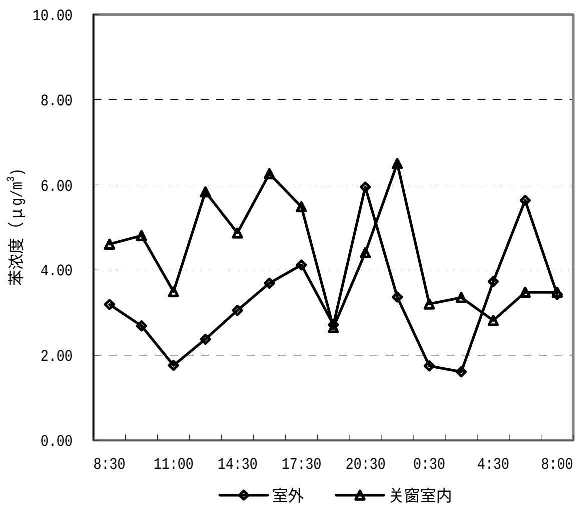

图 8 关窗条件下室内外苯浓度的日变化规律

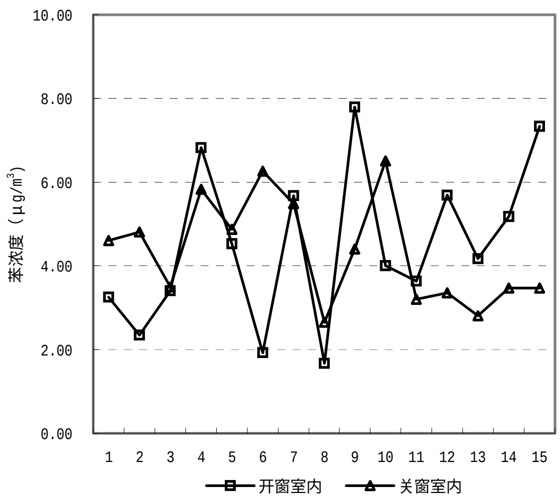

图 9 不同通风条件的室内苯浓度的日变化规律

造成对流运动剧烈，对空气中的一氧化碳的稀释和净化能力较强。开窗条件下测得的 CO 室内浓度的日变化趋势与室外基本一致。而关窗条件下测得的 CO 室内浓度的日变化幅度相对较小，这可能是因为在没有室内污染源的条件下，影响室内 CO 浓度的因素主要是室外污染源。而在关窗条件下室外污染源对室内的影响程度要小于在开窗的条件下。所以实验测得的关窗条件下室内 CO 浓度小于开窗条件下。

由图 4－6 可以看出，室外 NO_2 的日变

化曲线同样呈现四个较为明显的峰值，其峰值出现时间与 CO 基本一致。开窗条件下的 NO_2 浓度要大于关窗条件下。

由图 7－9 可以看出，室外苯的日变化曲线同样呈现四个较为明显的峰值，其峰值出现时间与 CO、NO_2 基本一致。由于苯除存在室外污染源外，还存在着较强的室内污染源，因此开窗条件下室内苯的日变化规律与室外变化规律并没有呈现较强的相似性。

4 结论

通过对军工路－控江路交叉口旁边、杨浦大桥浦西引桥旁边的室内外 TSP、PM_{10}、CO、CO_2、NO_2、甲醛、苯、甲苯、二甲苯浓度的监测并分析，可得到了以下结论：

（1）甲醛、CO_2、苯和二甲苯的 I/O 均大于 1，说明两个监测点室内存在着这些污染物的污染源。

（2）TSP、PM_{10}、NO_2 和 CO 的 I/O 均小于 1，说明其室内浓度在很大程度上受到室外浓度的影响。

（3）室外污染物对室内污染均有不同程度的影响，特别是在早晨和傍晚时，室外的浓度均较高。主要污染物 PM_{10} 和 TSP，室内外均有不同程度的超标。因此，实验结果显示，城市交通主干道两侧室内空气污染受室外的影响较大，其污染程度主要取决于机动车交通流量及其所使用的燃料。

（4）不同监测点的污染物浓度存在着一定的差异。说明机动车的流量及其所使用的燃料对空气污染物的种类、浓度都会产生一定的影响。

（5）开窗室内的 NO_2 和 CO 变化规律和室外变化规律基本相似。

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生物标志物在室内空气质量健康影响评价中的应用

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摘　要　生物标志物检测是目前研究健康影响因素早期预防和诊断检测最常用的方法之一,本文介绍了室内空气主要指示污染物的确定方法，以及近年来几种代表性的室内污染物（甲醛、苯和氡）生物标志物的研究进展，并探讨了生物标志物在室内空气质量健康影响评价的应用。

关键词　生物标志物；室内空气质量；健康影响；应用

Biomarkers and Application for Health IAQ Assessment

Abstract　At present biomarker detecting is one of the most popular prevention and diagnoses methods for detecting the factors that affect the health. This paper introduces the methods to determine the main pollutant indicators for indoor air, and the research proceed of the representative biomarkers, such as formaldehyde, benzene and Radon. Also the paper discusses biomarkers application for indoor air quality health risk assessment.

Keywords　biomarker, indoor air quality, health, effect,

1　引言

随着人们生活水平的提高，许多家庭对室内进行了装修，在美化室内生活环境的同时，有些建筑材料和装修材料（如涂料、胶合板材、壁纸和油漆等）的使用给室内带来了新的污染。这些材料产生的污染物据测定达五百余种，大部分是挥发性有机物（甲醛、苯系物、氨等）和放射性物质等（氡及其子体）等[1]，其中约有 20 多种为致癌物或致突变物。各种污染物在室内装修后一段时间内会不断释放到室内空气中，对于 80%时间生活在室内的人们来说，可能产生不同程度的健康损害，如一些呼吸道刺激性症状和疲乏、无力、记忆力下降等症状（即所谓的“不良建筑物综合症”），严重的可致癌[1]。

在室内多种污染物的健康危害评价中，一般选取一种或几种污染物进行动物短期高剂量暴露实验资料进行外推。但是污染物毒性从高剂量向低剂量外推必然存在不确定性，且缺乏长期低剂量暴露健康效应的资料和从总体上分析和评价多种室内污染物的联合作用。目前室内空气质量与室内人群健康研究存在着室内污染物浓度较低，而高剂量向低剂量外推的方法在室内污染物种类较低的情况并不完全适用。因此采用生物标志物技术，将检测机体暴露于低剂量污染物后，检测机体出现的神经行为、生理、生化、细胞、免疫或分子的变化以及污染物在机体内的代谢产物水平，分析它们与污染物的暴露水平和出现各种效应之间的相关程度，估计这些污染物与特定危险性的关系。

由于室内污染物种类太多，因此必须从众多污染物中选取在污染物总量中占比例较大的具有代表性的指示污染物，分析这些指示污染物在不同暴露水平下动物和人群出现的各种效应及其生物学

标志物，计算各种指示污染物对在各种效应中的贡献率，选择具有代表性接触的效应生物标志物，建立数学模型，对室内空气中污染物进行卫生学评价。

2 指示污染物的确定方法

室内指示污染物的确定主要包括理化性质分析，动物实验研究和人群流行病学调研。

2.1 调查市场上各种建筑装修材料的制造工艺、主要成份及它们的理化性质，查阅文献，了解它们在动物和人体内的生物转化代谢过程和毒作用强度。选择新建或新装修的住房，检测室内实际存在的污染物，并对各种污染物之间进行相关分析，依照其相关程度进行分类，测定各种污染物的在室内的转归情况、浓度变化，最终确定各类污染物的指示污染物。如挥发性有机物有甲醛、苯、二甲苯、三氯乙烯、三氯甲烷、二异氰酸、氨和甲苯酯等，但甲醛和苯占 90%以上，所以甲醛和苯可作为挥发性有机物的指示污染物[2]。放射性物质主要是氡及子体。

2.2 动物实验，对所确定的指示污染物进行动物实验，检测各种指示污染物在不同暴露水平不同时间，动物出现各种效应时的接触和效应的生物学标志物。实验可分为两部分，首先用每一种指示污染物在染毒室内进行毒理学实验（急性、慢性、三致试验），测定其在染毒的不同暴露水平和不同时间内，出现某种效应时的污染物室内浓度、动物接触总剂量、体内生物材料（血、尿等）中的此污染物及代谢产物的含量并作相关性分析。然后在单个指示污染物的毒性实验基础上，模拟室内装修环境，检测在不同时间内污染物的暴露水平，动物出现可检测到的接触和效应的生物标志物，各种污染物所占的比例及对某种毒性效应的贡献率。

2.3 暴露人群流行病学研究，由于室内装修中装修工人职业接触各类污染物的时间较长，各种污染物对他们的作用也比较强，产生的各种毒效应也比较明显，可以先选择这一特殊人群进行健康调查，结合以上动物实验和收集前人研究资料的结果，采集易得的有效的生物样品，检测在出现各种效应时各种生物标志物的含量及其与指示污染物暴露水平的关系，进一步选择有代表性的接触和效应的标志物。再选择装修后迁入住宅的人群，测定室内空气中各种污染物在不同时间内的浓度变化，根据污染物的理化性质和在生物体内的代谢特点，在不同暴露水平和不同时间内，计算人群的各种指示污染物的累积暴露量，采集易得的生物样品检测不同健康效应下的接触和效应的生物标志物，并对污染物室内浓度、暴露接触总剂量、体内生物材料（血、尿等）中的指示污染物及其代谢产物的含量作相关性分析。

几种代表性指示污染物的生物标志物

国内外室内环境中化学性和放射性污染研究比较深入，室内空气中化学性和放射性污染物对机体的健康影响的生物标志物主要集中在甲醛、苯和氡及其子体在机体内产生可检测到的生理生化变化。

甲醛：甲醛是一种刺激性的气体，经呼吸道吸入引起呼吸道和肺部症状，可再经血液累及其他系统，导致鼻腔鳞状上皮细胞癌和肺癌[3]。由于甲醛进入血液后和人血清蛋白（HAS）共价结合，使得与半抗原甲醛有关的甲醛－HAS 加合物的含量升高，且经实验检测其含量与甲醛的暴露水平相关性很强，所以甲醛－HAS 加合物可作为甲醛接触生物标志物[4]；动物实验表明，甲醛引起大鼠肺细胞损伤和脂质过氧化作用，可检测出肺组织中脂质过氧化物（LPO）量及 LPO／GSH－PX 均

增高，且与甲醛存在剂量－反应关系，亦可致大鼠肺巨噬细胞 DNA 交联性和 DNA 单链断裂损伤[5]；在人群暴露调查中，发现甲醛可引起人外周血淋巴细胞、人鼻粘膜上皮细胞微核率增加[6]，这些都说明甲醛还是一种染色体断裂剂和非整倍体诱变剂。

苯：苯经呼吸道、皮肤进入机体，在体内的代谢产物具有致毒、致癌作用。 因此可以通过检测暴露于苯后机体内各种活性代谢产物的含量，并分析它们与苯的暴露水平的相关性，以确定苯在低暴露水平机体内的接触和效应的生物标志物。与苯暴露水平相关性较好的代谢产物可作为苯在体内的内剂量标志物的有尿反－反式粘康酸的苯疏基尿酸[7]；小鼠毒性实验表明苯及其主要代谢产物均能在小鼠骨髓细胞中形成 DNA 加合物，显示髓样毒性，且与 DNA 加合物水平平行[8]；人群研究证明苯氧化物可与血红蛋白、血清蛋白中的半胱氨酸形成蛋白质加合物，且与苯接触水平有关[9]；由于长期接触苯可引起再障、白血病等，是一种致癌物，苯对 DNA 的损伤可作为苯对机体致癌效应的生物标志物，在接苯人群中外周血淋巴细胞微核检出率增加且随暴露时间上升[10]；苯及其代谢产物可引起机体 8－OHDG 排出增多，8－OHDG 是反映 DNA 受羟基基团攻击损伤的指标，能引起 DNA 断裂[7]；另外粘蛋白 A（GPA）突变法检测外周血红细胞突变表达可检验骨髓细胞中的干细胞或细胞前身细胞的突变，且与累积接苯量有明显的剂量－反应关系，与苯致白血病危险性相关性最强，因此 GDP 可能是苯致白血病因子作用的早期效应标志物[11]。由于上述资料多来自于长期接触工人，暴露水平和时间可能与室内装修有较大的区别，所以必须进一步实验以探索在低暴露水平下敏感的人群接触和效应的生物标志物。

氡及其子体：空内放射性物质氡及其子体占 90%，所以室内氡可作为放射性污染的指示污染物。氡及其子体可经呼吸道进入肺，在放射性衰变中发出放射线对人体健康造成慢性或潜在的危害；另一方面，氡的衰变产物也会浸入肺支气管壁形成凝结体，Tayolr 在 1994 年发现在氡引起的肺癌中有三分之一的 P53 基因发生了突变[12]。氡又可经血液到达骨髓，并溶解于脂肪细胞中，发生衰变产生的粒子向周围的骨髓的造血细胞释放能量，造成骨髓中造血细胞的放射损伤[13]。Richardson 观察了外周血淋巴细胞次黄嘌呤磷酸核糖转移酶基因的突变率与室内氡浓度存在明显的相关性[13]。提示可从分子水平结合氡在体内的代谢和转运过程寻找接触和效应的生物标志物。

生物标志物在人群健康危害评价的应用

室内空气污染存在着污染物复杂，低浓度和长期暴露的特点，且污染物对室内人群产生的健康影响由于所选择的健康损害器官及其产生的生理生化变化较大。因此要对室内所存在主要污染物毒性进行危害认定和评价。必须先选择具有代表性的污染物，其应具备长期存在、稳定、易检测和且经济技术上可行等特点。然后再对室内污染物检测与分析、毒理学动物实验、人群健康调查和生物监测，对所选择的指示污染物进行分析，探索这些污染物在低剂量长时间暴露后，可能产生的健康效应的类型和特征。

通过分析指示污染物在机体内的代谢、转移和消减机制，选择特定组织成分中特异性强、灵敏度高、在体内稳定的生物标志物，分析它们与污染物的暴露水平和出现各种效应之间的相关程度，估计这些污染物与特定危险性的关系。计算各种指示污染物在室内可接受的浓度，并蒋健康危害的程度加以量化，使多种污染物的健康效应具有横向和纵向性可比性。综合各种指示污染物在室内暴

露水平、机体在可接受的效应的危险度水平下出现的各种接触和效应的生物标志物、在污染物总量中的比例和对健康影响的贡献率，建立数学模型，对室内空气污染物对健康影响的危险度进行综合评价。为制定室内污染物的卫生标准提供科学资料，达到控制室内各种污染物水平，从而最大限度地保护人群健康。

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住宅建筑室内声、光环境的调研与分析

——《上海市生态型住宅小区技术实施细则》室内声、光环境评估和要求探析

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摘　要　生态住宅的建设和评估是一个全新的课题，是一个开放的体系；应当随着相关专业领域研究工作的深入不断充实新的内容。本论文根据作者的实地调研对城市住宅建筑室内声、光环境所存在的缺陷作了初步的分析。

关键词　室内声环境；室内光环境；生态型住宅

Research on the Indoor Lighting and Acoustic Quality in the Ecological Residential Buildings

——indoor lighting and acoustic requirements analysis according to the "*Ecological Residential Buildings Guidance manual of Shanghai*"

(Shanghai Research Institute of Building Sciences, 200032)

Abstract　The construction and assessment of ecological residential buildings are new topics for the researchers in related fields. So we should renew or amend this guidance manual with the developing of our research work.

Key Words　indoor lighting environment; indoor acoustic environment; ecological residential buildings

1　室内声环境

1.1　卧室之间的隔声要求

主卧与次卧最好在平面上分开布置，因为主人和孩子的作息常常是不一致的，这样可以减少或避免两者之间的相互影响。平面上相邻时应加强隔墙、门的隔声性能。在接受采访的家庭当中，主卧、次卧的门隔声效果普遍很差，门的隔声能力主要取决于其自身的隔声性能和密封程度，笔者认为在现有情况下提升门自身的隔声能力是不现实的，最简易的方法是提高门缝的密封性。据笔者观察密封程度正是影响组合墙体隔声性能的主要原因，只要将普通门的密封性提高或将已有的密封条/垫做的更专业一些，其隔声能力就会在原有的基础上得到比较乐观的改善。

1.2　客厅、餐厅对卧室的影响

两厅的户型，客厅、餐厅一般相临布置，这在室内构成最大的活动空间。由于一般只在客厅内有沙发等表面积较大的软面层家具，而后者常常放置一些硬质的家具，如木质、不锈钢或者玻璃餐桌、座椅等，这些家具的吸声能力很差，使得发生在客厅、餐厅的交谈、玩耍、家庭影院等活动产生的对卧室的噪声影响不可忽视。在调查中发现，晚间看电视与孩子温习功课之间的矛盾甚至不可容忍；某些家庭，有夜间上班的成员（如医生、某些需要倒班的工厂工人等），白天的休息常常被客厅活动干扰的现象也不在少数。当然这个问题的主要矛盾还是在于卧室的门隔声性能上，但如果能将餐厅、客厅和卧室的相对位置处理好，并且在客厅的家具布置上注意声学问题则会减轻后两者

对卧室的噪声的影响。

1.3　卫生间的隔声问题

卫生间的隔声问题主要分为两种情况，一是卫生间的门隔声效果较好时楼上对楼下的影响，这种情况主要是因为落水管道噪声、楼板隔声（空气声隔声、结构声隔声）能力差引起的；当卫生间的门很轻、密封性很差时，来自卫生间的管道、洗浴、冲马桶的声音对客厅、卧室甚至距离较远的餐厅产生的影响就不可忽略了，尤其是在有人洗浴的时候对客厅乃至卧室的干扰比较明显。倘若上述两种情况同时发生，那么居室内的声环境则是非常糟糕了。

1.4　户门的隔声

户门的隔声目标主要是保护家人谈话的私蜜性和减少楼梯间、走廊里人员的交谈、穿梭走动的声音对居民的影响；当户门之间相临、相对布置时，距离很近，所以住户之间家庭活动的相互影响也是不容忽视的。当然，夏季人们为了获得良好的室内通风而将户门打开就要另当别论了。

2　室内光环境

居室内的照明应该避免过度重视其装饰性而对照明质量的认识不足的情况。特别应当避免的是在室内照明方式、手法和室内装修风格上将住宅“涂抹”成了宾馆。

2.1　客厅照明

应当避免发生的情况是客厅的亮度过高，使户外、室内亮度对比太大，显得室内的气氛生硬而不够热情。另外常见的现象是客厅的照明偏冷并缺少调光装置，这样的照明气氛下如果家具的颜色搭配不慎很容易弱化家庭的温暖感。

2.2　书房照明

书房照明应当处理好一般照明和局部照明的关系，如果背景亮度太低造成室内亮度对比过大会使气氛压抑，并容易出现视觉疲劳。书房的一般照明常用吸顶灯或吊灯，这种情况下应注意该灯具的配光范围，如果书柜的垂直照度不够，就会发生查书、换书的视觉困难。

写字台上的局部照明一般是在正前、上方的墙面安装荧光灯管，并在左前的方位布置台灯。这时需要注意的是台灯的配光范围、光束角应做到适当地宽些，最好上方的荧光灯管配有反射灯具且选择好安装角度，这些做法有助于提高写字台上的照度和照度的均匀性。

写字台上放置电脑的情况下，各个光源和显示器的相对位置就显得特别重要，处理不当会出现光帷眩光和干扰性眩光，从而大大降低书房的视看效率和视觉舒适性。除此之外，放置电脑的书房，在电脑显示器位置的垂直照度和水平照度的对比也应达到相应的标准。

2.3　次卧照明

次卧大多是孩子睡觉和温习功课兼用，据笔者调查，上海市一个普通的中学生一般要在卧室里学习的时间平均每天 2 个小时以上。当前学生的近视现象越来越严重，表现为学生的视力下降发生的越来越早并且同年龄段的近视率逐年提高。在这种背景下，家长们不得不对次卧的照明要有足够的重视。调查中发现，在这类空间内照明的设计存在以下问题：

（1）背景亮度不够，书桌或写字台的局部照明与背景照明对比较为强烈，孩子在集中一段时间学习后转移视线过程中眼睛为适应亮度的变化而发生的调节次数多，容易造成视疲劳，长久如此

势必带来视力的下降。

（2）桌子上的台灯位置摆放不当，会在阅读区、书写区产生了手、头部的阴影，或者桌面的亮度均匀性太差；而如果桌面的材料为定向反射材料时（如玻璃板）、定向扩散反射材料时，则会产生光帷眩光或者干扰性眩光。这是一个严重的问题，因为光线的均匀性太差以及视野内出现眩光时会加速孩子的视觉疲劳，而视看区域内的阴影会使得孩子的坐姿不自觉的改变，这种改变可能避免了阴影对视看的影响，但往往使得学生的眼睛离桌面更近，而且不协调的坐姿还会容易造成身体的局部疲劳甚至影响孩子的健康成长。

（3）孩子的床头灯是方便上床休息使用，现实当中孩子们也常常躺着或坐在床头看书，这是一个很不健康的习惯。所以对床头的照明问题，首先家长们要注意提醒自己的孩子尽量不要躺着或坐着看书；其次，依照现实的情况，孩子们在床头看书的现象还是常常发生的，所以要注意床头灯应当提供足够的亮度，因为在读书的时候往往是在关闭其它灯具只开床头灯；另外从放置高度和灯具选型上要注意使灯具的配光在床的方向上适当宽些，以避免转身、换姿的时候照度不够。

（4）另外，有调光旋钮的照明控制电路使用户可以根据需要调整灯具发光量的多少，体现的节能的生态理念，是一个不错的选择。

2.4　厨房、餐厅照明

现代的人们由于工作的忙碌，使用厨房的时间大大减少。这让人们更加重视在家里使用厨房的机会，因为这是一天中难得的家庭美满、其乐融融的时间，有利于身心的放松和增进家人的感情。因此，厨房餐厅的照明应有足够的亮度、适宜的显色性和色表，不但要满足厨房的功能要求，还要满足人们对这种场合的心理需要。惬意而有吸引力的灯光显然能提高制作食物的热情，增强乐意融融的家庭气氛。

3　小结

在声环境方面，《上海市生态型住宅小区技术实施细则》将各个户型作为对象，强调了来自室外、其它住户（同层或者上下层）噪声防护问题，对室内不同空间的噪声控制提出了控制指标，但对内部建筑结构没有提出相应的要求，如隔墙、各个房间的门等也应当提出隔声的要求。客厅内有娱乐活动和嬉戏时产生的“噪声”一般在 65dB 以上，所以对于卧室和书房来讲，这类房间的门隔声指数最好在 30dB 以上，具体的数值可以在可能的评估细则升级版中经过对国内外室内噪声控制标准的对比并结合当地更多的调查研究来确定。另外，为了使门的隔声性能得到体现，安装施工当中的密封性也应当明确提出来。

在光环境方面，由于《上海市住宅设计规范》的实施，住宅小区特别是新建住宅的室内采光问题一般不大。在受访者当中，无论是采光时间还是卧室的窗地比都是满足规范要求的。但正如上文分析，室内的人工照明存在的问题还是比较多。《上海市生态型住宅小区技术实施细则》根据《民用建筑照明设计标准》（GBJ 133—90）对卧室、书房、厨房等的照明质量提出了相应的要求。根据上文的分析，在可能的细则升级中可考虑如下内容：为了保证居民的视力健康，对书房尤其是孩子的卧室照明应有明确的照度要求。考虑到孩子在卧室内的活动性质和规律对局部照明和背景照明提出设计指标，建议对孩子阅读区的照度要求要达到 300Lx 以上，并且室内的照度均匀度不低于 0.5。

客厅、主卧、厨房和餐厅的照明如前所述也不仅仅是一个照度值、显色性的要求，应当考虑加入色表、灯具的维修清洗是否方便、材料的反射率和色坐标、水平照度和垂直照度（如厨房、书房）等更为具体而有效的考核指标。

建筑的生态内涵不仅仅是小区环境的绿化，也不仅仅指“室内的绿化”，更重要的实质是建筑物本身和室内是否达到生态的标准，具体包括水环境、空气环境、声环境、光环境、热环境、绿色建材等等内容。以上的分析可能不只是提到生态住宅的高度才有要求的，但它在现实中常常被开发商和业主忽视，而这些问题却已经在影响着人们的生活质量甚至威胁着居民的身体健康。所以应当在《上海市生态型住宅小区技术实施细则》当中明确提出，以提高人们的居住水平，帮助人们发现影响其居住质量的问题所在，促进住宅建设水平的提高。

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建筑系统环境性能模拟方法研究

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摘　要　建筑系统环境性能模拟是建筑环境性能研究的基础。通过对建筑系统环境性能现有模拟方法的详细分析，提出了一种直接集成模拟新方法。在提出的直接集成模拟法中，确定采用从下往上的方法对建筑系统的各种环境影响进行分类，并根据综合分析方法从中选取了几类主要环境影响种类作为模拟的对象；定义了一个环境影响公共基本单位——黑点，并根据被研究国家或地区现阶段的实际情况，采用层次分析法和专家问卷调查结果确定了各类主要环境影响的权重系数和当量值。

关键词　建筑系统；环境性能；模拟方法；直接集成；层次分析法

Research on Modeling Method of Environmental Performance of Building Systems

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Abstract Environmental performance modeling is essential to research and assessment of environmental performance of building systems. After reviewing the existing modeling methods, a new method, which defines the weights of various environment impacts basing on experts questionnaire and Analytic Hierarchy Process (AHP) method, were proposed. Equivalence of various impacts were calculated basing on global and national emission gross of different pollutants and the weights calculated. All the influencing factors were unified to a general basic environmental influencing unit, “black point”, which expresses the environmental performance of building system directly and precisely and makes the integration of building system’s environmental performance smoothly.

Keywords Building systems, environmental performance, modeling method, direct integration, Analytic Hierarchy Process (AHP)

一般地，在对建筑系统的环境性能[1]进行深入研究（如评价）之前，首先必须确定和表达这个被研究建筑系统的环境性能，这个过程就称作建筑系统环境性能模拟。这就是说，建筑系统环境性能模拟是建筑系统环境性能研究的基础，因此选用一个好的模拟方法可以起到事半功倍的效果。

1　模拟方法分析

1.1　清单式模拟和集成式模拟

同任何事物一样，环境性能的模拟方法也经历了一个由简单到复杂的发展过程，即由最初的清单式模拟向集成式模拟转变。

（1）清单式模拟方法

清单式模拟方法是指对被研究对象的各类环境影响分别进行模拟，其结果为一系列环境影响的列表，故被称作为清单式模拟[2]。清单式模拟方法的步骤简单，计算方便，不需进行各类环境影响

的集成，因此其模拟结果的误差较小。但在实际工作中，由于各类环境影响的危害性质都大不相同，因此清单式模拟方法的使用范围受到了很大限制，只能应用于一些简单的模拟研究中。

（2）集成式模拟方法

对于不同的研究对象，在其全寿命周期中，环境影响的种类和危害的程度都会不同，因此，当对环境性能进行某些研究时（如环境性能评价和优化），则必须首先应用一定的方法将被研究对象的所有环境影响集合成一个整体的环境性能指数，然后才能继续进行下一步的研究[3]。这就是集成式模拟方法。集成式模拟方法的适用范围广，模拟结果简单，但由于其计算过程复杂，需要进行环境影响的集成，因此可能出现较大的误差。

表 1 为清单式模拟方法和集成式模拟方法的比较。在现阶段的建筑系统环境性能模拟研究中，根据模拟目的的不同，采用的模拟方法也不同，例如，在建筑系统环境性能评价中，一般采用集成式模拟方法对建筑系统环境性能进行模拟。

表 1　清单式模拟方法和集成式模拟方法比较

	清单式模拟方法	集成式模拟方法
计算过程	步骤简单，计算方便	计算过程复杂，需要进行集成
误差大小	误差较小	误差较大
模拟结果	一系列环境影响的列表	一个整体的环境性能指数
应用范围	只能应用于一些简单的研究	适用的范围广
应用实例	一些材料环境影响的研究[2]	BREEAM[4]，LEED[5]，GBTool[6]

1.2　集成式模拟的量化方法

在集成式模拟进行集成前，需要将各类环境影响进行量化。常用的量化方法有以下两种：基准比较法和直接量化法。

（1）基准比较法

基准比较法首先将环境性能分为几个大类，每个大类又分为多个子项，每个子项分别制定一个或一系列基准，然后根据这些标准对各个子项的表现进行打分，将各大类中每个子项的得分累加，得出各大类的总分，最后，根据一定的权重系数对各大类的得分进行集成。由于环境性能的子项一般都比较多，且现阶段基础研究资料非常匮乏，使得各子项之间的相对重要性很难科学地确定，因此很多时候开发者只好根据自己的主观进行，这就导致基准比较法存在着较大的误差。例如，在 LEED 中，新建筑的能耗降低 20%，可以得到 2 个分值，而采用当地生产的建筑材料，也同样可得到 2 个分值[5]。但是，如果从对环境危害的后果来看，这两项的得分应该有较大的差别。另外，在基准比较法中经常采用定性的概念，如当地生产的建筑材料等，这又可能给模拟结果带来较大的误差。

（2）直接量化法

环境性能集成式模拟采用的另外一种量化方法为直接量化法，如荷兰环境影响评价体系 Eco-indicator[7]中采用的量化方法。与基于基准的量化方法不同，直接量化法首先根据一定原则将被研究对象的环境影响进行分类，并确定各分类的基本单位量，最后，根据这些基本单位量对各分

类的环境影响进行直接量化。由于各分类的基本单位量不同，因此在随后的集成中，存在着较大的困难。例如，在 Eco-indicator 中按危害对象的不同将环境影响分为对人类健康的危害、对生态环境的危害和对自然资源的危害三大类，各类的基本单位量分别为 DALYs（Disability-Adjusted Life Years）、PAF（Potentially Affected Fraction of species）和 EER（Effort of Extracting Resources）[7]，由于这三类基本单位量的性质根本不同，因此 Eco-indicator 最后只好又采用分类与基准进行比较的方法对结果进行分析。

表 2 为基准比较法和直接量化法的比较。在现阶段用于建筑系统环境性能评价的模拟研究中，一般都是采用基于基准的量化方法，因此误差较大。

表 2　基准比较法和直接量化法比较

	基准比较法	直接量化法
量化过程	与一个或一系列标准进行比较，但标准需要经常进行调整	根据基本单位量对环境影响直接进行量化
误差大小	误差较大	误差较小
量化结果	可以直接用于评价	需进一步进行处理，但处理比较困难
应用范围	现阶段应用较多	现阶段应用较少
应用实例	BREEAM，LEED，GBTool	Eco-indicator

2　本文提出的模拟方法

2.1　主要思路

通过以上对建筑系统环境性能模拟方法的分析，并借鉴 Eco-indicator 中环境性能的量化过程，本文提出了一种新的建筑系统环境性能模拟方法——直接集成模拟法。与 Eco-indicator 中的模拟方法不同，该方法不仅确定了各分类的基本单位量，而且还确定了各分类基本单位量的当量值。新方法的主要思路如下：

（1）首先对建筑系统的环境影响进行分类，确定各分类的基本单位量；

（2）定义一个建筑系统环境影响公共基本单位，确定出各分类基本单位量对这个公共基本单位的当量值；

（3）最后根据各自的当量值对各分类进行模拟。

由于各分类全部采用公共基本单位，因此最后的模拟结果可以直接进行集成。

2.2　新方法的优点

与现阶段建筑系统环境性能评价体系采用的模拟方法相比，本文提出的直接集成模拟方法具有以下优点：

（1）误差大幅减少

在本文提出的直接集成模拟方法中，只需对各大类环境影响的相对重要性进行确定，因此可以采用比较科学的多因素决策方法[8]，这样就明显地减少了模拟过程中出现的系统误差。

（2）过程简单，更适合采用计算机处理

采用本文提出的直接集成模拟法，需要输入的各项参数大大减少，因此适宜于采用计算机进行

处理，这样就大大降低了使用过程的复杂程度，且有利于进行全过程的研究。

（3）结果具有实际含义，易于理解

直接集成模拟法定义了一个具有实际含义的环境影响公共单位，这就使得模拟结果易于理解，还可以使得不同类型的建筑系统可以直接进行环境性能比较。

（4）有利于推广

与采用基准比较法的集成方法相比，各国和地区使用时只需对方法中应用的统计数据库进行调整，而不再需要重新进行基础研究，且需调整的项目非常少。

（5）有利于后续工作的开展

直接集成模拟法的结果为定量结果，与定性的结果相比，它更适宜于后续工作的开展，如评价等。

3 直接集成模拟法的基本研究

由于各国环境污染程度和环境承载力都大相径庭，这使得相同环境影响在不同国家造成的危害都不相同，因此所有的研究均应以被研究国家的实际情况为背景，各项计算均尽可能地采用被研究国家现阶段的数据。

3.1 环境影响的分类

建筑系统对环境的影响多种多样，几乎包括了地球上存在的所有环境影响，因此不可能对建筑系统的全部环境影响都进行模拟。由于一些影响对环境危害的性质相同，而一些影响对环境危害的对象相同，因此，通过适当的分类方法可以把这些环境影响合并成同一类进行模拟，从而大大简化建筑系统环境性能的模拟过程。

到目前为止，世界上已进行了大量有关环境影响的研究，但是仍有很多环境影响的作用机理还不是很清楚，另外，一些环境影响之间还存在着相互作用的关系，因此，在实际应用中，采用合适的分类方法可以取得较好的模拟效果。

对环境影响进行分类的方法一般有两种：从下往上法和从上往下法[9]。

按各种环境影响的危害性质进行分类的方法称作从下往上的方法，例如，将环境影响分成温室效应、臭氧层破坏、酸雨等[9]。在采用从下往上法进行分类的环境影响模拟中，环境影响量化的计算比较简单，例如，通常可以采用一些当量系数将一些相同危害的影响进行合并。但是，如果采用这种方法进行分类，则会出现比较多的类别，另外，在形成的各个环境影响类别中，量化所采用的单位也会不相同，因此，各类环境影响的集成存在着一定的困难。

从上往下的方法是按各种环境影响的危害对象进行分类，它一般分成对人类健康的危害、对生态系统的危害和对自然资源的危害等几类[9]。与从下往上法相比，在从上往下分类的环境影响评价中，其环境影响的量化过程比较复杂，需要对环境中有害物的排放量、浓度、危害等进行一定程度的模拟。不过，由于从上往下分类得到的危害种类的定义比较明确，且数量较少，因此有利于后续研究工作的进行。

根据以上对环境影响分类方法的分析，由于现阶段对一些基础研究仍进行得还不够，很多基础数据都无法得到，因此本文提出的直接集成模拟法采用从下往上的分类方法对建筑系统的环境影响

进行分类，即根据各种环境影响危害的性质进行分类，这样就不仅可以避免了复杂的环境影响量化工作，而且还可以减少模拟过程中出现的误差。

按照从下往上的分类方法，建筑系统的环境影响可以划分为以下几大常见类：(1) 温室气体；(2) 酸雨气体；(3) 臭氧层破坏物质；(4) 固体废弃物；(5) 废水；(6) 室内空气污染物；(7) 悬浮颗粒物；(8) 噪声；(9) 光污染；(10) 热岛效应；等。

3.2　环境影响的选取

通过对建筑系统的环境影响进行分类后，建筑系统环境影响的种类可以大大减少。但是，从分类结果可以看到，整个建筑系统环境影响的种类还是很多，如果对这些环境影响种类都进行模拟，则会使模拟过程变得非常复杂，因此，只能从这些环境影响种类中选取几种主要的类别进行模拟。直接集成模拟方法采用分项评分的方法选取需要模拟的环境影响种类，即先根据文献资料对各类环境影响的危害性、数据的科学性、影响的范围、建筑系统的贡献和去除的难易程度等几项内容分别进行口头评价，然后将口头评价转化为相应的评分（分值越高表明研究的意义越大），最后，从中选取总分最高的几类环境影响作为模拟的对象。

各项口头评价的内容如下：(1) 环境影响的危害性是指各类环境影响对周围环境和人类健康的危害。环境影响的危害性越大，对其进行研究的意义越大。(2) 数据的科学性包括两个方面的内容，一是现有基础研究数据的多少，二是模拟的难易程度。数据科学性越好，则意味着模拟中出现的误差越小。(3) 环境影响的范围可以分为全球、区域、城市、小区和室内等五类。影响的范围越大，则该类环境影响被研究的意义越大。(4) 建筑系统的贡献率是指在全球的环境影响中建筑所占的比例。贡献率越大，则模拟的现实意义越大。(5) 去除的难易程度是指去除这类环境影响的困难性。越难去除的环境影响，则越需要重视。

各项口头评价的分级与相应的评分如表 3 所示。

表 3　各项口头评价的分级与相应的评分

口头评价					评分
危害性	数据科学性	影响的范围	建筑系统贡献	去除难易程度	
很大	很好	全球	很大	很难	9
大	好	区域	大	难	7
一般	一般	城市	一般	一般	5
小	差	小区	小	易	3
很小	很差	室内	很小	很易	1

由于本文提出的直接集成模拟法准备在下阶段采用层次分析法（Analytic Hierarchy Process, AHP）来确定各类环境影响的权重系数，而 AHP 一般只适应于 7 种以下因素的应用[10]，因此选取的环境影响种类应不超过 7 类。

3.3　权重系数的确定

权重系数是以某种数量形式对比、权衡被评价事物总体中诸因素相对重要性的量值。它既是决策者的主观评价，又是指标本质的物理属性的客观反映，是主客观综合度量的结果。权重系数主要

决定于两个方面：第一，指标本体在决策中的作用和指标价值的可靠程度；第二，决策者对该指标的重视程度[11]。

各类环境影响集成是一个多因素决策问题。在多因素决策问题中，各种因素通常不可能采用同样量纲来测定，某些因素要么根本不可能测定，要么测定的代价太高，因此，大多数多因素决策要求决策者先对问题中各因素的重要性分出级别，然后根据这些重要性级别确定各因素的权重系数，最后再进行集合[8]。

通常有两种基本的方法可以得到各类环境影响的重要性级别。一种是观察社会在其他但是有关的情形下做出的实际选择，它一般以政府组织制定的目标或者社会为此准备付出的代价为基础，因此又被称作偏爱显示法。另一种方法是直接对社会上有代表意义的一个小组进行调查。在很多的实例中，这个小组一般是一个专家小组，因此这种方法又被称为专家小组法[12]。

由于通常很难分开和解释一些与社会有关的基本价值，例如，政府制定的政策目标经常是在减少负荷的需要和准备做出必需的牺牲之间的妥协，因此采用偏爱显示法得到的结果可能与实际情况并不是非常符合。另外，一些涉及范围很广的问题，像保护人类健康、生态系统质量和自然资源的花费在现实生活中也非常难以得到。因此，偏爱显示法在建筑环境影响评价中的应用不是非常广泛[12]。

在专家小组法中，当确定重要性级别时，采用的分类原则非常重要。当各个种类的定义过于复杂（一般需要较深的背景知识），且种类的数目过多时，对于被要求给出重要性级别的被调查人员来说，则明显的存在着严重的认知压力。因此，要想运用专家小组法取得合理的重要性级别，则最好将被调查的环境影响种类限制在一定的数量之内[12]。

通过专项研究得出各项环境影响间的重要性级别后，可以采用多种方法来确定各项环境影响的权重系数，其中，AHP 是在实际中运用得最多的一种方法，它是一种定性和定量相结合的、系统的、层次化的分析方法，可以很方便地计算出各类环境影响的权重系数[10]。

根据以上分析，直接集成模拟法中各类环境影响权重系数的确定采用以下方法：根据专家小组的意见确定各类环境影响的重要性；根据各类环境影响的重要性程度确定各类环境影响间的重要性差别；利用 AHP 计算出各类环境影响的权重系数。采用以上方法可以尽可能地减少环境影响权重系数确定过程中出现的误差，从而提高了环境性能模拟的准确性。

3.4　各类环境影响当量值

权重系数确定以后，各类环境影响在被研究区域内总环境危害中所占比例即已确定。因此，如果可以确定一定时期内被研究区域内各类环境影响的排放总量，就可以根据权重系数计算出该研究区域内各类环境影响危害的当量值。这就是直接集成模拟方法确定各类环境影响当量值的基本思路。

在直接集成法选取的几类主要建筑环境影响中，各类影响危害的范围都不相同，其中，温室效应和臭氧层破坏属于全球环境影响，而酸雨、固体废弃物和废水则属于区域环境影响，因此它们的排放总量应根据不同的原则选取。

（1）全球环境影响

对于全球环境影响，由于其在一定区域内受到的危害与这一区域排放该类环境影响的多少并无直接关系，而是与全球这类环境影响的排放总量有关。因此，为了表征某一区域受到这类环境影响危害的程度，直接集成模拟法定义了一个效用排放量 E_{eff} 的概念：效用排放量 E_{eff} 等于区域内造成现有某种环境危害应有的这种环境影响的排放量。假设在一定区域内，各类环境影响的危害都与人口数量呈正比，且在全球范围内每个人受到的同一类环境影响的危害一样大，则有：

$$E_{eff} = E_{ave} \times P_{area} \tag{1}$$

式中：E_{eff} 为某区域的效用排放量；E_{ave} 为全球人平排放量；P_{area} 为某区域内总人数。

（2）区域环境影响

对于区域环境影响，如果其危害的区域小于或等于被研究的区域，则可认为区域内这类环境影响造成的危害是由该区域内这类环境影响的排放总量决定的。例如，如果以中国为研究对象，则酸雨、固体废弃物和废水这三种环境影响的排放总量可以按一定时期内全中国的排放总量计算。

确定了被研究区域一年内各类环境影响的排放（或效用）总量，并根据各类环境影响的权重系数，可以计算出该研究区域中各类环境影响的当量值。

3.4 环境影响公共基本单位

为了方便各类环境影响最后的集成，直接集成式模拟法要求定义一个环境影响公共基本单位，本文将该公共基本单位称为 “ 黑点 ”。由于在建筑系统对周围环境的影响中，能源消耗带来的环境影响所占的比例最大，又由于在建筑系统消耗的能源中，以电力形式消耗的能源最多，因此“ 黑点 ”采用与电力直接联系的定义：一个“ 黑点 ”即代表被研究区域内现阶段生产 1kWh 电力（包括火电、水电和核电）过程中平均对周围环境造成的影响，这样就可以更加形象地表示建筑系统的环境性能。

根据 “ 黑点 ” 的定义和各类环境影响的当量值，可以计算出 1000 “ 黑点 ” 对应于各类环境影响的当量值。

基本环境影响单位当量值确定后，则在直接集成式模拟法中，各类环境影响都可以直接转化为采用 “ 黑点 ” 表示的数值，这就使得环境性能的集成过程变得非常简单，且结果更加形象具体。另外，由于采用了相同的环境影响单位，更可以在各模拟对象间进行横向和纵向的比较，使得研究的应用范围大大拓宽。

4 结论

本文通过对建筑系统环境性能模拟方法的详细分析，提出了一种直接集成模拟新方法。在本文提出的直接集成模拟法中，确定采用从下往上的方法对建筑系统的各种环境影响进行分类；根据综合分析方法从中选取了几类主要环境影响种类作为模拟的对象；采用专家问卷调查和层次分析法确定各类主要环境影响的权重系数；根据各类主要环境影响的权重系数和被研究国家或地区现阶段的实际情况确定各类环境影响的当量值；定义一个环境影响公共基本单位——黑点并计算出其对于各类环境影响的当量值。该方法具有可以大幅减少误差；过程简单，更适合采用计算机处理；结果具有实际含义，易于理解；有利于推广和后续工作的开展等优点。

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可持续建筑评估体系之发展

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简介：

可持续的建筑有助于提供一种减少能源消耗的生活模式。但是，可持续发展的建筑不只是具有减少能源消耗及保护环境等因素，还要能够与社会，心理，生活，经济，生态，文化等保持协调的步伐。这些因素应在整个建筑物生命周期中，包括从设计到拆迁，全面考虑。因此，可持续建筑设计应根据可持续性发展为蓝本进行设计，施工维修及管理，从而改善整体环境及建筑之表现。利用可持续建筑评估体系能估算出建筑物于上述范畴表现，并能提供资料有助于不同的设计决策。利用建筑评估技术，为设计师或投资者提供有关可持续性发展决策之资料，并能比较各项目设计之成效，使得可持续的建筑设计能确切地实行。从而建立出美观、革新、和谐及可持续建筑。

本论文将简述国际上可持续建筑评估体系之最新发展，并利用实例指出该评估体系在可持续建筑设计中的应用，从而进一步验证可持续发展评估体系之重要性。

1. INTRODUCTION

Sustainable buildings can contribute to deliberate lives that are less demanding on the earth's resources. However, environmental and energy conservation should not be the only issue that is to be considered. Instead, it involves interrelated issues including social, psychological, economical, technical, ecological and cultural. These issues should be addressed at all stages of a building development, starting from design to demolition stages, which aimed to improve environmental and building performance through good designs, construction, maintenance and management. Use of sustainable building assessment tools could evaluate the performance of buildings across a broad range of considerations and provide guidance on making the decisions. Adoption of sustainability assessment tools help bring sustainability into practice, and can inform designers and clients at all stages of design and development, including comparison of project options. At the end, aesthetic, innovative, harmonised and sustainable buildings are created.

This paper describes the key features of the current building assessment schemes and their merits or deficits as viewed by the scheme users. Case study in China is also presented to highlight the achievements and benefits bring for adopting the building assessment scheme in real projects.

2. EVOLUTION OF BUILDING ASSESSMENT SCHEMES

The building industry will be increasingly scrutinized and required to develop approaches and practices, which address immediate environmental concerns and adhere to the emerging principles and dictates of sustainability. Within this context, it will become increasingly important to understand how well or poorly buildings are performing, to be able to communicate this performance to building users and to benchmark progress in improving performance. Building environmental assessment methods have emerged as a way to evaluate the performance of buildings across a broad range of environmental considerations against an explicit set of criteria.

Until the release of the *Building Research Establishment Environmental Assessment Method* (BREEAM) in 1990 little, if any, attempt had been made to establish an objective and comprehensive means of simultaneously assessing a broad range of environmental considerations against explicitly declared criteria and also offering a summary of overall performance. Before then building environmental performance was largely discussed in terms of a limited number of individual criteria such as energy use, thermal comfort or lighting conditions.

The field building environmental assessment has matured remarkably quickly since the introduction of BREEAM, and the past twelve years has witnessed a rapid increase in the number of building environmental assessment methods in use world-wide. Many countries either have, or are in the process of developing domestic assessment methods. These methods reflect a combination of:

- The interests and priorities of the agencies/stakeholders responsible for the sponsorship and development of the method.
- The collective level of understanding about environmental issues at the time of method's development.
- The capabilities of the building design and development community at whom the method is directed.

With the exception of the initial version of the *Building Research Establishment Environmental Assessment Method* (BREEAM) for New Office Buildings released in 1990, existing methods have drawn on the collective knowledge and experience of other systems. Some, such as the *Hong Kong Building Environmental Assessment Method* (HK-BEAM) and BREEAM-Canada, have adopted the scope and structure of BREEAM but customised the performance criteria for the new regional context. Others, such as the proposed *Comprehensive Assessment System for Building Environmental Efficiency* (CASBEE) in Japan have drawn selectively from *GBTool* and other systems, yet are set within a conceptually different framework.

Whereas the term assessment "method" relates to a tool designed to assess the environmental merits of a building, an assessment "scheme" or "program" relates to a suite of tools/versions covering different building types and support materials. BREEAM in the UK, HKBEAM in Hong Kong and the *Leadership in Energy and Environmental Design* (LEED™) program in the US, have now matured into schemes that offer assessments for a variety of building types operating under the same "brand" name.

Review has been conducted to examine several existing building environmental assessment methods. The primary objective is to evaluate the characteristics of these methods/schemes and identify their key characteristics, strengths and weaknesses, which help to determine the key elements for the success of an assessment scheme.

2.1 General Characteristics of an Assessment Method

An assessment method consists of three major components:

- A declared set of environmental performance criteria organised in a logical fashion.
- The assignment of a number of possible points or credits for each performance issue that can be earned by meeting a given level of performance.

- A means of showing the overall score of the environmental performance of a building or facility. This can be a profile, a single aggregate score, or both.

2.2 Characteristics of existing Building Assessment Schemes

Each building assessment method has its own characteristics and serves for different purposes. The following summarized the strengths and weaknesses including criticisms and limitations of those assessment methods reviewed. Since some of these assessment methods are still at their early stages of development, it is not possible to review all the methods to the same level of extent.

GHEM （China） [1]

The scheme relates to Chinese performance standards and to a set of design guidelines; stringent requirements for pre-requisites; and it uses simple rating system that without explicit weighting system.

It is too early to ascertain the success of the program. However, it only relates to residential projects; doubtful credibility since the developers are the sponsors for the assessment and labelling; and there is not clear definition for the degree of severeness for unsatisfied prerequisite requirements.

BREEAM (UK) [2]

BREEAM was the first and remains to be the most long-lasting amongst all existing building environmental assessment methods; From now on, there are more than 25% of new office buildings have been assessed, as claimed by BRE; It has become a distinct and important “brand name” within the UK building industry, which receive enormous and widespread coverage both in the UK and internationally;

However, the take-up of BREEAM for assessing existing buildings is considerably less popular than for new projects and there is no public registry or disclosure of the projects that have had a BREEAM assessment. As a result, there is criticism that BREEAM acts as a barrier for their application in practice since it often require a well-advanced project design to be assessed.

LEED™(USA) [3]

LEED™ has very simple and straightforward structure; It is very transparent as it operated by the USGBC; It gains sheer volume of interest and support from the architectural and engineering design community. LEED™ draws on and involves input from the diverse membership of the US Green Building Council and its success derives from support that educates the building industry on environmental issues and encourages acceptance in private development/design industry. Over the past three years, more than 1,000 projects were registered under LEED and there are few hundreds in the process of certification.

However, there are concerns that some credits are shaped too much by industry interests; It is not easy to understand the basis upon which the points allocation and The assessment mixes construction process, management issues and design performance issues. Further, it is expensive, time-consuming process.

NABERS (Australia) [4]

It uses simplified self-administered questionnaire approach carried out annually with or without the need to hire independent assessors; and It provides performance assessment results as early as possible. The most important, there are government initiative to support the industry;

Though it is too early in the development and implementation to fully gauge NABERS’s success, several concerns regarding the framework and implementation issues have been raised by the *Property Council of*

Australia: It is not sufficiently tuned and not flexible enough to respond and adjust to other regional intricacies in Australia; It heavily loaded to factors dependent on the lifestyle choices of the building occupants; and it provides little or no encouragement for building designers, builders and/or owners to improve that part of the built environment that they do have control over.

GBTool (Canada) [5]

GBTool has the most comprehensive framework. It uses a consistent measurement scale for all criteria; It has introduced absolute performance indicators to complement the relative scores;It normalises some of the key environmental measures for both area and occupancy; It is good basis for further international developments as it represents a relatively good consensus between 14 countries.

GBTool was not designed as a market place assessment tool and would have to be changed considerably to make it so. In its desire to provide a comprehensive assessment more than 90 individual performance assessments are necessary – requiring time and effort on the part of the assessment team and the four levels of weighting necessary to summarise the performance results significantly compromises confidence in the overall result; It assesses only "potential" performance and assessment principles for many of the individual criteria are quite subjective. Sensitivity analysis has shown that assessment results are extremely sensitive to changes in the weighting system; The most important There is lack of documentation.

CASBEE(Japan) [6]

CASBEE introduces the concept of *Building Environmental Efficiency* as the means of summarising overall building performance. This approach provides a conceptually different way of describing performance and sets the discussion within the notion of "efficiency"; CASBEE is planned as a coordinated suite of tools directed at providing design guidance and performance assessment; the assessment is organised as a staged approach; and it uses a variety of different output formats, providing the opportunity to tell different "stories" about a building's performance.

It is too early in the development and implementation to fully gauge CASBEE's success or how it will handle different building types. Although the notion of building environmental efficiency represents a powerful conceptual shift, it is unclear at this stage if the wider public will be able to make sense of the performance results presented in this way.

EMGB (Taiwan) [7]

EMGB assesses the least number of performance criteria - the most recent version of the program assesses 9 environmental criteria; the scheme only assesses the well-established performance criteria that are quantifiable which somehow help effective administration; and there is support from the Government.

It is too new to ascertain success and whether it is comprehensive enough. However, it is a single version of assessment for all buildings over Taiwan, which may not be able to reflect regional differences. It only assesses the well-established and quantifiable performance criteria, the non-quantifiable issues like social and economic issues had been intentionally been omitted which will lead to some gaps in coverage

Eco-Quantum (Netherlands) [8]

EcoQuantum is the only method that is explicitly and comprehensively based on Life-Cycle Assessment; It assesses the environmental burden of a complete building on the basis of LCA; It is easy to use and has extensive database with the most commonly used materials and products.

EcoQuantum is qualitatively different from the other assessment tools in that it is not a comprehensive assessment method; It is only applicable to single residential buildings.

SPeAR® [9]

SPeAR® is the only existing assessment method that attempts to characterise the performance from the perspective of sustainability; SPeAR® uses a "rose-diagram" graphic output, it assesses both positive and negative impacts; and it is a universal tool that applies to all types of buildings

SPeAR® can make assessments of sustainability because it does not deal with comparing the performance against other projects; It has only been used within the context of Arup's and has not been presented or scrutinized by the wider community; and It required a trained assessor to develop an assessment method to address the issues.

HK-BEAM [10]

HK-BEAM has provided evidence of issues associated with the environmental improvement of buildings in Hong Kong; It relates to local standards and requirements; HK-BEAM was initiated by the private sector and has the support of the Real Estate Development Association (REDA). HK-BEAM is also supported by bodies representative of industry including the *Provisional Construction Industry Coordination Board* and the *Construction Industry Task Force*. HK-BEAM has also gained support from areas of Government over time. Government remains the biggest single user of HK-BEAM (commissioning over 25% of assessments), with HK-BEAM requirements included in the development, design and construction briefs of many of the projects assessed. Until now, 89 premises (covering over 50 million ft2 of floor space) have so far adopted HK-BEAM. 40% of these are existing buildings (the application of other schemes reviewed to mainly new buildings is rightly considered a weakness in the report). HK-BEAM is also exceptional in assessing new buildings "as built" rather than "as designed".

Despite having a fairly long presence, relatively few buildings have been assessed using HK-BEAM and criticisms suggest that it places too great an emphasis on building systems performance. The assessment process is not transparent; and It addresses items for which there is good evidence of the environmental problems they cause, and for which effective performance criteria can be define, which the non-quantifiable issues like social and economic issues had been deliberately

2.3 Key element to success

Based on the international scheme review conducted, it found out that the status of development for the building environmental assessment methods varies in a great extent. The majority of assessment methods reviewed only have a few years of development history, with BREEAM being the most long-lasting building environmental assessment method. Some of the assessment methods, like the CASBEE and the China's Assessment Handbook for Ecological Residential Building, are still at their early stages of development. The longevity of the assessment scheme in the market may indirectly demonstrate its acceptance.

The findings of the review suggest that there are some key elements that could lead to the success of a building assessment scheme. Simplicity, practicality and cost in terms of both undertaking an assessment and maintaining the system are considered critical requirements for successful market-based schemes.

2.3.1 Support from all parties

From the experience of BREEAM and LEED, it is found that support from all parties is vital for the success of an assessment scheme. Government, developers, designers and all other building professional should be involved. Education and awareness raising is considered as one of the important steps for gaining supports from all parties.

2.3.2 Public recognition

Publicity places an important part in leading to the success of an assessment scheme, which can be proven by comparing the adoption rate of BREEAM and LEED relatively to HK-BEAM. If the scheme or the certification achieved is recognizable by the professionals locally and internationally or even by the general public, it could be used as a marketing tool as well as a decision-making tools for building users. It could also serve as an educational tool to promote the need for green / sustainable buildings.

A well-publicized scheme should be a system that enables the designer/ developer to express design objectives and expedite their design process and let the users know how their buildings will function over time. In addition, the building labelling scheme can be made use by the building purchasers, renters or users to know the building environmental performance explicitly. The current building price setting method is wholly controlled by the developers, bankers and real estate professionals. The small flat owners or users do not have the real capacity to set their property price, but is controlled by the controlled market price. The price of a building is mainly restricted by several physical and subjective factors, which are building age, view, decorating materials, facilities provided, etc. Genuine building environmental performance is an important factor that affecting the performance of buildings and users, but currently not considered in the price of a building. The building purchasers, renters and users are inevitably sacrificed for having a genuine improvement of building environment, and the associated sustainability benefits. What the building purchasers, renters and users received are mainly on short-term benefits only. Long-term benefit is not secured by the current practices.

2.3.3 Affordable assessment cost

It has been emphasised that the cost of assessment would be an influential factor for the success of an assessment scheme. The cost of assessment would, indirectly, determine its scale of adoption since only large developers would be financially capable to undertake the assessment if its cost is high. If the assessment cost is too high, it is just an example of how the small firm is being squeezed. The cost and time involved in obtaining a certified designer is usually a luxury reserved for the larger firms.

2.3.4 Credibility of administrators

Most of assessment methods are mainly implemented and operated by the scheme developers, which are usually privately owned. Accreditation for the buildings were by the privately owned organization and some of them accredited their assessors by providing training courses. Only the Evaluation Manual for Green Buildings in Taiwan and the NABERS are operated or implemented by the Government. Majority of the existing assessment methods are voluntary and market-based schemes, which make them with no authority power and may limit the wider adoption of the scheme. Indeed, it is important to have a creditable administrator to encourage wider adoption and effective use of the assessment scheme.

2.3.5 Objective of schemes

Origins and intents for various assessment schemes for buildings differ from tools intended for use at the design stage to post occupancy evaluation tools. Very few systems make a clear distinction between environmental performance based on inherent properties of the building and performance resulting from the operation of the building [11]. Scheme with clear objective is more receptive to the market.

2.4 Building Assessment Schemes in Hong Kong

Building environmental assessment methods are typically designed, either implicitly or explicitly, for the particular context that they will operate. The unique high rise, high density built environment in Hong Kong made it a necessity for a tailor-made assessment scheme for determining the environmental performance of buildings locally. The introduction of HK-BEAM and SPeAR® in Hong Kong have provided some evidence of issues associated with the environmental improvement of buildings within the market-orientated building industry. The on-going Study initiated by the Buildings Department (BD) of the Hong Kong Special Administrative Region in 2001 to draft a Comprehensive Environmental Performance Assessment Scheme (CEPAS) for buildings in Hong Kong is targeted to serve as a unified yardstick for a common, comprehensive assessment scheme for buildings in Hong Kong. The ultimate goal for developing CEPAS is to raise the environmental standard for buildings in Hong Kong.

3 CASE STUDY: APPLICATION OF ASSESSMENT SCHEME IN CHINA

It is important that the benefits of adopting or complying with building environmental assessment schemes be clearly articulated and communicated to the various stakeholder groups. As a project with high commitment to sustainable design, the Xihu Tiandi in Hangzhou, China has been undergoing the process of gaining the LEED (Leadership in Energy and Environmental Design) Rating.

Hangzhou Xihu Tiandi is a retail development composed of new and refurnished buildings with a semi-opened courtyard. The development is situated on the south-side of West Lake, which is famous for its historic culture and natural beauty. Accommodating sustainability is one of the profoundly notions for the development. The project is about cherishing the old, embracing the new, and the sustainable development of Hangzhou’s three key assets: its Culture, Nature and West Lake. Sustainable system designs such as earth ventilation system, radiant cooling and heating system, photovoltaic system and exhaust heat recovery system have been applied. It has also been accepted as the pilot project for the newly released LEED™ Core and Shell Scheme. As a pilot project, Hangzhou Xihu Tiandi will be in the vanguard of not only Chinese building projects but also international building projects. It is hoping that the project’s exceptional performance and continued leadership in the Chinese marketplace could act as the catalysis to bolster the demand for green buildings, especially for commercial buildings, in China. By undertaking LEED as the assessment, improvements and benefits has been demonstrated via:

- Identifying success at meeting an expected level of building performance in a number of declared environmental criteria.

- Providing clear guidance on the environmental strengths or deficiencies of a building that can offer feedback to an evolving new design or be used by building owners to identify priorities for future administration measures, building retrofits, etc., which can help keep a property current within a changing marketplace.
- Providing building owners a means to communicate to prospective tenants the inherent environmental qualities of the building they are leasing and, in a more general sense, provide a valuable tool for improving public awareness of these important matters.

The integration of the energy saving and innovative features require the coordination among all parties, including design architect, architect, engineers, project management team, contractors and other related parties. It is important to 'educate' the whole project team and respective parties for the LEED concept before commencement of work. Efforts have also been placed in resolving the cultural and code implications.

Continued improvement on the sustainability performance of the development has been conducted. Design strategies are refined through the whole process of design stage and the scoring form and project history are being updated periodically to reflect the situation. The strategies and requirements are identified and included in the construction documents and specifications and be incorporated in design development.

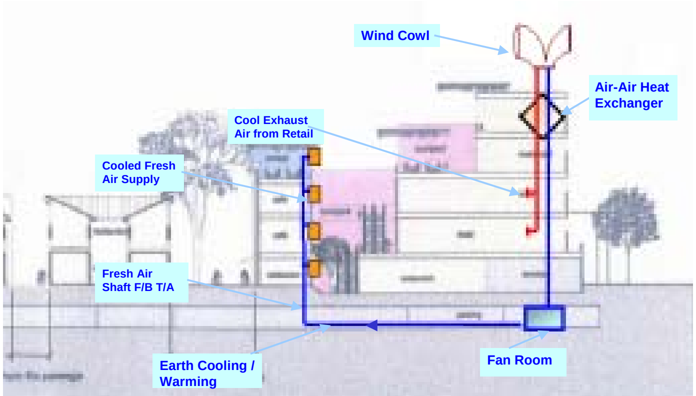

Figure 1 Schematic Diagram for the Conceptual design for sustainable system in Xihu Tiandi

By creating a unique attraction around Culture, Nature and the West Lake, and by embracing Sustainable Development as a unifying theme, Xihu Tiandi will help Hangzhou secure its place in the global tourism market. In the process, it is the project team's aim to demonstrate that society can maintain a balance between human habitat and natural habitat, preserve the past while embracing the future.

4 CONCLUSION

As designers, developers, and place makers, we have a responsibility to future generations to keep this planet alive long after we are gone. Environmentally responsible site planning, building design, construction, and operation is fundamental to and indivisible from conserving the finite life sustaining resources of this planet. Social sustainability is all about considering the impact of a project on society, communities and 'users' that enhances the quality of lives. Some areas of relevance to a sustainable future from an economic perspective economic perspective including Whole Life Cycle assessments, environmental evaluation, green accounting, sources of funding and etc. Building assessment schemes not only help to justify the sustainability performance of buildings by providing a standard for measurement, but also promote the practices of green or sustainable building designs within the building industry. There are also on-going researches demonstrating building assessment schemes could facilitate positive results for the environment, occupant health and especially the financial return [12]. It is essential for everyone to act and transforming the marketplace!

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再生骨料混凝土的配制与应用

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摘　要　随着市政建设的进展，大量建筑物被拆除而产生的建筑垃圾对城市的环境造成严重的污染。本文探讨了用混凝土再生骨料代替部分天然骨料、用掺合料代替部分水泥配制再生骨料混凝土技术，同时介绍了再生骨料混凝土的应用情况。

关键词　再生骨料；掺合料；再生骨料混凝土；废弃混凝土块

The Preparation and Application of Reclaimed Aggregate material Concrete

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Abstract　Due to the urban renewal, a great of waste building materials from the pulled down old houses polluted the environment seriously. This paper approached the technology of reclaimed aggregate material as the replacement for the natural aggregate and the mixture as the replacement for the cement to prepare the reclaimed aggregate material concrete(RAM concrete). This paper also introduced the application of the RAM concrete.

Keywords reclaimed aggregate material ; mixture; reclaimed aggregate material concrete(RAM concrete); abandoned concrete block

1　前言

目前，我国建筑垃圾的数量已占到城市垃圾总量的 30%~40%。据统计，我国每年仅施工建设所产生和排出的建筑垃圾就有 4000 万 t。[1]绝大部分建筑垃圾采用露天堆放或填埋的方式进行处理，造成环境污染。建筑垃圾中 80%以上是砖瓦及混凝土碎块，可加工成不同粒径的再生骨料，部分或全部代替天然骨料，用于配制再生骨料混凝土。

此外，传统水泥行业是耗能、排废大户。据统计，每生产 1t 水泥熟料，消耗标准煤 0.25t，排放 CO_2、SO_2 和 NO_X 约 1t。用工业废渣掺合料代替部分水泥，有利于保护环境，降低施工成本。

本项目研制的再生骨料混凝土，是将废弃混凝土块经过清洗、破碎、分级和按一定比例相互配合后得到的“再生骨料”代替部分天然骨料，以工业废渣掺合料代替部分水泥配制的混凝土。再生骨料混凝土完全满足世界环境组织提出的“绿色”的三大含义：(1）节约资源、能源；(2）不破坏环境，更应有利于环境；(3）可持续发展，既可满足当代人的需求，又不危害后代人满足其需要的能力。因此，它是一种可持续发展的绿色混凝土。[2]

2　试验用原材料

试验用原材料主要有：水泥、矿粉、粉煤灰、再生骨料、天然骨料和减水剂。

2.1　水泥

水泥的物理性能见表 1。

表 1　水泥的物理性能

水泥品种	初凝　终凝 (h:min)	安定性膨胀值(mm)	筛余量(%)	标准稠度(%)	抗压(MPa)		抗折(MPa)	
					3d	28d	3d	28d
P．O42.5	2:18　3:31	0.8	6.2	23.8	21.4	47.1	4.8	8.9

2.2　矿粉

矿粉的物理性能见表 2。

表 2　矿粉的物理性能

矿粉级别	密度 (g/cm^3)	比表面积 (m^2/kg)	活性指数（%）		流动度比（%）
			7d	28d	
S95	2.9	432	83	120	104

2.3　粉煤灰

粉煤灰的物理性能见表 3。

表 3　粉煤灰的物理性能

粉煤灰品种	细度（%）	需水量比（%）
II 级低钙灰	10.5	105

2.4　再生骨料

再生骨料的生产原料是混凝土道路、混凝土灌注桩桩头、混凝土构件破碎后的废弃混凝土块，其生产工艺如下：

旧混凝土块 → 分拣（剔除钢筋、旧砖块）→ 破碎 → 筛分 → 清洗 → 配合混匀 → 各种规格再生骨料。

通过这一生产工艺，80%以上的废弃混凝土块可回收利用，生产出再生骨料。

再生骨料的物理性能见表 4。

表 4 再生骨料的物理性能

骨料名称	颗粒级配	含泥量（%）	针片状含量（%）	表观密度 (g/cm^3)	堆积密度 (g/cm^3)	空隙率（%）	吸水率(%)	压碎指标（%）
再生粗骨料	5~20 连续	2.2	3.4	2380	1170	50.5	6.4	17.2
GB/T14685 规定的 II 类碎石		<1.0	<15	>2500	>1350	<47		<20
再生细骨料	II 区	18.4		2326	1293	44.4	11.9	
GB/T14684 规定的 II 区砂		<3.0		>2500	>1350	<47		

注：再生粗骨料的 9.5mm 累计筛余较多，已高出 GB/T14685 规定上限的 3.0%；再生细骨料的 1.25mm 累计筛余较多，已高出规范规定上限的 12%。

由表 4 的试验结果可知，再生骨料的级配不理想，密度小，吸水率高，含泥量高。但是再生粗骨料的强度较高，针片状颗粒含量较少。故利用再生骨料配制混凝土时，应注意调整砂率，从而改善混凝土的和易性。

2.5　天然骨料

天然砂：细度模数 μ_f=2.6 的中砂。

天然碎石：5～20mm 的碎石。

2.6 减水剂

中效减水剂 HL-2A，高效减水剂 LEX-9H。

3 再生骨料混凝土的配合比试验

再生骨料混凝土的配合比试验见表 5。

表 5 再生骨料混凝土的配合比试验(kg/m^3)

配合比编号	水	细骨料		粗骨料		减水剂	坍落度 mm	抗压强度（MPa）		
		天然砂	再生细骨料	天然石	再生粗骨料			R7	R28	R60
GR001	158	748	0	1033	0	中效6.6	195	41.1	60.3	66.9
GR002	174	748	0	517	517	中效.6.6	195	35.0	47.9	53.6
GR003	186	748	0	0	1033	中效6.6	175	31.0	40.6	44.6
GR004	208	374	374	1033	0	中效.6.6	190	29.6	41.0	41.0
GR005	211	374	374	517	517	中效6.6	170	26.2	42.2	45.3
GR006	213	374	374	0	1033	中效.6.6	170	26.5	31.7	33.1
GR007	191	0	748	1033	0	中效6.6	40	28.5	33.3	38.4
GR008	236	0	748	517	517	高效5.76	77	28.0	30.8	38.6
GR009	236	0	748	0	1033	高效5.76	0	22.9	28.3	30.6

注：以上配合比中水泥用量均为 176 kg/m^3，矿粉用量均为 185 kg/m^3，粉煤灰用量均为 79 kg/m^3。

由表 5 可得出：

（1）在混凝土的坍落度为 180±10mm 的前提下，使用再生骨料取代部分或全部天然骨料，均会使混凝土用水量提高，混凝土抗压强度降低。这是由于再生骨料的表面附着水泥硬化灰浆，造成再生骨料吸水性较强。

（2）当混凝土中细骨料全部为天然砂，使用再生粗骨料取代 50%天然石时，混凝土用水量提高 10.1%，混凝土 28 天抗压强度降低 20.6%；使用再生粗骨料全部取代天然石时，混凝土用水量提高 17.7%，混凝土 28 天抗压强度降低 32.7%。

（3）当混凝土中粗骨料全部为天然石，使用再生细骨料取代 50%天然砂时，混凝土用水量提高 31.6%，混凝土 28 天抗压强度降低 32.0%；使用再生细骨料全部取代天然砂时，即使混凝土用水量提高 20.9%，并使用高效减水剂，混凝土的坍落度也只有 40mm，不能满足泵送要求，混凝土 28 天抗压强度还降低 44.8%。

（4）以上说明由于再生细骨料的吸水率更大，它对混凝土流动性和抗压强度的影响，远超过再生粗骨料对混凝土流动性的影响。

（5）GR003 的配比中，将再生粗骨料全部取代天然石，而不使用再生细骨料，混凝土拌合物的坍落度为 175mm，和易性良好；硬化混凝土的 28 天强度可达到 40.6 MPa。该混凝土的胶凝材料用量为 440 kg/m^3。故配制 C20~C30 再生骨料混凝土时，可通过试配情况，适当降低胶凝材料用量。

4　再生骨料混凝土的工程应用和力学性能、耐久性试验

4.1 再生骨料混凝土的施工配合比

表 6　再生骨料混凝土的施工配合比(kg/m^3)

配合比编号	强度等级	水	水泥	矿粉	粉煤灰	砂	再生粗骨料	减水剂 HL－2A	坍落度 mm
JK-20	C20	192	90	146	62	865	1016	2.38	160
JK-30	C30	185	159	167	72	726	924	5.57	150

由表 6 的再生骨料混凝土的施工配合比可得出:

1．将再生粗骨料全部取代天然碎石，再生粗骨料占全部骨料的比例达 54%-56%；

2．在混凝土胶凝材料中矿粉、粉煤灰占全部胶凝材料的比例达 60%；

3．通过以上技术措施，使再生骨料混凝土中 3R 材料的比例达 56%-57%，提高混凝土的绿色程度，满足生态工程的需要。

4.2 再生骨料混凝土的施工情况

C20、C30 再生骨料混凝土分别用于某工程的垫层和基础，数量分别为 63 m^3、325 m^3。C20 再生骨料混凝土施工气温为 28℃；C30 再生骨料混凝土施工气温为 12℃。C20 再生骨料混凝土出厂坍落度 160 mm，一小时后到达工地，实测坍落度 140 mm；C30 再生骨料混凝土出厂坍落度 150 mm，一小时后坍落度为 120 mm。再生骨料混凝土的和易性良好，泵送、浇捣方便。

4.3 再生骨料混凝土的力学性能和耐久性试验

该工程施工时，从搅拌车中取样，成型混凝土试件，进行再生骨料混凝土的力学性能和耐久性试验。

4.3.1 再生骨料混凝土的力学性能和抗渗性

表 7　再生骨料混凝土的力学性能和耐久性(28 天)

配合比编号	抗压强度,MPa	轴心抗压强度,MPa	劈裂抗拉强度,MPa	抗折强度,MPa	弹性模量,MPa	抗渗	收缩值
JK-20	26.4	14.4	2.14	3.9	1.60×10^4	P4	443×10^{-6}
JK-30	34.8	31.5	3.32	4.2	2.96×10^4	P8	335×10^{-6}

再生骨料混凝土的抗压强度可满足设计要求，其它力学性能指标和耐久性指标与普通混凝土基本接近。

该工程基础混凝土拆模后，混凝土无裂缝、表面光滑，混凝土质量良好。

4.3.2 再生骨料混凝土和普通混凝土的力学性能比较

在胶凝材料、骨料及减水剂的用量一致的条件下，C30 再生骨料混凝土和 C30 普通混凝土的力学性能对比如下。

表 8　C30 再生骨料混凝土和 C30 普通混凝土的力学性能对比

试件名称	水，kg/m^3	坍落度，mm	抗压强度，MPa	轴心抗压强度，MPa	弹性模量，MPa
C30 再生骨料混凝土	185	160	34.8	31.5	2.96×10^4
C30 普通混凝土	173	155	43.0	35.8	3.46×10^4

由表 8 可得出：

1．再生骨料混凝土比普通混凝土的用水量提高 12 kg/m^3，提高幅度为 6.9%；

2．再生骨料混凝土的 28 天抗压强度比普通混凝土降低 19.0%；

3．再生骨料混凝土的轴心抗压强度比普通混凝土降低 12.0%；

4．再生骨料混凝土的弹性模量比普通混凝土降低 14.4%；

5．再生骨料混凝土的收缩性能及抗冻性能，尚需进一步试验研究。

5　结论

5.1　再生骨料混凝土中使用再生骨料和工业废渣材料的比例超过 50%，是一种绿色环保型的混凝土材料。

5.2　试点工程和试验研究证明，再生骨料混凝土的和易性良好，可满足泵送要求；硬化再生骨料混凝土的力学性能可满足通常民用建筑的使用和设计要求。

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TECECO CEMENTS – Carbonation = Sequestration – Waste Utilization = Resource

A John W Harrison, B.Sc. B.Ec. FCPA.

Abstract Around 26 billion tonnes of CO_2 are released to the atmosphere annually, around 20 billion metric tonnes of which is from the burning of fossil fuels and a significant 2 billion tonnes from the production of Portland cement. Given the huge size of the built environment, tec-eco and enviro-cements represent a novel new method of reducing emissions or sequestering large amounts of CO_2 as calcium and magnesium carbonates in bricks, blocks, pavers, mortars and other building materials.

Over two tonnes of concrete are produced per person on the planet per annum, representing and enormous opportunity to not only do a lot about global warming but to also utilize solid wastes for their physical property rather than chemical composition in cementitious composites with improved properties.

This paper discusses the potential impact on sustainability of the new tec and eco-cement technologies.

Keywords Abatement, sustainable, sustainability, sequestration, CO_2, brucite ($Mg(OH)_2$), durability, reactive magnesium oxide, materials, nesquehonite ($MgCO_3$.3H2O), lansfordite ($MgCO_3$.5H2O), magnesian, magnesia, reactive magnesia (MgO), magnesite ($MgCO_3$), hydromagnesite ($Mg_5(CO_3)4(OH)_2 \cdot 4H_2O$), fly ash, pozzolan, hydraulic cement, Portland cement, concrete, process energy, embodied energy, lifetime energy, durability, shrinkage, cracking, extract, extraction, permeability, rheology, emissions, flow, matter, materials, substances, wastes, reduce, reducing, reuse, re-using, recycle, recycling,.

摘 要 每年约有 260 亿吨 CO_2 排放到大气中，其中约 200 吨来自于化石燃料燃烧，20 亿吨来源于波特兰水泥(普通水泥)的生产。由于在建筑环境中这些能源的用量巨大，生态技术和环境水泥的革新方法，可以象减少砖、木材、铺路材料和灰泥等建筑材料中的钙镁等碳酸盐类物质的排放一样减少或阻止大量的 CO_2 的排放。

全球每年混凝土的产量人均约 2 吨，这个产量表明，不仅在全球变暖问题上有许多工作要做，而且对按固体废弃物固有物理特性进行回收利用，而不用改良特性方法化学合成粘性合成物，均有更大的发展机会。

本文讨论了新技术和生态水泥技术可持续性的潜在影响。

关键词 消除，可持续的，可持续性，隔离，CO_2，氢氧镁石($Mg(OH)_2$)，耐久力，活性氧化镁，材料，3 水碳酸镁($MgCO_3.3H_2O$)，5 水碳酸镁($MgCO_3.5H_2O$)，氧化镁，碳酸镁，飞灰，火山灰，水泥，波特兰水泥，混凝土，加工能耗，物化能耗，终生能耗，收缩，破裂，提取，渗透性，流变学，散发，流动，废物，减少，重新使用，再循环

John Harrison has degrees in science and economics and is managing director and chairman of TecEco Pty. Ltd. John is best known for the impact on sustainability of tec, eco and enviro-cements. John is an authority on sustainable materials for the built environment and was a founder of the Association for the Advancement of Sustainable Materials in Construction. He has been the keynote speaker at many conferences and is committed to finding ways of improving the sustainability of the built environment.

Introduction

Eco-cements became known to the world mainly through an article on them in New Scientists Magazine and a program shown by Discovery Channel (Pearce 2002). There have been several reasons for the intense interest – the potential lower embodied energy, the ability of the material to benignly encapsulate a wide range of wastes and the potential for reduced emissions (tec-cements) and CO_2 sequestration on a massive scale (eco-cements). The ability of tec and eco-cements to reduce net carbon dioxide emissions and utilise wastes are the main subject matter for this paper.

The built environment is our footprint on the globe and probably accounts for around 70% of all materials flows and of this "Buildings account for 40 percent of the materials and about a third of the energy consumed by the world economy. Combined with eco-city design principles, green building technologies therefore have the potential to make an enormous contribution to a required 50% reduction in the energy and material intensity of consumption in the post-modern world." (Rees 1999) Current cement production is over two billion tonnes per annum which is used to make over two tonnes of concrete per person on the planet per annum. (USGS 2004)

Global carbon dioxide flows in tonnes CO2 are (Haughton 2004 converted from tonnes C):

Atmospheric increase	=	Emissions from Fossil fuels	+	Net emissions from changes in land use	-	Oceanic uptake	-	Missing carbon sink
12.07 (±0.73)	=	20.152 (±0.1.83)	+	5.86 (±2.56)	-	7.32 (±2.93)	-	6.59 (±4.39)

Unless we want to face climate change on a massive and global scale we must sequester around 6 billion tonnes of CO_2 per annum. As we are unlikely to kick the fossil fuel habit until it kicks us the need is urgent. Now Russia has joined the Kyoto treaty it has come into affect and countries that do not make an effort to sequester carbon will in due course face sanctions. What better way to sequester carbon than in our own built environment? TecEco cements mimic nature by sequestering large amounts of carbon dioxide or reducing output of the gas with the added benefit of utilising wastes.

Basic Chemistry

TecEco cements include in their formulation reactive magnesia, a hydraulic cement such as Portland cement and usually a pozzolan. The Portlandite released during the curing of the Portland cement component is consumed by the pozzolan to produce more calcium silicate hydrate, a strength giving mineral or in eco-cements can also carbonate.

When reactive magnesia is substituted for OPC the first noticeable affect is an improvement in the rheology; blocks go through block machines with fewer failures, mortars spread more easily and stick better, concretes are easier to place. There are several reasons for this. Principal amongst them are the fineness of the reactive magnesia which affects particle packing and lubrication and the high surface charge density of the magnesium ion in solution which attracts layers of orientated water molecules.

Water is consumed by the hydrating brucite reducing shrinkage, and decreasing the voids paste ratio increasing strength. A higher short term pH may also contribute to more affective pozzolanic reactions. More wastes can be included mainly because of the lower long term pH.

TecEco Tec-cements generally contain less than 10% MgO and are more sustainable because they require less cement for the same strength. In concretes made using them, as for ordinary pc concretes, carbonation only proceeds to a relatively shallow depth as the formation of magnesium carbonates also results in greater density and the blockage of pores, which impedes further absorption of CO_2 into the cement. The main difference in the longer term is that the equilibrium pH controlled by brucite and CSH is much lower, reducing alkali silica reaction (ASR) problems but still sufficiently high to maintain the passive oxide layer around steel rebar deep in the substrate. Durability is improved mainly because of the pore filling affect, lower pH and lower solubility of Brucite compared to Portlandite.

In the presence of carbon dioxide and moisture inside an eco-cement block or mortar that is reasonably porous brucite ($Mg(OH)_2$ carbonates forming hydrated magnesium carbonates such as nesquehonite and lansfordite and possibly an amorphous phase at room temperatures. Although theories abound it is thought that there is a gradual desiccation with lansfordite loosing water forming nesquehonite and so on, particularly in relation to the formation of magnesite which Deelman claims to have solved (Deelman 2003). Significantly, both magnesium and calcium appear to carbonate more readily in porous concretes made using TecEco eco-cements containing magnesia that in concretes containing only Portland cement (PC) as the binder.

The silicification reactions of Portland cement are relatively well known and not discussed in this short paper. Carbonation of both Portlandite and brucite adds strength to eco-cement concretes used for blocks, mortars and renders and is encouraged for this and sequestration reasons. Calcium carbonates seem to at least obey Ostwalds law in the sequence of vaterite=>aragonite=>calcite carbonates formed however this is not the case for magnesium which forms a big range of basic and hydrated carbonates. There are a number of chemical pathways in which they can form and what favours the more important pathways is still being determined. The thermodynamics predicts hydromagnesite but more recent work has demonstrated that for kinetic reasons hydrated carbonates are formed.

Sustainability

Reducing Net Emissions and Utilizing Wastes

“In 1999, construction activities contributed over 35% of total global CO_2 emissions - more than any other industrial activity. Mitigating and reducing the impacts contributed by these activities is a significant challenge for urban planners, designers, architects and the construction industry, especially in the context of population and urban growth, and the associated requirement for houses, offices, shops, factories and roads.” (UNEP 2001)

According to the Human Settlements Theme Report, State of the Environment Australia 2001 (CSIRO 2001), “Carbon dioxide (CO_2) emissions are highly correlated with the energy consumed in manufacturing building materials. “On average, 0.098 tonnes of CO_2 are produced per gigajoule of embodied energy of materials used in construction. The energy embodied in the existing building stock in Australia is equivalent to approximately 10 years of the total energy consumption for the entire nation. Choices of materials and design principles have a significant impact on the energy required to construct a building. However, this energy content of materials has been little considered in design until recently, despite such impacts being recognized for over 20 years."

Tec cements reduce emissions by requiring less CO_2 emitting cement and utilizing a higher proportion of pozzolans for the same strength development whilst eco-cements set by absorbing carbon dioxide from the air.

Both tec and eco-cements provide a benign environment in which significant quantities of waste can be utilised. The shear thinning properties tend to prevent segregation of materials like plastics which is a problem with Portland cements and the lower pH prevent internal reactions from occuring.

Changing the Economic Paradigm – Converting Waste to Resource.

The widely held view is that sustainable strategies for construction are complex to devise and politically difficult to introduce. Currently it is more expensive to reuse and recycle than to use newly extracted resources. There would be a rapid improvement in sustainability if this hurdle could be overcome so that it was not only cheaper to reduce, reuse or recycle, but the process resulted in superior properties.

The problem is the costs involved. Sorting waste streams and then transporting sorted recyclable materials back to a location in which they can be used is expensive and tends to make recycled inputs more expensive than raw materials. Disorder is prevalent for two main reasons; things are made with mixed materials and the waste collection process tends to mix them up even more.

The current technical paradigm for the recycling process generates separate outputs based on chemical composition rather than class of property. Costs are incurred and waste generated in separating what is required from the balance of materials and then transporting to factories that can only use specific waste inputs.

The TecEco cement technologies provide an inherently more economic process as they change the technology paradigm redefining wastes as resources (Pilzer 1990). TecEco cements are benign low long term pH binders that can utilise waste more on their class of property rather than chemical composition, and therefore reduce sorting problems and costs associated with recycling.

Carbon taxes give the production of CO2 a cost. TecEco cements either reduce emissions or sequester the gas and should be eligible for credits in a fair system.

Carbonation of Eco-cement Bricks, Blocks, Pavers and Mortars

In TecEco tec-cements carbonation is not desirable if reinforced with steel but desirable otherwise. It is therefore generally appropriate that tec - cements are dense so carbonation is not driven by loss of water or access by CO_2. With formulations such as eco-cements, carbonation is desirable and is encouraged by the porous nature of these products. After hydration environments with a high relative humidity and wet - dry atmosphere seems best with humidity not dropping below 50-60%.

Eco-cements were the first TecEco cements to become known because they carbonate readily and therefore sequester CO_2. With the inclusion of wastes containing carbon such as sawdust or plastics they are net carbon sinks.

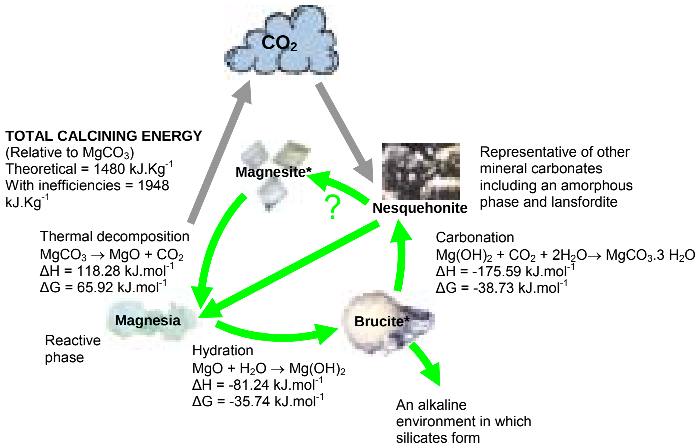

Figure 1 The Magnesium Thermodynamic Cycle

In porous eco-cement concretes magnesia first hydrates forming brucite and this then carbonates forming hydrated magnesium carbonates including an amorphous phase, lansfordite and nesquehonite. A simplified thermodynamic cycle is depicted in Figure 1 but is in reality more complex.

The high charge density of Mg^{++} explains why in water polar molecules of H_2O appear to line up in layers around the Mg^{++} ion making carbonation other than via a hydrated carbonate difficult if not impossible.

The more important carbonates of calcium and magnesium are listed in Appendix 1 – Calcium and Magnesium Carbonates on page 475

The XRD traces for a simple block formulation using sand as an aggregate are shown before and after treatment with HCL used to remove carbonates in Figure2 and are clear evidence that the binder in eco-cements is a mixture of calcite, lansfordite and nesquehonite, not calcite, hydromagnesite and magnesite as the author originally thought.

The XRD does not show an amorphous form but semi quantitative XRD indicates a possible shortfall which may be expressing as the amorphous from commented on by Deelman (Deelman 2003) or have insufficient lattice order to show up. Further work will include quantitative acid neutralisation to try and prove this.

The rate of carbonation of both calcium and magnesium compounds depends on the dissolution rate of Ca^{2+} and Mg^{2+} and partial pressure and transport of CO_2. These in turn are influenced by the mix design, affect of aggregates on porosity and setting atmospheric conditions. Dry mixes as in masonry unit formulations appear essential and wet dry cycles appear to promote carbonation providing alternatively transport and reaction media. Well graded aggregates including a coarse fraction are essential. Ideal carbonation conditions are still being considered, presently 50 – 70% relative humidity and exposure although wet dry is thought to work best.

The observed products of carbonation in eco-cement blocks are calcite, possibly vaterite, lansfordite and nesquehonite and all have strength giving properties. In the case of the magnesium carbonates this is considered to be mostly microstructural due to their shape and interactions with other matrix minerals.

Of the calcium minerals aragonite is the strongest with a hardness of 3.5 – 4. Both calcite and vaterite are relatively soft with a hardness of 3. Nesquehonite or lansfordite contribute to strength and the reason is thought to be microstructural as they are not particularly strong with a hardness of 2.5.

Of the calcium carbonates only vaterite and rarely aragonite are fibrous. Most of the carbonates and hydrated carbonates of magnesium can be fibrous or otherwise elongated. For example nesquehonite is prismatic and generally forms star like clusters thought to be a possible source of microstructural strength. Fibrous and needle like crystal growths add more microstructural strength than more rounded or tabular crystals such as calcite because of the 3D structures formed.

Calcium silicate hydrates can form elongated growths but commonly have a more granular or tabular habit. All are harder than Brucite or the carbonates of calcium or magnesium. Harder minerals that form more quickly tend to have the physical effect of forcing the growth of slower growing softer minerals into interstitial spaces. It is also possible that the more reformation processes that occur, the more crystals interlock with each other adding to strength and that the hydroxides and carbonates of magnesium are compressed adding to strength. According to CANMET, compressed brucite is, for example, as strong as CSH (Beaudoin J. J. 1977).

The micro tensile strength of the various carbonate minerals in the system are not generally considered and not known. It is essential this work is done as micro tensile strength is known to have a big impact on dental cement strengths. The strength development in tec-cements could well be a result of micro tensile strength in amorphous and crystalline Mg hydrated carbonates acting somewhat like a glue between stronger minerals that provide the bulk strength.

Lansfordite and nesquehonite are more soluble than magnesite and hydromagnesite which are virtually insoluble (both with a solubility of approximately .001 g L^{-1}), however both are more soluble than Brucite with a solubility of .000154 g L^{-1} (K_{sp} = 1.8 x 10^{-11}) which is virtually insoluble. (See Appendix 1 – Calcium and Magnesium Carbonates on page 475).

Carbonation starts at the surface and works inwards and can be accelerated by exposure to the weather. It is generally accepted medium to high humidity is best. Simple experiments performed by the author have also demonstrated that the presence of accelerators such as iron salts and triethanolamine may accelerate carbonation. The use of CO2 producing organics such as carbonic acid, EGDA or propylene carbonate are considered uneconomic and of academic interest only. The use of carbonated steam, carbon dioxide foam and other substance which release CO_2 is also being considered.

Masonry units are usually made hollow and due to the manufacturing process they are porous and the presence of air voids clearly speeds up carbonation. The maximum depth is less that 40 – 50 mm and averages more like 25 or 30 mm. If a porous aggregate such as bottom ash, scoria or pumice is also added an even higher internal surface area results further speeding up carbonation.

Reactive magnesia fly ash eco-cements carbonate more rapidly than similar formulations with just Portland cement. Portland eco-cements carbonate better than Sorel cements. In all cases, carbonation occurs rapidly only in porous dry mix materials.

Other magnesium cements such as magnesium oxychloride and magnesium oxysulfate take a long time to carbonate and as reported by Cole and Demediuk (Cole and Demediuk 1955) tend to remain as unstable oxy compounds, but do eventually carbonate.

Carbonation Volume Changes

Consider the volume changes that occur when Portlandite carbonates to calcite:

$Ca(OH)_2 + CO_2 \rightarrow CaCO_3$

$74.08 + 44.01 \leftrightarrow 100$ molar mass

$33.22 + \text{gas} \leftrightarrow 36.93$ molar volumes

Slight expansion. But shrinkage from surface water loss

Consider the volume changes that occur when Brucite carbonates to nesquehonite:

$Mg(OH)_2 + CO_2 + H_2O \rightarrow MgCO_3.3H_2O + H_2O$

$24.3 + (g) \rightarrow 74.77 + (l)$ molar volumes[1]

Significant expansion.

The water lost by Portland cement as it shrinks is used by reactive magnesia as it hydrates negating or eliminating shrinkage.

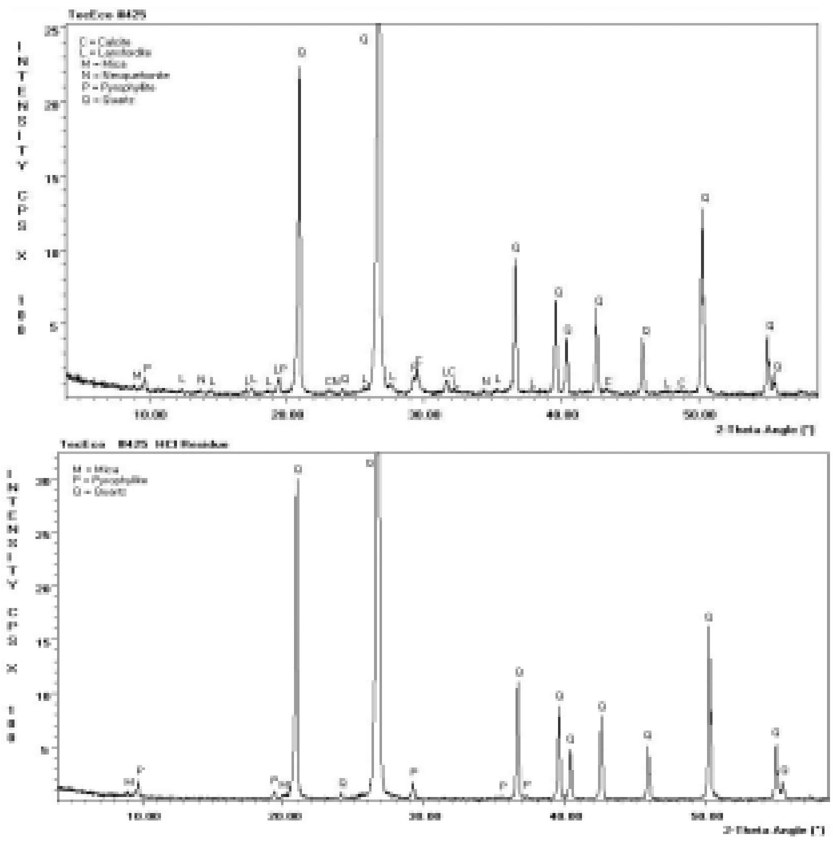

Figure 2 XRD Showing Carbonates Before and Minerals Remaining after their Removal with HCl in a Simple Mix (70 Kg PC, 70 Kg MgO, colouring oxide .5Kg, sand unwashed 1105 Kg)

The Extent and Potential of Carbonation in Portland compared to Eco-Cement Concretes

The amount of CO_2 concretes absorb is dependent on a number of factors.

Porosity is the main factor. Mortars like old fashioned lime mortars must be porous. For this a graded sand containing coarser particles is essential. Concrete masonry units tend to be more porous as they are mixed dry. It is important to note that porosity does not necessarily infer inferior quality. There is much to be said for mortars and concrete masonry units that "breathe".

[1] The molar volume is equal to the molar mass of atoms or molar mass of molecules divided by the density.

Thickness is another key factor - only the outer 35-50 mm (1 ½ to 2") of poured Portland cement and somewhat less for TecEco tec-cement concretes will absorb CO_2. Concrete masonry units and mortars are on the other hand more porous and not very thick in cross section and will generally absorb CO_2 throughout.

Eco-cements contain a high proportion of reactive magnesia. In masonry products such as mortars and blocks made using TecEco eco-cement, there is a much greater proportion of materials such as reactive magnesia (and thus Brucite) in the cement component that carbonate and carbonation proceeds to completion and much more CO_2 is reabsorbed. A typical eco-cement formulation for masonry products for example would contain 50 - 85% readily carbonated material in the cement component compared to 20-25% in the cement component of ordinary CMU's containing Portland cement only. There is therefore approximately 50 % more carbonation in an eco-cement block compared to an ordinary concrete block.

The carbonation of a typical block formulation containing 15% cement is depicted in Figure 3 The Carbonation of a Typical Eco-Cement Block on page 472.

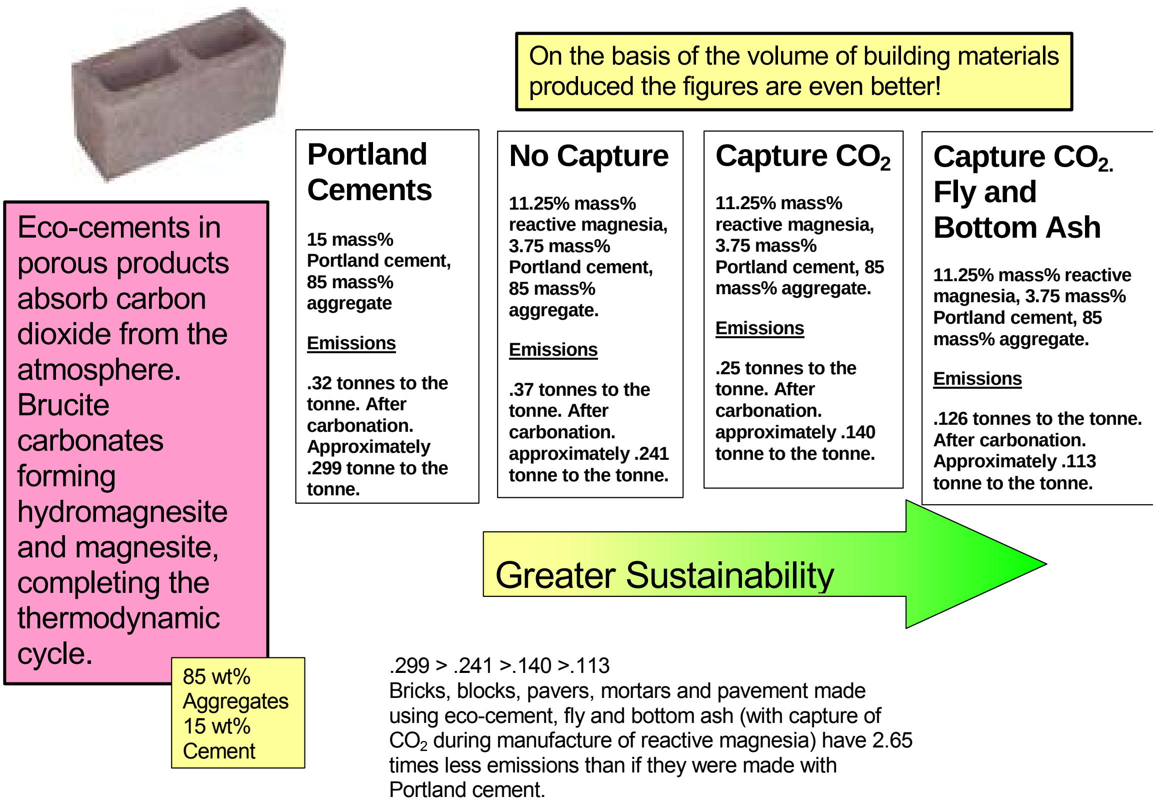

Figure 3 The Carbonation of a Typical Eco-Cement Block

The calculations do not take into account the use of sustainable energy to produce eco-cements or the capture of CO_2 at source as planned by TecEco.

Sustainability Other Than by Carbonation

Superior Strength Development with Less cement and Blended Pozzolans

There are many ways in which sustainability can be improved. It has been demonstrated that tec-cements which contain a much lower proportion of reactive magnesia develop strength more rapidly from day 0 and continue to develop strength in a straight line at least for 90 days, even with a significant proportion of added pozzolans. Increased strength for the same amount of cement is no different to the same strength for less cement.

Durability

The less often something is replaced the less energy and emissions used to replace it. TecEco cements have been demonstrated to be much more durable than their Portland cement counter parts.

Waste Utilization

Apart from global warming, the other biggest problem on the planet today is the disposal of waste. The answer is to convert waste to resource and TecEco have developed cementitious composites that provide a benign environment suitable for waste immobilization.

Many wastes such as fly ash, sawdust, shredded plastics etc. can improve a property or properties of the cementitious composite based on their physical property rather than chemical composition.

If wastes cannot directly be used then if they are not immobile they should be immobilized. TecEco cementitious composites represent a cost affective option for both use and immobilization.

TecEco waste inclusion technology is more suitable than any other means of incorporating large volumes of wastes. Durability and many other problems are overcome. Reasons include:

- Lower reactivity (less water, lower pH)
- Reduced solubility of heavy metals (lower pH)
- Greater durability
- Dense, impermeable and
- Homogenous.
- No bleed water
- Are not attacked by salts in ground or sea water
- Are dimensionally more stable with less cracking

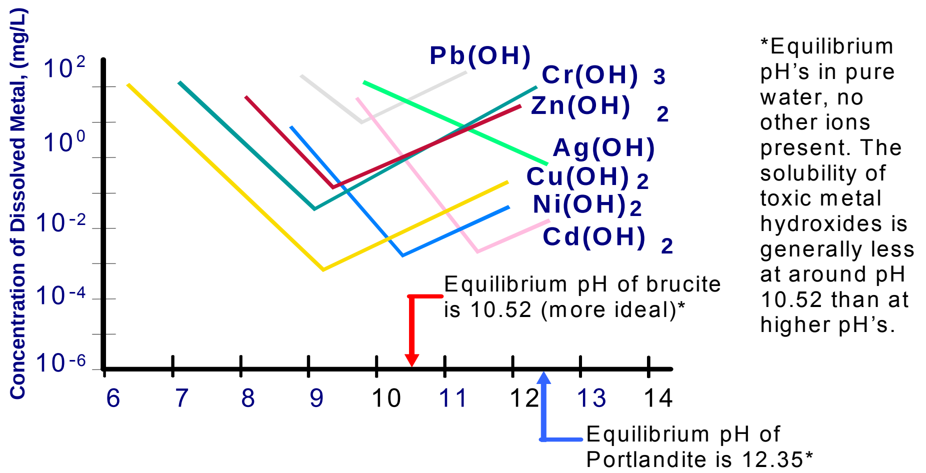

Figure 4 The Low pH regime of TecEco cements Minimises the Solubility of Heavy Metals

Immobilisation Mechanism

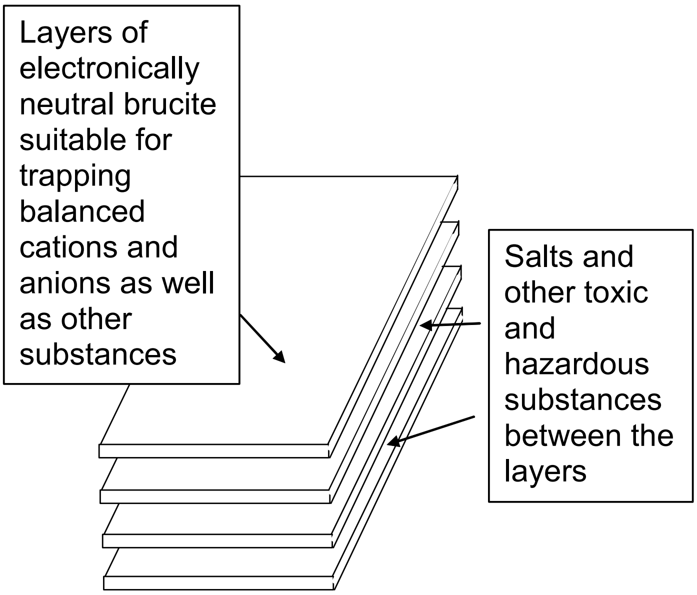

Figure 5 The Layers of Brucite Trap Toxic Wastes

In a Portland cement-brucite matrix OPC takes up lead, some zinc and germanium. The magnesium mineral is mainly brucite although hydrotalcite may form under some conditions. are both excellent hosts for toxic and hazardous wastes. Heavy metals not taken up in the structure of Portland cement minerals or trapped within the brucite layers end up as hydroxides with minimal solubility. The minimum solubility of most heavy metal hydroxides is in the pH range governed by brucite, not in the pH range governed by Portlandite. There is a 10^4 advantage.

The brucite in TecEco cements has a structure comprising electronically neutral layers and is able to accommodate a wide variety of extraneous substances between the layers and cations of similar size substituting for magnesium within the layers and is known to be very suitable for toxic and hazardous waste immobilisation.

Summary

The late great H.F.W. Taylor, perhaps the most pre-eminent cement chemist ever, predicted a need to do something about global warming and wastes in regard to cement and concrete publicly at least as far back as 1990 in his address to a Conference on Advances in Cementitious Materials (Taylor 1990) forecast many changes not only in the way cements are made but in their composition, particularly in relation to the incorporation of wastes.

TecEco cements are a new innovation that offers sustainability in our own back yards. Tec-cements promise greater durability than ever achieved before and stronger materials with lower embodied energies and associated emissions whilst eco-cements are the first construction materials that successfully uses carbon dioxide and wastes.

As stated by Fred Pearce in the article on eco-cements that was published in the New Scientist “There is a way to make our city streets as green as the Amazon Forest. Almost every aspect of the built environment from bridges to factories to tower blocks, and from roads to sea walls, could be turned into structures that soak up carbon dioxide – the main greenhouse gas behind global warming. All we need to do it change the way we make cement.”

Appendix 1 – Calcium and Magnesium Carbonates

Numerous magnesium carbonates, hydrated magnesium carbonates and hydroxide carbonates exist. Mixed Mg-Ca, Mg-Fe Mg-Na etc. carbonates not shown but numerous. For a list of carbonates see http://mineral.galleries.com/minerals/carbonat/class.htm. For detail see http://webmineral.com

Basic Magnesium Carbonates

Numerous magnesium hydroxide carbonates exist.

Mineral	Formula	XRD (By Intensity I/Io)	Molecular Weight	Hardness	Density	Solubility (Ml^{-1}, cold water)	ΔH^o reaction from hydroxide ($kJ.mol^{-1}$)	ΔG^o reaction from hydroxide ($kJ.mol^{-1}$)	**Comment**
Artinite	$Mg_2CO_3(OH)_2.3H_2O$	2.736(1), 5.34(0.65), 3.69(0.5)	198.68	2.5	2.02		-194.4	-49.81	Hydrated basic magnesium carbonate
Hydro magnesite	$Mg_5(CO_3)_4(OH)_2.4H_2O$	5.79(1), 2.899(0.82), 9.2(0.39)	365.31	3.5	2.16	.001095	-318.12	-119.14	Hydrated basic magnesium carbonate
Dypingite	Mg5(CO3)4(OH)2.5H2O	10.6(1), 5.86(0.9), 6.34(0.6)	485.65		2.15				Hydrated basic magnesium carbonate
Giorgiosite	Mg5(CO3)4(OH)2.5H2O	11.8(1), 3.28(0.7), 3.38(0.7)	485.65		2.17				Hydrated basic magnesium carbonate
Nesquehonite	$Mg(HCO_3)(OH)\cdot2(H_2O)$ or $MgCO_3\cdot3(H_2O)$	6.5(1), 3.86(0.9), 2.61(0.7)	138.36	2.5	1.85	.012937	-175.59	-38.73	Commonly formed at room temperature and from Lansfordite
Pokrovskite	$Mg_2(CO_3)(OH)_2\cdot0.5(H_2O)$	2.6(1), 2.17(0.9), 6.1(0.7),	151.64	3	2.51				Alteration product

Carbonates and Hydrated Carbonates

Mineral	Formula	XRD	Molecular Weight	Hardness	Density	Solubility (Ml^{-1}, cold water)	ΔH^o reaction from hydroxide ($kJ.mol^{-1}$)	ΔG^o reaction from hydroxide ($kJ.mol^{-1}$)	Comment
Vaterite	$CaCO_3$	2.73(1), 3.3(1), 3.58(1)	100.09	3	2.54			-61.33	Polymorph of calcite and aragonite
Calcite	$CaCO_3$	3.035(1), 2.095(0.18), 2.285(0.18),	100.09	3	2.71	.0001399	-69.58	-64.63	Polymorph of vaterite and aragonite
Aragonite	$CaCO_3$	3.396(1), 1.977(0.65), 3.273(0.52),	100.09	3.5-4	2.93	.00015			Polymorph of vaterite and calcite
Ikaite	$CaCO_3.6H_2O$	5.17(1), 2.64(0.9), 2.63(0.7),2.8(0.5), 2.46(0.3), 2.61(0.3), 4.16(0.3), 5.85(0.3), 4.16(0.3),	208.18		1.78				Forms in cold saline marine waters
Monohydrocalcite	$CaCO_3.H_2O$	4.33(1), 3.08(0.8), 1.931(0.6),2.17(0.6), 2.83(0.5), 2.38(0.4), 2.28(0.4), 1.945(0.3),	118.10	2-3	2.38				
Magnesite	$MgCO_3$	2.742(1), 2.102(0.45), 1.7(0.35)	84.31	4	3.009	.001257		-19.55	The most stable form but difficult to make.
Amorphous	$MgCO_3,nH_2O$	Amorphous							Exists in nature and the lab
Magnesium carbonate monohydrate	$MgCO_3{\cdot}H_2O$								Does not exist in nature
Barringtonite	$MgCO_3{\cdot}2(H_2O)$	2.936(1), 3.093(1), 8.682(1)	120.34		2.83				Rare form
Lansfordite	$MgCO_3{\cdot}5(H_2O)$	3.85(1), 4.16(1), 5.8(0.8)	174.39	2.5	1.73	.01009			Commonly forms at room temperature

Mixed Carbonates and Hydrated Carbonates of Calcium and Magnesium

Mineral	Formula	XRD	Molecular Weight	Hardness	Density	Solubility (Ml^{-1}, cold water)	ΔH^o reaction from hydroxide ($kJ.mol^{-1}$)	ΔG^o reaction from hydroxide ($kJ.mol^{-1}$)	Comment
Dolomite	CaMg(CO3)2	2.883(1), 1.785(0.6), 2.191(0.5)	184.4	3.5-4	2.84	insoluble			Massive.
Huntite	CaMg3(CO3)4	2.833(1), 1.972(0.3), 2.888(0.2)	353.03	1-2	2.696	Rel. insoluble			Rare
Sergeevite	Ca2Mg11(CO3) 9(HCO3)4(OH)4 ·6(H2O)	2.82(1), 1.965(0.3), 2.87(0.3),3.58(0.3), 7.14(0.3), 1.755(0.2), 3.37(0.2), 2.68(0.1)	1,307.78	3.5	2.27	insoluble			Very rare

Source thermodynamic data for calculation ΔH^o and ΔG^o and reaction from hydroxide: Robie, Richard A., Hemingway, Bruce S., and Fisher, James R. Thermodynamic Properties of Minerals & Related Substances at 298.15K and 1 Bar (105 Pascals) Pressure and at Higher Temperatures. U.S. Geological Survey Bulletin 1452. Washington: United States Government Printing Office, 1978.

Source Solubility Data: Data extracted from CRC Handbook of Chemistry and Physics, 74th Edition, 1993-1994 and from Chemistry Web Server at California State University at http://155.135.31.26/oliver/chemdata/data-ksp.htm valid 01/11/2003

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阳光板的应用及经济性分析

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摘　要　阳光板（Polycarbonate Panel）由于具有透光性高、抗冲击性强、隔热性能优异等特点在我国得到日益广泛的应用。本文着重分析了阳光板在我国建筑业、现代化农业温室中的应用情况，并引用实例分析了阳光板作为温室覆盖材料经济性合理、节能效果显著。同时指出国内对阳光板的研究还处于起步阶段，阳光板很多技术性能包括热物理特性等还有待深入研究。
关键词　建筑技术；阳光板；温室；节能

Application and Economic Analysis of Polycarbonate Panel

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Abstract　Polycarbonate panel which is called PC panel has been used increasing widely in architecture engineering in China because polycarbonate panel has advantages of high transmissivity, strong anti-impact ability and excellent heat insulation, In this paper the applications of the PC panel in building and modern agricultural greenhouses of China are mainly analyzed. Economic and high energy conservation effect are illustrated by the example that PC panel is used as a kind of greenhouse-covering material. By the meantime, It is pointed out that the research on PC panel is still in the preliminary phase in China, and there are many technologies and performance such as thermalphysical characteristic needed to be investigated in the future.
Keywords　Building technology, Polycarbonate Panel, Greenhouse，Energy conservation

1　概述

阳光板（Polycarbonate Panel）是一种以聚碳酸树脂为原料，采用挤出成型法制造的工程塑料板材，学名聚碳酸酯板，简称 PC 板。聚碳酸酯的透光性甚佳，其板材多用于建筑物采光和农业温室，故称其为阳光板。它作为一种新型建筑材料在光学、热学及力学性能方面均显示出优异的特性。

阳光板基本分四大类：实心平板（Solid Panel），俗称单层板(Mono-wall Panel)；蜂窝格子状空心平板（Honeycomb Hollow Panel），俗称多层板（Multi-wall Panel）；波纹板（Corrugated Panel），俗称浪板，薄膜（Film）[1]。阳光板的颜色有很多种，其中以透明无色、绿色、蓝色、咖啡色、浅灰色等颜色为主导。

本文从研究阳光板的技术性能入手，着重分析其在农业温室建设中的应用情况，阳光板作为温室覆盖材料具有能耗低、抵御自然灾害能力强等特点。

2　阳光板技术性能

阳光板透光性良好、材质轻、抗冲击性强、隔热性能优、耐候性强，与玻璃建筑装饰材料相比，

具有一定的优势。它的主要特点包括：

- 光学性能：通过实验研究表明，双层阳光板的透射比与玻璃相差不大。
- 力学性能：与玻璃等其他透光建筑材料相比，阳光板具有材质轻、强度高的优点。双层阳光板每平方米重量仅为2.4kg[2]，具体抗冲击强度见表1。
- 热工性能：在厚度相同的条件下，阳光板比玻璃节能，可有效降低建筑能耗。
- 耐候性强：阳光板能适应从严寒到高温各种恶劣的天气变化，在长期荷载作用下允许使用温度为-40℃至+120℃，在短期荷载作用下允许使用温度为-90℃至+135℃。在此范围内，板材不会出现明显的变形和破坏[3]。
- 防露滴功能：阳光板在室内相对湿度低于80%时，材料的内表面不会结露，足以满足湿度高、内外温差的环境的特殊要求。
- 阻燃性能：阳光板的自燃温度为630℃，为难燃一级材料，并在燃烧过程中不产生毒性气体。
- 隔声性能：在厚度相同的条件下，阳光板的隔声量比玻璃提高3-4dB
- 良好的加工性能：阳光板的可塑性和柔性良好，最小弯曲半径为板厚的175倍。
- 阳光板与普通玻璃的性能比较见下表

表1　阳光板与玻璃性能比较

性能 / 材质	透光率（无色）%	抗冲击性（N/m^2）	导热系数（W/m.K）	耐候性	防露滴功能	隔声性能
普通玻璃	89	2940	2.8(中空玻璃)	弱	湿度略高，结露明显	——
阳光板	80	10780	0.2	强	湿度 80%以下不结露	隔声量比普通玻璃提高 3-4dB

3　阳光板在我国应用现状

PC阳光板因其特有的高品质，得到了建筑设计、装饰工程、环境工程、广告业的广泛认同。它的应用范围主要包括公共建筑、工业建筑、建筑的内外装修、装饰；火车站、航空港等候厅及通道顶棚；农业温室大棚覆盖材料；高速公路及城市高架路隔音屏障等。在我国，一批重点建设工程项目：深圳国际贸易大厦、杭州香格里拉饭店、北京四川饭店、北京世界公园、北京西客站和上海高架桥隔音材料等均率先采用了阳光板。国内已有浙江、福建、湖北、河北、山东等地厂家看好阳光板生产项目，拟设厂生产阳光板材[4]。

目前我国现代化农业温室建设主要用玻璃、双层薄膜等作为温室建设的覆盖材料。采用这些材料建造的现代温室主要存在的问题是，温室的能耗高，抵御自然灾害的能力差，薄膜在用过后还将造成白色污染。而阳光板作为现代化农业温室的第四代覆盖材料具有强度高、能耗低、抗温差性强等优势。在我国，温室建造主要在北方的一些城市，形式有全部使用阳光板建造的温室，有山墙和侧墙使用阳光板建造的温室；在温室作用方面有以生产为主的生产型温室，有以花卉交易中心为主的商业型温室，以及以科研为主的温室等等。

温室的结构中会采用不同的覆盖材料。这些覆盖材料主要为玻璃、聚乙烯（PE），聚氯乙烯（PVC）

聚脂温室塑料薄膜、有机玻璃（PMMA），聚氯乙烯（PVC）和聚碳酸脂（PC）材料的塑料板等。我们在选择覆盖材料时主要考虑寿命、抗冲击强度、隔热性、在使用期间的透光和反射功能等等。下面是对一些指标的说明。将对阳光板（以下简称 PC 板）和其它覆盖材料进行比较。

- 材质自身质量比较：10mm 厚 PC 板质量为 1.7 或 2.0 公斤/平米。而 4mm 厚玻璃单位质量为 10.0 公斤/平米。
- 强度比较：使用 PC 板做为覆盖材料强度较高。直径 20mm 的冰雹可破坏玻璃或聚丙烯物质（断口或碎裂），比较起来，PC 板没有受到破坏。当受到直径超过 20mm 的冰雹袭击时，PC 板表面会出现轻微破坏的痕迹。
- 抗温差性比较：PC 板具有出色的机械性能，并在相当大的温度范围内能够保持该特性。即使长时间暴露在极高或极低的温度中，PC 板也能保持其荷载能力和稳定性。

表 2　不同覆盖材料在高温下的耐久使用温度

材料	耐久使用温度
聚碳酸脂	120℃
聚丙烯	80℃
PVC	60℃

- 抗气候性：经过长时间的天气及日照影响，合成的覆盖材料的透光性会有所减弱。10 年内透光性会下降 8－10%。共挤的板材可防止这种透光性的减弱。经过处理的材料 10 年内透光性降低 4%。
- 阳光板的透光性：冬日阳光不足是影响温室内作物生长的一个重要因素，因此要求覆盖材料必须具有很好的透光性，室外 70%以上的光线应该能够到达温室内。鉴于此点，温室的结构部分应减至最少（质量和数量），同时温室的结构应达到光线充足的要求。例如，因 PC 板的质量和标准可减少压条的数量。从而整体光线量可增加约 2%。温室内光线量多少的一个很重要的因素是从透光性和节约能源出发选择合适的覆盖材料。

表 3　不同覆盖材料的透光性

材料	透光率%*
单层玻璃	89－92
隔热玻璃	84－85
10mmPC 板	79－81

*透光率是指，当光线以垂直角度入射时光线透射的百分比。

4　阳光板经济合理性分析

本文以阳光板在农业温室中的应用为例，对阳光板的经济性进行分析，工程造价是通过比较同等情况下的温室覆盖材料的工程造价。阳光板物理性质决定了其良好的保温性能，同其他采光材料传热系数相比，10 毫米厚双层阳光板的保温性能相当于 150 毫米厚混凝土墙或 240 毫米厚砖墙。用 10 毫米厚双层阳光板代替 6 毫米厚单层玻璃，节能近 50%。同时，采用阳光板作为温室覆盖材料，工程投资较低，低于玻璃的工程造价。因此，阳光板对降低能量成本有着重要意义。

根据德国标准 DIN4701，可以计算出传热系数每降低 0.1W/m2ºC，每平方米采光面积每年可节

煤 1.18 公斤。

实例 1：

表 4　农业温室大棚具体环境

气候	寒冷潮湿，冬季短暂寒冷；夏季炎热
建筑地点的发展	良好充足的水源、电源和天然气
已有的园艺生产能力	生产蔬菜和花卉的园艺公司；温室及其周边地区占地 10000m^2

选择设施方案

表 5　方案选择与结构处理

温室形式和形状	根据热量消耗和劳动生产力选择沟脊形温室
采光材料	侧墙和山墙使用 10mmPC 板，屋顶使用单层玻璃
通风	25%左右的通风能力即可（自然通风）
供热和供热系统	燃油烧沸水和温水供热系统，使用管道、水泵和阀门系统在温室内供热
隔热层	需要，有遮盖和节能结构
其它设备	地面或桌面有园艺培养基；温室内有自控气候条件系统

节能效果、工程造价计算：

用阳光板做采光材料的节能效果优于玻璃，10mm 厚的三层板、16mm 厚的双层板甚至优于双层玻璃。节能效果计算公式：

$$\text{节省的燃料} = \frac{dK \times S \times T \times dt}{n \times H}$$

其中： K＝热损失值，即热量通过覆盖材料散失的热量值(W／·m^2· °C)

dK＝现采用的覆盖采光材料与原覆盖采光材料的 K 值之差。(W／·m^2· °C)

S=覆盖采光面积（m^2）

T=取暖或使用空调的时间（h）

dt=室内外平均温度之差（°C ）

n=产热设备的效率系数，一般是 0.5-0.8，平均 0.7。

H=燃料最低发热值（kJ／kg）

10000 m^2 联跨温室使用不同覆盖材料时，锅炉需产生的热量

表 6　不同覆盖材料所产生的热量及工程投资情况表

覆盖材料	需产生的热量		工程初投资（元/m^2）
	[kW]	[%]	
屋顶：单层玻璃 侧墙及山墙：单层玻璃	3356.4	100	玻璃造价：200-300 阳光板造价：60-70
屋顶：单层玻璃 侧墙及山墙：10mm PC 板	3225.1	96	玻璃造价：200-300 阳光板造价：60-70
屋顶：单层玻璃 侧墙及山墙：10mm PC 板及遮阳网	2692.8	80	玻璃造价：200-300 阳光板造价：60-70
屋顶：10mm PC 板 侧墙及山墙：10mm PC 板	2075.6	62	阳光板造价：60-70

通过此例我们可以明确得出；从材料投资情况可以看出，屋顶、侧墙和山墙全部用 PC 板造价最低，同时锅炉所需产生的热量最小,。这是因为 PC 板的优越的隔热性能。用 10 毫米厚双层阳光板代替 6 毫米厚单层玻璃，节能近 50%。因此，阳光板对降低能量成本有着重要意义。根据德国标准 DIN4701，可以计算出 K 值每降低 0.1W/m^{2}℃，每平方米采光面积每年可节煤 1.18 公斤。

5 制约阳光板在我国发展的不利因素

由于阳光板生产材料工艺较为特殊，目前材料的价格还比较高，我国聚碳酸酪主要依赖进口。迄今为止，世界聚碳酸酪市场由三大公司主导：即GE塑料公司、拜耳公司和道化学公司，他们占世界市场75%的份额。由于阳光板完全依赖进口，2000年，我国聚碳酸酯价格从年初的25500元／吨以每月1000多元的速度上升至12月份的4万元／吨[5]。

我国目前对阳光板的理论研究还处于起步阶段，理论研究有待深入，我们对阳光板的性能的研究分析仅限于光学和力学性能研究[6]，对于阳光板热工性能、防露滴性、耐侯性能、阻燃性能等方面认识不够深入，特别是在理论方面，没有具体的理论研究实验及分析数据。在阳光板的加工工艺形式上也比较单一，有待开发更多形式品种的阳光板板材。

6 结束语

阳光板有优越的技术性能，它的隔热性能、抗老化性能，防雾滴性能、强抗冲击性能及高透光率等性能，使它成为众多采光材料中的理想产品。从材料自身性能上、经济合理性上来讲，阳光板均是一种极为良好的公共建筑装饰材料，特别在现代化农业温室建设上，阳光板更发挥出了其强度高、耐候性能优越、节约能源等特点，既提高了温室强度又减少了温室建造的成本，成为第四代温室覆盖材料。我国是农业大国，人口众多，土地资源有限，发展现代农业，进行工厂化高效农业温室的建设是农业发展的根本出路，阳光板作为农业温室建设的新一代材料将面临巨大的商机。我国有关阳光板的研究及生产情况与世界先进水平差距还比较大，我们应加强对阳光板进行更为深入的理论研究及分析，从而更好的利用这种新型的材料。

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高性能中空玻璃与超级间隔条

王铁华

目前我国建筑能耗占全国总能耗的比例约 27.6%，其中门窗的能耗比重占 25-30%左右。用于解决门窗能耗的基本节能措施是加大力度推广使用中空玻璃，尽快减少和杜绝使用单层玻璃或双玻窗。但目前的情况是，一方面，中空玻璃的使用非常有限，据统计，2003 年我国中空玻璃的生产量为 3000 万平方米，约占当年竣工建筑面积的 5%，既有面积的 1%。另一方面，已使用的中空玻璃的节能性能和质量又参差不齐。在有限的中空玻璃使用中低性能中空玻璃占 90%以上（有关高低性能中空玻璃的概念在下面将展开讨论），而影响中空玻璃的密封寿命的密封结构和材料也有许多企业采用落后的结构和不合格的原材料。

本文旨在（1）讨论影响中空玻璃节能的各个因素，从而揭示低性能中空玻璃向高性能中空玻璃过度的必要性；(2）通过比较不同密封结构对中空玻璃密封寿命的影响得出，提高中空玻璃的密封寿命必须使用双道密封替代单道密封结构的结论；(3) 介绍发达国家目前的中空玻璃的基本现状，并介绍国外日趋广为使用的作为高性能中空玻璃的必要配置的超级间隔条。

高性能中空玻璃

理解高性能中空玻璃的概念应首先了解从热传递的几种方式和中空玻璃的概念。

中空玻璃

根据国家标准 GB 11944-2002 中对空玻璃的定义是两片或多片玻璃以有效支撑均匀隔开并周边粘结密封，使玻璃层间形成有干燥气体空间的制品。

该定义有以下含义：

1） 中空玻璃可以由两片或多片玻璃构成；

2） 中空玻璃的结构是密封结构；

3） 中空玻璃空腔中的气体必需是干燥的；

4） 中空玻璃内必需含有干燥剂。

但中空玻璃国标重点是对中空玻璃的制作和检测方法给予规范,对中空玻璃的节能并没有界定。因此，要想探讨中空玻璃的节能我们必需了解中空玻璃和热传递几种方式之间的关系。

热传递的三种方式

影响中空玻璃热传递的三种方式为：热辐射、热对流和热传导。其中，热辐射占热传递的 50-60%，热传导和热对流分别占 20-25%左右。

普通中空玻璃

中空玻璃的节能主要取决于其对热传递的阻隔方式。

从节能的角度看，普通中空玻璃的配置包括透明玻璃（俗称白玻）、空气和槽铝式间隔条。

中空玻璃由于采取密封结构，玻璃间隔空气层内的干燥空气在 15mm 范围内，处于静止状态，基本上解决了热传递中的热对流。由此，其 U 值约为 3 $W/m^2 \cdot K$，相比单片玻璃的热传递值 U 值 6 $W/m^2 \cdot K$ 改善 50%。

但是，普通中空玻璃对热传递的热辐射和热传导并没有解决，见表 1。因而，节能是十分有限的。通过改善中空玻璃要素的配置，可以进一步提高中空玻璃的节能效果。

表 1 普通中空玻璃配置要素的技术参数

中空玻璃配置要素	辐射率	导热系数 W/m· K
透明玻璃	0.84	
铝间隔条		160
空气		0.024
玻璃		1

高性能中空玻璃

从节能的角度看，高性能中空玻璃同时从解决热传递三方面入手，采用低辐射玻璃、惰性气体和暖边间隔条技术，进一步提高中空玻璃的节能效果。

表 2 高性能中空玻璃配置要素的技术参数

中空玻璃配置要素	辐射率	导热系数 W/m · K
低辐射玻璃		
在线 LOW-E	0.1-0.2	
离线 LOW-E	0.1	
氩气		0.016
超级间隔条		0.168

通过使用不同的材料替代普通中空玻璃配置的材料,可不断改善中空玻璃的节能效果。用低辐射玻璃替代普通中空玻璃中的透明玻璃，节能改善 25%；在此基础上，使用暖边超级间隔条，节能效果将进一步提高 36%。采用高性能中空玻璃配置，即低辐射玻璃、超级间隔条和氩气，从三个方面同时减少中空玻璃的热传递，U 值降低到 1.6 $W/m^2 \cdot K$,与普通中空玻璃配置相比，节能效果改善 44%，见表 3。

表 3 高性能中空玻璃窗节能性能

中空玻璃配置	中空玻璃中央 U 值 $W/m^2 \cdot K$	边部密封	整窗性能 $W/m^2 \cdot K$	与普通中空玻璃窗相比性能改善%
用低辐射玻璃替代透明玻璃				
空气				
双玻中空道	1.8	金属间隔条	2.1	25%
低辐射玻璃		聚硫胶		
用低辐射玻璃替代透明玻璃、暖边超级间隔条替代铝间隔条				
空气				
双玻中空道	1.8	超级间隔条	1.9	36%
低辐射玻璃		热融丁基胶		
高性能中空玻璃：低辐射玻璃、超级间隔条和氩气				
氩气				
双玻中空道	1.6	超级间隔条	1.6	44%
低辐射玻璃		热融丁基胶		

注：上述数字摘引自《建筑玻璃实用手册》，2004 年版，清华大学出版

暖边技术

与高性能中空玻璃配置中的低辐射玻璃和惰性气体氩气相比，我们对发达国家目前广泛使用的暖边技术认识是十分肤浅的。但是，暖边技术在高性能中空玻璃配置中占有重要作用，因此，有必要对此进行讨论。

人们使用中空玻璃的主要目的在于节能。但是普通中空玻璃结构中，铝间隔条的导热系数是 160 W/m· K，分别是空气的 6667 倍和玻璃的 160 倍（参见表 1）。不难看出，在室内外存在温差情况下，热能通过铝间隔条（冷桥）跑掉，因而成为中空玻璃节能的软肋。因此，铝间隔条又被称为冷边。

据美国门窗协会统计，1990 年以铝间隔条技术（即冷边）制作的中空玻璃占北美市场的 85%，而以导热系数低的间隔条制作的中空玻璃仅仅占 15%；但到 2000 年底冷边技术下降到 20%，而导热系数低的间隔条的市场份额则上升到 80%。

暖边的定义

任何一种间隔条只要其热传导系数低于铝金属的导热系数，就可以称为暖边。根据该定义，暖边可以采用三种方法得到：

（1） 非金属材料， 如超级间隔条、TPS、玻璃纤维条；

（2） 部分金属材料，如断桥间隔条、实唯高间隔条；

（3） 低于铝金属传导系数的金属间隔条，如不锈钢间隔条。

可见发达国家有关暖边的定义是十分宽松的。由此，我们可将其按节能的性能分为以下三大类：低性能、中等性能和高性能间隔条。

表 4

低性能间隔条	中等性能间隔条	高性能间隔条
实唯高胶条（内含铝带）	实唯高胶条（内含不锈钢带）	超级间隔条
断热间隔条（铝断热间隔条）	PPG 的 U 型（不锈钢）间隔条	TPS
不锈钢间隔条		玻璃纤维间隔条
PPG 的 U 型间隔条		
等等	等等	等等

（1）低性能间隔条的特点是含有部分金属或采用比铝金属导热系数低的金属。采用 NFRC（美国国家门窗等级评定委员会）标准窗，低性能间隔条对整窗的 U 值改善程度为 0.01，采用 SIGMA（美国密封中空玻璃制造业协会）对中空玻璃 U 值测试方法显示，U 值改善程度是 0.01~0.02（引自 SIGMA 技术报告 TR-140-96）。

（2）中等性能间隔条的特点是含有部分金属或采用比铝金属导热系数低的金属。采用 NFRC（美国国家门窗等级评定委员会）标准窗，低性能间隔条对整窗的 U 值改善程度为 0.02，采用 SIGMA（美国密封中空玻璃制造业协会）对中空玻璃 U 值测试方法显示，U 值改善程度是 0.03~0.04（引自 SIGMA 技术报告 TR-140-96）。

（3）高性能间隔条的特点是采用非金属材料，因此导热系数大大低于铝金属。采用 NFRC（美

国国家门窗等级评定委员会）标准窗，低性能间隔条对整窗的 U 值改善程度为 0.03，采用 SIGMA（美国密封中空玻璃制造业协会）对中空玻璃 U 值测试方法显示，U 值改善程度是 0.04~0.05（引自 SIGMA 技术报告 TR-140-96）。

综上所述，普通中空玻璃只基本解决了热传递中的热对流，而对热辐射和热传导并没有解决，因而节能是十分有限的。如果要进一步提高节能效果，就必需采用低辐射玻璃、氩气和高性能暖边间隔条。中空玻璃从诞生到现在有 100 多年历史，才发展到今天的高性能中空玻璃，虽然，中空玻璃在我国真正的发展不到 10 年，但我们没有必要等到 100 后才采用高性能中空玻璃配置，而应该采取拿来主义的办法。这不但是技术上可行的，而且是进一步提高我国建筑节能所迫切需要的。

如果说中空玻璃的配置情况直接影响中空玻璃的节能效果，那么采用何种中空玻璃密封材料和结构合理与否就直接影响中空玻璃的密封寿命，从而影响中空玻璃可否长期发挥节能效果。

中空玻璃的密封寿命

勿庸赘述，中空玻璃的节能与其密封效果有关，中空玻璃能否长期节能取决于中空玻璃的密封寿命的长短。当中空玻璃出现密封失败时，中空玻璃的空气层内出现冷凝现象。结果有二：(1）气相水冷凝后的液体状态，较之空气的导热系数大；(2）玻璃空气层内的气体出现微循环，即热对流现象。由此，密封失败的中空玻璃节能效果与密封的中空玻璃相比，要差。不仅如此。如果我们理解的中空玻璃的主要功能除节能之外，更重要的是保证建筑物的通透性的话，那么，密封失败导致的空气层内的水凝结在玻璃的表面，会影响人们的视觉。

造成中空玻璃密封失败的主要原因是中空玻璃密封结胶没有起到阻隔外来干涉水气进入中空玻璃空气层内的作用，使间隔条内的分子筛丧失摄水能力，当中空玻璃空气层内的温度达到露点温度时，就会形成内冷凝水凝聚在玻璃之间的表面上。

下面讨论影响中空玻璃密封寿命的原因以及根据实验给出的各种密封结构的预期密封寿命。

中空玻璃的“泵”现象

中空玻璃在使用寿命其间始终受温差、气压、风荷载、紫外线等自然因素的作用，出现“泵”现象。中空玻璃空气层内气体的不断热胀冷缩过程，在中空玻璃的边缘密封部位的密封胶处相应地形成应力（拉伸和压应力），导致胶体的延展和压缩交替进行。紫外线对有机密封胶的化学分子长链具有破坏作用。一些密封胶耐紫外线能力差，经紫外线照射出现老化，丧失密封胶的弹性和结构强度。因而，从理论上讲，密封的中空玻璃最终是要出现密封失败的。人们所能做的是找出影响密封寿命的各种原因，对症下药，尽可能地延长其密封使用寿命。

影响密封寿命的原因

目前我国中空玻璃存在着密封寿命短的问题，即中空玻璃过早地出现密封失败，表现中空玻璃的空气层内出现冷凝，严重的出现鱼缸现象。

影响中空玻璃密封寿命的因素主要包括密封结构和密封材料。中空玻璃系统的密封和结构稳定性是靠中空玻璃密封胶来实现的。

（1）密封结构。中空玻璃使用中始终面临着外来的水气渗透、温差、气压和风荷载等影响，因此，要求密封胶不但要具有水气密封的功能，而且还必需具备保证中空玻璃系统的结构稳定的功

能。显然，理想的情况是采用一种密封胶来满足中空玻璃的密封需要。但现实中任何一种胶都不能同时具有良好的水气密和结构性的特点。因此，人们不得不采用双道密封来满足中空玻璃的密封寿命需要。传统双道密封是先密封后结构。一般来说，第一道密封主要采用丁基胶，主要作用是防止水气渗透，防止惰性气体和空气进出中空玻璃，并在中空玻璃制作中起辅助定位作用。丁基胶与玻璃和间隔框之间形成物理黏接。第二道密封通常采用结构胶包括聚氨酯、聚硫胶和硅酮胶，主要功能是将玻璃和间隔条黏接成中空玻璃，防止中空玻璃内的分子筛跑到外部。二者各司其职，缺一不可。中空玻璃只有在双道密封的情况下，在其他条件不变的条件下，才能保证较长的密封寿命。对此，我们也可以通过 P1 加速老化实验来佐证。P1 实验条件内容包括：60^0C（140^0F）高温，连续淋水（r.h.100%）和 2500W/cm^2 的紫外线照射。该实验结果通过的每一周寿命模拟自然界中中空玻璃的一年寿命。根据是中空玻璃密封胶在 P1 加速老化实验中随着温度每提高 10^0F，胶的化学反应提高一倍老化过程增加 1 倍，见表 5。

表 5

华氏温度	
80^0F	1 周
90^0F	2 周
100^0F	4 周
110^0F	8 周
120^0F	16 周
130^0F	32 周
140^0F	64 周

P1 实验结果的数据见表 6。

单道密封结构	检测达到的密封寿命
丁基胶/铝间隔条	24 小时
复合胶条（实唯高胶条）	2 周
硅酮胶/铝间隔条	3 周
聚硫胶、聚氨酯或热融丁基胶/铝间隔条	6-8 周
双道密封结构	
丁基、聚硫/聚氨酯、四边插角铝间隔条	12-18 周
丁基、硅酮胶、四边插角铝间隔条	15-20 周
硅酮胶、实唯高胶条	25 周+
丁基、硅酮胶、连续弯管铝间隔条	40 周+
超级间隔条、热融丁基胶	100 周+

从表 6 可见，采用双道密封结构的中空玻璃密封寿命大大长于单道密封结构。单道密封结构的密封寿命在 2-8 年之间，而双道密封结构最短 12 年，最长可达 100 年以上。

上述理论上的陈述不但通过实验的证明是正确的，根据北美中空玻璃协会对中空玻璃 20 年实际使用情况的统计调查也证明了这一点。该统计表明，采用单道密封结构的中空玻璃的密封失败占密封失败总数的 95%以上。

综上所述，中空玻璃的密封结构是否合理直接影响中空玻璃的密封寿命。应大力推广使用双道密封结构的中空玻璃提高中空玻璃的密封寿命。

（2）密封材料

从表 6 可见，密封材料（间隔条和密封胶）在密封结构一定的情况下对中空玻璃的密封寿命具有明显的影响，值得探讨。

（i）铝间隔条。一般铝间隔条的密封方式，是以铝条两侧的丁基胶条起到主要的密封作用。在中空玻璃的内外挠曲的“ 泵 ”运动中，丁基胶条会发生拉伸，位移，剪切等情况，使水汽渗透的通道缩短。就槽铝式工艺来讲，不管是连续弯管还是用角接键，铝条边部的密封由丁基胶完成了，但是背部或拐角处的连接处还没有完全密封（造成密封失败只需一处密封不足就够了），另外，丁基胶本身在低温下的粘结性能降低，上述任何一种情况都可以导致密封性能减弱或失败。

（ii）密封胶种类。双道密封结构中，丁基胶本身的质量及涂布工艺的好坏，直接影响中空玻璃的密封寿命。一般认为，与结构胶相比，丁基胶对中空玻璃的密封寿命的影响占 80%，因此，第一道密封又称为主要密封。

除此之外，第二道中空玻璃密封胶即结构胶对中空玻璃的密封作用也起着至关重要的作用。通常人们认为在聚硫胶、聚胺酯和硅酮胶三者之间，聚硫胶是最适于作为中空玻璃门窗的结构胶的。我们认为这种看法似是而非。这种看法的依据是根据各种中空玻璃胶的水气渗透率（MVTR）不同而得出的。见表 7。

表 7

种类	MVTR
硅酮胶	50
聚硫胶	19
聚氨酯	12.4
丁基胶	2.25

但人们特别是生产和经销聚硫胶的厂家在引用数字时却有意无意地忘却了，这种测量水气渗透率（MVTR）的实验条件是在室温 25^0C 条件进行的，而实际情况是，中空玻璃使用的条件，特别是在夏天在我国的决大多数的地方中空玻璃的内在温度都接近或高于 60^0C。在温度升高的条件下，不同胶的水气渗透率会发生不同的变化。事实上，在 60^0C 条件下，聚硫胶的 MVTR 与硅酮胶的 MVTR 是十分接近的。从北美对中空玻璃实际使用寿命情况跟踪 20 年的结果也证实了这一点，即使用/丁基胶/硅酮胶双道密封结构的中空玻璃较之比使用其他结构的中空玻璃的密封寿命要长。

既然如此，我们有必要寻找其他方法来代替理想状态条件下的 MVTR 实验手段。实践表明，用玻璃胶的浸水试验更能比较准确地表示密封胶的密封性能。

浸水实验的方法简述为：将 500 克重的胶块放入温度 600C 的水中浸泡 60 天，然后对其体积和重量进行度量观察变化。结果列表（表 8）如下：

表 8

种类	体积变化%	重量变化%
硅酮胶	3-10	2-6
聚氨酯	15	12
聚硫胶	50	30

上述实验数据表明，(1) 结构胶的体积和重量都有不同程度的增加，增加的幅度大小为，聚硫胶>聚氨酯>硅酮胶；(2) 吸水体积重量前后的变化与它们的 MVTR（水气渗透率）所表示的结果不同。

（iii）分子筛

一般来说，中空玻璃制作合片后的空气层内含有一定水分，如果对其不进行干燥处理，在露点温度下就会形成内冷凝，不但影响玻璃的通透性，还会提高中空玻璃的热传递值 U 值，降低中空玻璃的节能效果。此外，中空玻璃使用寿命期内，由于铝间隔条的丁基胶的涂布不均匀或出现断点、气温变化导致的中空玻璃的泵现象，以及密封胶的水气渗透率等诸多因素，导致水气进入中空玻璃的空气层内，也需要使用干燥剂来保证中空玻璃内的低露点温度（如-40^{0}C）

选择用于中空玻璃的干燥剂可参照表 9 进行。

表 9

干燥剂种类	孔直径/Å	能吸附的	不能吸附的
3A 分子筛	3	水	除水以外的其他物质
4A 分子筛	4	水、空气、氩气和氮气	六氟化硫、氙气、溶剂
13X 分子筛	8.5		没有
硅胶	20-300		没有

从表 9 可见，如果使用的中空玻璃密封胶中不含有溶剂，3A 分子筛最适用于中空玻璃的干燥剂，3A 分子筛具有亲水性，只吸附水不吸附其他物质，所以可以保证在正常条件下中空玻璃的片与片之间平行，减少玻璃在边缘密封处的应力，延长中空玻璃的寿命；使用 4A 分子筛会导致中空玻璃的向内挠曲，空气层中央部位缩小，使玻璃产生视觉变形，热传递增加，节能效果降低，并且因降低中空玻璃的密封寿命；如果使用的中空玻璃密封叫内含有溶剂的话，应考虑使用两种分子筛的混合物，通常的作法是采用 75%的 3A 分子筛和 25%的 13X 分子筛，使其兼有吸附水和溶剂的功能。

目前，在发达国家使用 3A 分子筛是非常普遍的。在我国，由于 4A 分子筛的成本较 3A 分子筛低，有相当一部分厂家使用 4A 分子筛干燥中空玻璃，结果如上所述，建议用 3A 分子筛替代。

超级间隔条和高性能中空玻璃

目前，发达国家高性能中空玻璃已经得到相当的普及，如低辐射玻璃和暖边技术的市场占有率分别在 90%和 80%以上。

综上所述，(1) 暖边较之冷边节能效果要好，但不同的暖边之间的热传导系数是不同的；(2) 采用某项暖边技术，虽然可以在一定程度上节能，但同时是以牺牲中空玻璃密封寿命为代价的；(3)

中空玻璃的密封寿命较之其局部的暂时的节能效果改善更重要；(4) 人们制作中空玻璃的目地是为了节能，但使用铝间隔条制作中空玻璃却成了中空玻璃的软肋；(5) 尽管用改进后的铝间隔条（如连续弯管）制作的中空玻璃的寿命有了显著的提高，但其导热系数高的缺点却仍然存在。

显然，在传统的思维框架里，无论人们如何努力和改进、改善中空玻璃的节能效果和提高密封寿命，是不能兼得的。

20 世纪 80 年代，两位勇于进取富有挑战精神的加拿大科学家第一次开发出同时解决中空玻璃节能和耐久性一对矛盾的方法，即超级间隔条，在中空玻璃行业引起了一场革命。超级间隔条是使用一种无任何金属、内含 3A 分子筛的微孔材料连续的弹性间隔条。

从超级间隔条的制作材料上我们不难理解，与其他暖边间隔条技术相比，超级间隔条制作的中空玻璃的热阻是最大的。故此，毋须赘述。相比之下，重点应放在为什么超级间隔条可以大幅度提高中空玻璃的密封寿命。我们在前面的表 6 给出的 P1 检测结果显示，超级间隔条制作的中空玻璃密封寿命最长寿命可高达 100 年以上。鉴于这种产品无论从产品本身还是从工艺上看都不同于传统的间隔条产品和工艺，有必要进行重点介绍，从而揭示密封寿命长的原因。影响超级间隔条中空玻璃密封寿命的最主要因素有二，即材料的弹性和逆向双道密封，兹分别论述如下。

（1）弹性间隔条

中边玻璃使用其间，由于受温差变化、风荷载、压强等外界因素影响，始终处于胀缩的“ 泵“ 运动中，在玻璃的边缘密封处形成应力。当玻璃向内挠曲时，玻璃内侧与间隔条上端的倒角接触处形成应力，上端的胶向内挤压，下端的胶特别是结构胶向外拉伸；当玻璃向外挠曲时，玻璃内侧与间隔条下端的倒角接触处形成应力，上端的胶特别是密封丁基胶向外拉伸，使水气通道变短，下端的胶特别是结构胶向外内挤压。

中空玻璃的这种“ 泵“ 运动对任何结构的中空玻璃结构来说都是不可避免的。但是在表现程度上极其产生的后果来说，却是不同的。对槽铝式间隔条来说，当中空玻璃胀缩运动时，由于铝金属具有刚性，不能吸收或缓冲玻璃运动产生的应力，因此，玻璃内侧与铝间隔条的接触面的应力是很大的；与此相反，采用硅酮或三元乙丙制作的超级间隔条具有弹性，当中空玻璃胀缩运动时，会与玻璃的运动方向一致，使的边布应力最小，从而最大限度地减少了中空玻璃的炸裂的可能性，并且提高中空玻璃的密封寿命。铝间隔条的刚性不但使该种结构的中空玻璃密封寿命有所缩短，而且增加了中空玻璃的炸裂的可能性，这一点在温度差别大的地区特别是冬季寒冷区表现最为突出。

（2）独一无二的逆向双道密封工艺

前面从三个不同角度解释了中空玻璃采用双道密封的必要性。根据表 7 我们得知中空玻璃密封胶的MVTR与中空玻璃的密封寿命有很大关系,在一定的条件下,MVTR越小则中空玻璃的密封寿命就越长。一般来说，中空玻璃的双道密封结构采取先密封后结构的做法。从表 8 看，传统结构中处于第二道密封位置的结构胶在与水气长期接触的条件下，无论是体积还是重量都会有所累积增加，导致了第一道密封胶丁基胶的水气通道的缩短，严重时与玻璃的黏接面脱离，使外部的水气进入中空玻璃的空气层内，当内部的 3A 分子筛干燥剂饱和时，中空玻璃内部就会形成冷凝，导致密封失败。

与这种先密封后结构的传统的密封结构不同，使用超级间隔条制作的中空玻璃采取了相反的做法，即先结构后密封。具体说，使用超级间隔条及其两侧预涂的具有结构强度的胶起结构作用，而外道则采用热融丁基胶起主要密封作用。这种逆向双道密封结构从外面就将水气隔离在外面，进入不到第一道密封胶的位置，延长了水汽渗透通道；此外，超级间隔条背部具有 10 层高聚脂材料既防止了分子筛的双向吸附又能在低温丁基胶密封性能降低的情况下起到辅助密封的功能。材料本身的弹性和两侧的高强度压敏丙烯酸粘合剂，杜绝了拉伸，位移和剪切，这样的结构和密封方式大大的增强了中空玻璃的密封性能和寿命。

从超级间隔条在发达国家的应用上看，方兴未艾，越来越广泛地普及和应用。由于超级间隔条的卓越性能，先后获得许多国家和行业的荣誉，如加拿大 1994 年太阳能协会本年度太阳能公司奖、2002 和 2004 年两次分别获得美国门窗协会的最高荣誉水晶成就奖和 2004 年英国门窗协会一年一度的被誉为该行业的奥斯卡大奖的 G04 节能创新奖。此外，人们还将使用超级间隔条制作的中空玻璃形象地比喻为中空玻璃中的卡迪拉克和奔驰汽车。在发达国家，当使用其他间隔条密封结构制做的中空玻璃提供的保质期仅仅为 5-15 年不等时，使用超级间隔条制做的中空玻璃的保质期则在 20-30 年。

综上所述，从增加密封寿命的角度上看，我们可以说，采用超级间隔条的逆向双道密封是优于普通双道密封结构的，使用超级间隔条制作的中空玻璃是制作高性能中空玻璃的必备材料。

结论

普通中空玻璃的节能是十分有限的。为了进一步提高建筑门窗节能效果，应该改善现有中空玻璃的配置，大力推广应用高性能中空玻璃窗；在高性能中空玻璃的配置中，低辐射玻璃、氩气和暖边间隔条是必备的三个基本要素，缺一不可。其中，使用超级间隔条可以基本上消除中空玻璃边缘处的冷凝现象。

中空玻璃的密封寿命至少与起热传递系数 U 值是一样重要的，如果不是更重要的话，必须引起足够的重视；如果采用铝间隔条并在短时期不能改变的话，应使用连续弯管替代四边插角的间隔条；在条件具备的条件下，应一步到位，采用超级间隔条。后者的采用，还可以减少中空玻璃的炸裂。

高性能中空玻璃除了应具有以上特点之外，我们认为，还应具有降低噪音的功能。概括地说，从降低噪音角度来看，配置包括，非对称厚度玻璃、含有胶片的夹层玻璃、增加玻璃的厚度和采用弹性超级间隔条。配置所增加的降躁效果，与普通中空玻璃相比，可提高 7-10 分贝，对居住在距离噪音源附近的人们，是十分重要的。

高性能中空玻璃是普通中空玻璃的更新换代产品，具有更绿色、更环保、更健康的功能。虽然目前我国的（普通）中空玻璃普及率占当年竣工项目的 5%左右，需要大力发展。但这不等于说，我们要等到全社会中空玻璃完全普及后在推广应用高性能中空玻璃。

建议

应该认识到，建筑节能政策的制定、实施，以及行之有效地发挥作用，仅仅靠市场本身是远远不够的。有关部门政府部门应该抓紧研究制定实施适合我国国情的建筑门窗节能的政策和法规，强

制实行。此外，政府还应联合有关方面，开展以下工作：

实行对全民中空玻璃窗知识的普及活动，对目前购房者进行节能窗方面“扫盲“。

建立中空玻璃寿命的检测方法。新的检测方法应类似美国的 P1 检测，区别于现有的国标方法。

尽快编写中空玻璃窗热传递值 U 值的检测标准，包括软件模拟方法和实验室的热箱检测方法。

开发商做一些实实在在的节能工作，政府应将不同等级的节能窗评出等级并贴上标致以便消费者识别。

中空玻璃生产厂家应该对中空节能窗实行至少 10 年的保质期。在保质期内，中空玻璃如出现密封失败，开发商无偿替换。

可持续资源城市垃圾焚烧飞灰的有效利用研究

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摘　要　随着我国经济的飞速发展和人口向城市的不断集中，城市垃圾的排放量急剧增加，如何处理城市垃圾已成为亟待解决的问题。焚烧法处理城市生活垃圾具有显著的减容、减重以及可回收热能等优点，已成为国内外处置城市生活垃圾的主要方式之一。垃圾焚烧后产生的焚烧飞灰中不仅含有与普通水泥原料石灰石和粘土相似的成分，且含有能被水浸出的 Cd、Pb 和 Cr 等多种有害重金属物质。基于将可持续自愿焚烧飞灰无害化处理与资源化利用同步进行的构想，借助 SEM、XRD 和 ICP 等现代测试手段并结合宏观性能的试验结果，分析了焚烧飞灰的化学特性；从微观和宏观层次上研究了焚烧飞灰对水泥基材料的影响；探讨了焚烧飞灰中的重金属在水泥基材料中安全使用的情况。研究表明，焚烧飞灰中的重金属可被固化于水泥水化产物中，得到无害化处置；同时焚烧飞灰具有较好的胶凝活性，有望被开发成一种新型水泥基材料应用于建筑工程中，实现可持续资源的有效利用。

关键词　焚烧飞灰；重金属；固化/稳定化；胶凝活性；浸出毒性；可持续资源

Research on valid utilization of Municipal Solid Wastes Incineration Fly Ash as a kind of sustainable resource

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Abstract Disposal of Municipal Solid Wastes (MSW) has become an urgent problem due to the dramatically increasing amount of MSW accompanying the rapid development of economy and the more and more crowded large cities in China．The incineration technology of MSW has some distinct advantages, such as reducing MSW in the volume and weight, and recycling heat energy as well. MSWI Fly Ash, the product of the incineration, the main components of it are same to that of limestone and clay in the common cement, however, hazard heavy metals, such as Cd, Pb and Cr which would pollute soil and groundwater, are also found in the MSWI Fly Ash. Based on the assume of harmless-disposal and utilization of MSWI Fly Ash, and by means of research technologies such as SEM, XRD and ICP, addition with the macro-properties experimental results, the chemical properties of MSWI fly ash were analyzed; the effects of MSWI Fly Ash on the properties of cement and its use in the cement-based materials were investigated; the leaching of heavy metals from harden cement pastes were also studied and discussed. Research showed that MSWI Fly Ash could be immobilized within the hydration phases and disposed harmlessly by Portland cement. According to its good cementitious activity, MSWI Fly Ash was predicted to develop into a new cement-based material in construction engineering to realize utilization of this kind of sustainable resource.

Key words MSWI fly ash; Heavy metal; Solidification/Stabilization; Cementitious activity; Leaching toxicity; Sustainable resource

1 引言

随着我国经济的飞速发展和人口向城市的不断集中，城市垃圾的排放量急剧增加，如何处理城市垃圾已成为亟待解决的问题[1]。以前通常采用的填埋、堆肥等城市垃圾处理方法，因其占地面积大、减量化效果不显著，不能满足城市规划与发展的需要。近年来，垃圾焚烧技术发展迅速[2]。该技术可使垃圾减容 80%~90%，一定程度上缓解城市用地紧张的问题，已应用于北京、上海、深圳等地。如上海四座垃圾焚烧厂日处理量已达 3000 吨左右，部分缓解了垃圾急剧增加的困境。

垃圾经过焚烧后，会产生一定量的焚烧飞灰，其成分较复杂，通常含有可危害环境的重金属物质[3]。由于城市生活垃圾来源的多样性，焚烧飞灰不仅含有 SiO_2 、Al_2O_3和 Fe_2O_3等主要化学成分，而且含有能被水浸出的 Cd、Pb、Cu、Zn 和 Cr 等多种有害重金属物质。这些重金属物质在飞灰中的含量通常较高，约为一般土壤中的 10～100 倍。若飞灰未经处置直接填埋，不但污染土壤、水体和大气，而且危及人体健康。在我国，焚烧飞灰已被《国家危险废物名录》列为危险废物，排放前必须经过无害化处理。

学术界对如何处置垃圾焚烧飞灰已经开展了很多探索与研究[4]。国际上对垃圾焚烧飞灰的处理主要以固化/稳定化 (Solidification／Stabilization)技术为主，即采用水泥基材料固化重金属矿物的方法来处理焚烧飞灰。但固化/稳定化处理后固化体的强度通常较低(28d 的强度仅 0.35～0.70MPa)[5]，必须置于填埋场。这既占用了大量土地，又存在着固化体中重金属在某些环境介质的侵蚀下重新转移到环境中的潜在危险。近年来，随着水泥基材料固化费用的提高和固化体浸出相关法规要求的日益严格，国内外学者开始将注意力由对焚烧飞灰的处置转向资源化利用上来[6][7][8][9]。如在荷兰，飞灰经处理后用作矿坑填料和密封材料[6]；日本已成功地将焚烧飞灰转化为水泥原料并建成了相应的水泥生产线[8]。

考虑到焚烧飞灰颗粒微细、比表面积大，主要化学成分与一般胶凝材料类似，从理论上可推知其具有一定的胶凝活性。本文基于将可持续资源焚烧飞灰无害化处理与资源化利用同步进行的构想，分析了焚烧飞灰的物理、化学特性，研究了焚烧飞灰与水泥复合后对水泥浆体力学性能的影响，分析了飞灰固化体重金属渗出情况，讨论了水泥对重金属的固化机理，为可持续资源焚烧飞灰的有效利用和无害化处置打下基础。

2 实验

2.1 实验材料

实验用水泥取自海螺水泥股份有限公司生产的 PⅡ52.5R 商品水泥。焚烧飞灰取自上海浦东御桥生活垃圾焚烧厂，并经水淋措施处理过，记为 FA。

2.2 实验方法

实验前，将焚烧飞灰烘干后粉磨，按照 GB/T208-1994 和 GB8074-1987 标准检验所得物料的密度和比表面积，控制其比表面积与商品水泥的比表面积基本相同。参照《固体废弃物实验分析评价手册》中的 3050 方法，将焚烧飞灰消解后过滤。采用电感耦合等离子体发射光谱（ICP）分析滤液中的重金属含量。

以焚烧飞灰部分取代水泥，参照 GB/T17671-1999，制成 4cm×4cm×16cm 的水泥胶砂试块，记

作 MF，24h 后拆模，20±2℃下密封养护 3d、7d、28d、60d 后分别测试其抗压强度。

将焚烧飞灰以不同比例与水泥复合，在保证流动度的前提下，制成 2cm×2cm×2cm 的水泥净浆试块，记作 PF，24h 后拆模，20±2℃下密封养护 1d、3d、7d、28d、60d 后分别用无水乙醇中止水化。一部分在 40℃条件下烘干，备作 XRD 观察分析用试样，另一部分用于重金属浸出实验。参照《固体废弃物浸出毒性浸出方法 水平振荡法》（GB5086-1997）规定。将飞灰固化体碾磨至粒径＜5mm，称取 100g，置于容积为 2L 的广口瓶中，加水 1L，调节 PH 值在 5.8～6.3；室温下振荡 8h，振荡频率 110±10 次/min，振幅 40mm，静置 16h；采用 ICP 测定浸出滤液中 Zn、Gu、Pb、Cd 和 Cr 等重金属的含量。实验具体设计参数见表 1。

表 1　水泥胶砂和水泥净浆实验设计

Mortar	Cement (g)	FA (g)	Slag (g)	W/S	Paste	Cement (g)	FA (g)	W/S
MC1	450	0	1350	0.5	PC1	500	0	27.7
MF1	405	45	1350	0.5	PF1	450	50	28.1
MF2	360	90	1350	0.5	PF2	400	100	28.6
MF3	315	135	1350	0.5	PF3	350	150	28.8
MF4	270	180	1350	0.5	PF4	300	200	29.1

表 2　原材料的主要化学成分与物理性质

	Chemical compositions(wt/%)										Physical properties	
	LOI(950℃)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Cl^-	density (g/cm^3)	Blaine surface area (m^2/kg)
cement	1.9	20.6	5.4	3.3	64.2	1.5	2.2	-	-	-	3.17	392
FA	22.0	24.5	7.4	4.0	23.2	2.7	12.0	4.0	4.0	10.0	2.58	369

表 3　焚烧飞灰中主要重金属元素的含量（mg/kg）

Heavy metals	Cd	Cr	Cu	Pb	Zn	Mn	Sn	Sb	Ni	Se	Ti	Mo	Sc	Hg
FA	36.7	157.0	563.2	1515.0	3269.0	704.2	358.5	35.8	70.6	81.9	424.3	27.1	42.8	3.6

3　结果与讨论

3.1　焚烧飞灰的性质与成分

水泥和焚烧飞灰的主要化学成分和物理性质示于表 2。X 射线荧光分析表明，焚烧飞灰主要由 SiO_2、CaO 和 Al_2O_3 等化学成份组成。从表 2 中可看出，与普通硅酸盐水泥相比，焚烧飞灰中 CaO 的含量偏低，而 SiO_2、SO_3、氯和碱的含量偏高，说明焚烧飞灰具有低钙、富硅、富氯和富硫的特点。本试验中焚烧飞灰中氯的含量高达 10%，这可能与我国饮食的特点导致厨余中食盐含量比较高有关，含有较高食盐含量的城市生活垃圾在焚烧过程中产生了较多的低熔点挥发性的金属氯化物和氧化物，它们在高温下气化并随烟气温度降低而冷凝成均匀的颗粒物质聚集于焚烧飞灰中。此外，焚烧飞灰的烧失量很大，约为 22.04%，说明焚烧飞灰中有机成份很高，这主要是由于垃圾焚烧过程中大量细小的有机物质未燃尽，这些细小颗粒在烟气中被除尘器捕集下来，造成有机成份比较高。

扫描电镜下观察到焚烧飞灰具有各种形态（见图 1)。其形状多为扁平形和圆形，或类似粉煤灰球形。凝聚成团时，呈棉絮状，这与文献[10]中的结果基本一致。XRD 分析（见图 2）表明，飞灰的结晶物主要以石英（SiO_2)、氯盐（KCL 和 NACL)、硫酸盐（无水石膏 $CaSO_4$）形式存在，并含有少量的方解石 $CaCO_3$，这与国外学者对焚烧飞灰成分的研究结果[9][11]基本一致。

由电感耦合等离子体发射光谱 ICP 测试结果（见表 3）表明，焚烧飞灰中重金属的总质量约占垃圾灰总质量的 1%左右，其中含量最多的重金属是锌和铅。XRD 分析表明焚烧飞灰中不含重金属矿物，这可能是由于重金属含量较少难于检测到，或重金属以复杂化合物或无定形形式存在[11]。

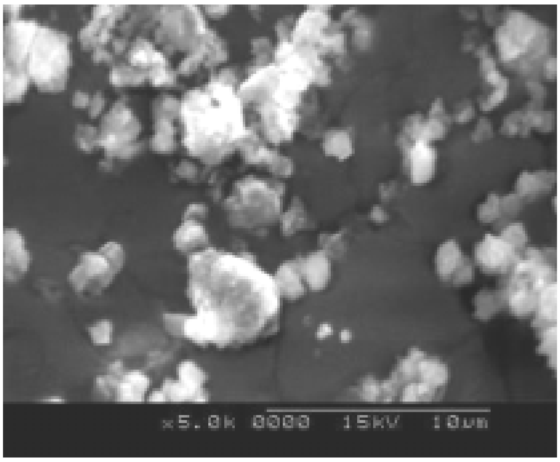

图 1　焚烧飞灰的 SEM 图像

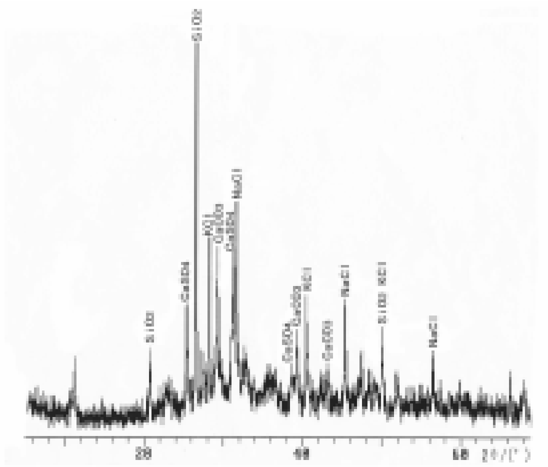

图 2　焚烧飞灰的 XRD 图谱

3.2　焚烧飞灰对水泥浆体力学性能的影响

焚烧飞灰对不同龄期水泥胶砂抗压强度的影响示于图 3。从图中可以看出，少量焚烧飞灰的掺入可提高硬化水泥浆体的早期强度。随着焚烧飞灰掺量的增加，其抗压强度逐渐减小。如在焚烧飞灰掺量≥20%情况下，3d 的胶砂抗压强度均大于基准水泥的强度。掺入焚烧飞灰对水泥浆体早期强度的激发，可能存在着两方面的原因：一方面，焚烧飞灰颗粒微细，其微集料填充效应对强度增长有利；另一方面，焚烧飞灰中碱与 Cl^-离子的含量都很高，可以促进水泥的早期凝结与硬化，提高水泥的早期强度。

根据图 3 中的数据，计算得到飞灰的活性指数 RFA=69%[12]，说明焚烧飞灰的活性较好。特别在焚烧飞灰掺量达到 40%后，IFA40 的 3d 抗压强度仍超过 10MPa，满足制备建筑材料的要求，可将其开发成一种新型辅助性胶凝材料。但在大掺量条件下，飞灰中高含量的碱和 Cl^-离子，对后期强度增长不利。可考虑通过对飞灰采取预处理、与其他掺和料复合、添加微量组分等技术措施，解决此类问题。

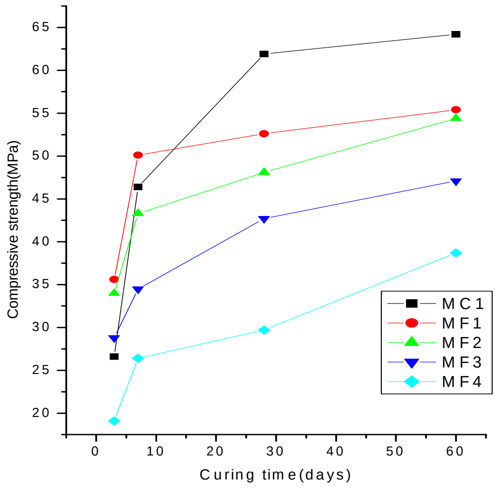

图 3　试样 PFA2 的抗压强度

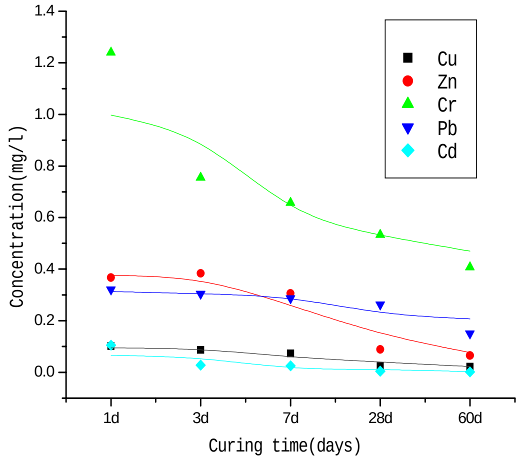

图 4　试样 PFA2 的重金属渗出浓度

3.3　焚烧飞灰重金属浸出及固化

鉴于飞灰中重金属含量较高，若将焚烧飞灰作为辅助性胶凝材料使用，则需控制飞灰固化体中的重金属浸出率。研究结果显示（表 4），纯焚烧飞灰浸出液中重金属 Pb、Cd、Cr 的浓度分别高于固体废弃物浸出毒性鉴别标准浓度。而焚烧飞灰以不同比例掺入水泥后所得固化体的重金属浸出浓度均远低于国家控制标准浓度。随飞灰掺量的增加，虽然重金属的浸出浓度相应增加，但随着养护龄期的增长，重金属的浸出浓度均呈逐渐下降趋势（见图 4），说明焚烧飞灰可满足安全使用的要求。

水泥固化重金属原理在于，通过物理包容和化学结合方式将溶液中的重金属离子固化于硬化水泥浆体内，降低其渗出，达到稳定化、无害化的目的[13]。图 5 是试样 PF2 水化产物的 XRD 分析图谱。结果表明，PF2 的水化产物主要为 $Ca(OH)_2$ 、AFt（$3C_3A \cdot 3CaSO_4 \cdot 32H_2O$）、$CaCO_3$、$MgCO_3$，以及 Friedel 相（$C_3A \cdot CaCl_2 \cdot 10H_2O$）。国外的相关研究表明[13] [14][15]，MSWI 飞灰主要化学成分中钙、硅、氯、硫含量较高，属 CaO-$CaCl_2$-SO_3-SiO_2 体系。在富铝的 CaO-SiO_2- Al_2O_3-$CaCl_2$ -H_2O 体系中，除形成对重金属离子有束缚稳定作用的 CSH 相外，硫酸根离子易形成对重金属有强束缚作用的 AFt 相，Cl^-则优先形成具有层状晶体结构的 Friedel 相。

不同的重金属与水泥基材料的作用可能不同。在碱性水泥浆体环境下，重金属离子既有可能被水泥矿物吸附而沉积在水泥颗粒表面，又可能与水泥水化产物发生化学反应生成新的化合物，或是上述两种作用同时存在[16]。图 5 为重金属离子固化于水泥水化产物的几种形式[17]。Zn 形成无定形的 $Zn(OH)_2$ 沉积在水泥熟料颗粒表面，与水泥水化产物 $Ca(OH)_2$ 反应生成无定形的 $CaZn_2(OH)_6 \cdot 2H_2O$；Cd 参与水化反应并形成一种新的水化产物 $CaCd(OH)_4$；Cr 能够被结合在水化产物中，尤其易结合在 C-S-H 凝胶中；Pb 在水化产物表面形成表面不溶性的沉积物。Cu 在图中没有说明，但有研究提出 Cu 不参与水化反应，通常在水泥颗粒表面沉积，以物理包容的方式存在于固化体体中[18]。

表 4　焚烧飞灰的重金属浸出(mg/l)

Heavy metals	Pure FA Concentration *	Concentration standard **	Leaching concentration of Cement pastes containing MSWI fly ash				
			PC1	PFA1	PFA2	PFA3	PFA4
Gu	8.17	50	0.019	0.018	0.016	0.031	0.035
Zn	46.11	50	0.080	0.039	0.083	0.050	0.054
Cd	0.597	0.3	0.001	0.005	0.002	0.007	0.013
Cr	2.464	1.5	0.620	0.606	0.533	0.437	0.590
Pb	26.47	3.0	0.170	0.199	0.263	0.282	0.517

* 掺入焚烧飞灰的水泥净浆试样的重金属渗出量

**鉴别标准数据为有色金属工业固体废物浸出液中最高允许浓度[10]

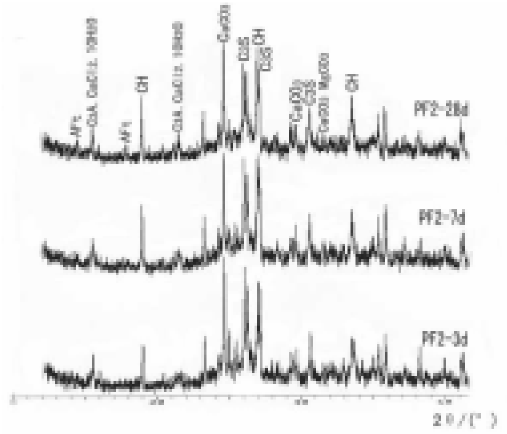

图 5 试样 PF2 的 XRD 图谱

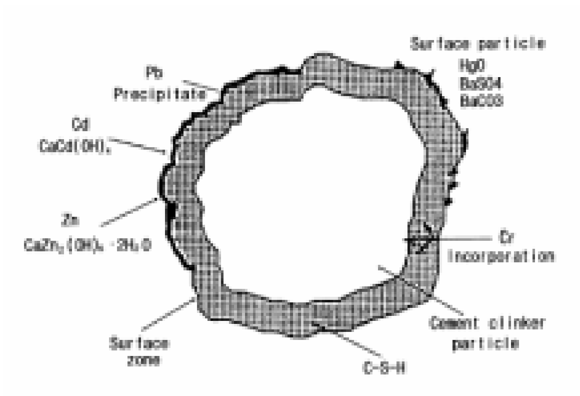

图 6 水泥水化产物对重金属固化和稳定

4　结论

1）焚烧飞灰中的碱与 Cl⁻离子对水泥水化有促进作用，掺入少量焚烧飞灰后，硅酸盐水泥浆体的早期水化速度加快，表现为硬化水泥浆体的早期强度较高。

2）城市垃圾焚烧飞灰具有较好的胶凝活性，在少掺量情况下，水泥浆体中形成一种层状晶体结构的 Friedel 相（$C_3A \cdot CaCl_2 \cdot 10H_2O$）。

3）焚烧飞灰中的重金属物质可通过物理包容和化学结合的方式固化于水泥水化产物中，在本试验条件下，硬化水泥浆体中重金属的渗出量远低于国家规定的重金属允许排放浓度。因此焚烧飞灰有望开发成一种新型的水泥基辅助材料，实现可持续资源的有效利用。

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水洗浆用于粉煤灰三渣基层材料改性技术研究

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摘　要　根据工业固体废弃物（水洗浆）对粉煤灰三渣混合料的作用，探讨粉煤灰三渣混合料的改性问题。研究表明：水洗浆改性粉煤灰三渣混合料具有早期强度高和耐久性较优等特性，并在试点工程中得到应用。
关键词　水洗浆；三渣；基层材料；强度；耐久性

1　引言

目前提高三渣早期强度的措施较多，但能推广用于实际工程的使用方法并不多[1、2、3]。基于上述情况，本研究利用水洗浆对粉煤灰三渣混合料进行改性，研究了改性粉煤灰三渣混合料的抗压强度和耐久性能。研究表明，改性粉煤灰三渣混合料在抗压强度和耐久性方面均优于普通粉煤灰三渣混合料。

2　原材料及试验方法

2.1　原材料

1）水洗浆：采用宝钢冶金公司废渣处理的水洗浆，其化学成分见表 1。

表 1　水洗浆化学成分（wt%）

SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	FeO	MnO	S	P_2O_5
11.84	2.22	3.13	53.58	2.74	2.97	0.35	0.841	0.04

2）粉煤灰：采用上海石洞口电厂原状III级粉煤灰，其化学成分见表 2。

表 2　粉煤灰化学成分（wt%）

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Loss
53.12	30.12	2.91	2.73	1.84	0.24	6.40

3) 石灰：采用三级石灰。外加剂：自配，掺量 0.5%

4）集料：采用最大粒径为 70mm 的碎石。

2.2　试验方法

粉煤灰——石灰二灰最佳含水率测得为 27%，最佳干密度 1.79kg/m^3，密实度为 99%，强度采用 Ø7×7（cm）圆柱体试模成型试件，粉煤灰和消石灰均用 5mm 筛过筛，以除去块状的杂质，避免影响强度发展。在试件的制备过程中，先将外加剂溶于水中再掺加，而且拌和好混合料应闷料 4～5 小时，以便使外加剂溶解分散于三渣之中。

干湿循环试验采用试件浸水 4d，然后在 80℃±5℃烘干 5h，再在水中浸泡 5h 作为一次循环，耐水性试验采用在水中浸泡 30d 后测定试件的质量和强度。

抗冻性能试验采用 GBJ82-85 规定，先将试件浸水 4d，在饱和面干条件下，放入-20℃～-17℃的冰箱中 4h，然后取出在 10℃～20℃的水中融化 4h 作为一次循环。抗硫酸盐侵蚀试验采用 GBJ82-85 规定方法进行。

3　结果与讨论

3.1　水洗浆改性粉煤灰三渣混合料配合比选择

三渣的强度检测是采用二灰的强度作为其强度的指标，按所配置的粉煤灰——熟石灰的重量比为 72∶28，分别采用各种比例水洗浆等量置换粉煤灰作为改性三渣的试件，在 20℃±3℃条件下养护 7 天及 28 天测定其强度作为性能指标，表 3 为各掺量水洗浆对粉煤灰三渣混合料强度的影响。

表 3　水洗浆掺量对粉煤灰三渣强度影响

编号	水洗浆掺量%	抗压强度（MPa）	
		7 天	28 天
0	0	1.47	2.31
1	20	2.21	3.71
2	40	2.65	3.26
3	60	2.59	4.12
4	80	1.83	2.51
5	100	1.89	1.56

由试验结果可知，随水洗浆掺量增加，三渣混合料的强度提高。当水洗浆掺加量达 60%时三渣混合料强度的 7 天强度达 2.59MPa,28 天强度为 4.12MPa，达到最高值。再提高水洗浆掺量，三渣混合料强度随之下降。因此可以认为在粉煤灰三渣混合料中用水洗浆部分置换粉煤灰可以达到早强目的，并且其最佳掺量为 60%。

3.2　水洗浆对粉煤灰三渣混合料早期强度影响

表 4 是各种配合比粉煤灰三渣混合料强度变化情况。

表 4　粉煤灰三渣混合料抗压强度

三渣混合料名称	早强剂	抗压强度（MPa）	
		7 天	28 天
普通三渣	——	0.78	1.52
早强三渣	HF 剂≤2.5%	1.57	5.86
掺水泥三渣	8%水泥	1.49	5.47
废石膏改性三渣	废石膏 35%	1.44	5.10
水洗浆改性三渣	水洗浆 60%	2.59	4.12

由表中试验结果可以看出，在普通三渣混合料中用 60%水洗浆来置换部分粉煤灰可以使三渣混合料 7d 强度从 0.78MPa 提高到 2.59MPa，提高幅度达 3 倍，从而提高粉煤灰三渣混合料的早期强度，并且其 28d 强度也相应得到大幅度提高。从比较试验结果还可以发现，水洗浆改性三渣混合料 7d 强度比水泥粉煤灰三渣和早强三渣 7d 强度都要高。

3.3　水洗浆改性三渣混合料强度发展

从以上的结果分析可知，水洗浆改性三渣混合料具有早期强度高的特点，为了了解长期强度发展情况，对其长期龄期的强度进行测定。图 1 使水洗浆置换 60%粉煤灰改性三渣混合料强度发展情况。

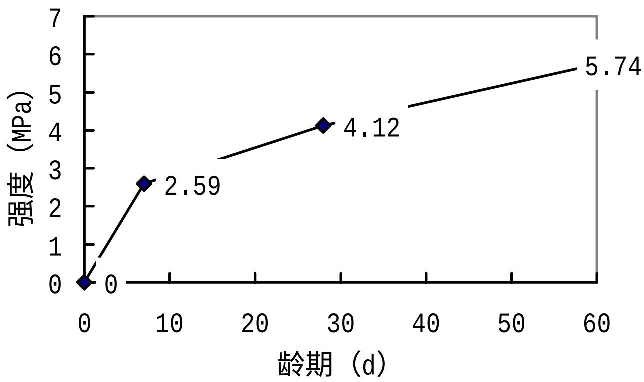

图1 水洗浆改性粉煤灰三渣混合料强度发展规律

由图中结果可以看出，水洗浆改性三渣混合料早期强度发展很快，后期强度发展趋于平缓但无倒缩现象。并且在养护至 60 天时，其强度可达 5.74MPa，完全满足道路施工的技术要求。

3.4 水洗浆改性三渣混合料体积稳定性

表 5 是各种不同置换量水洗浆改性三渣混合料的安定性测试结果。

表 5 水洗浆改性三渣混合料安定性

编号	水洗浆置换量（%）	安定性（mm）
0	0	3.2
1	20	2.8
2	40	2.4
3	60	1.9
4	80	2.2
5	100	2.6

由试验结果可知，采用水洗浆等量置换粉煤灰来配制三渣混合料无安定性不良现象，并且随水洗浆置换量提高，表征安定性的雷氏夹膨胀量下降，到置换量为 60%时最小。由此可见，采用水洗浆改性三渣混合料不仅可以提高三渣混合料早期强度、缩短三渣混合料养护周期，而且可以保持三渣混合料体积稳定性。

3.5 水洗浆改性三渣混合料耐久性的研究

耐久性是三渣混合料最重要的性能之一。长期以来，三渣混合料的试验环境都充满着影响其耐久性的有害介质，从而造成三渣混合料实际使用寿命的缩短。普通三渣混合料由于易开裂，养护周期长，孔隙多，促使其耐久性不佳。本文采用水洗浆来改性粉煤灰三渣，表 6 是水洗浆置换 60%粉煤灰改性三渣混合料的耐久性测试结果。

由表中试验结果可知，在本试验范围内，经水洗浆改性粉煤灰三渣混合料在 80℃高温下 7 天

强度提高 200%以上，在水中 30 天后强度基本没有损失。故在高温和水中环境下，水洗浆三渣混合料均能满足技术要求。此外，由试验结果分析还可以看出，经 5 次冻融循环后，水洗浆改性三渣混合料强度损失均不明显，可以认为其已满足路基工程所需的抗冻要求。

表 6. 水洗浆改性三渣混合料耐久性能

耐久性项目	耐久性指标	
	改性三渣	普通三渣
耐高温（80℃7 天）	2.32	1.73
耐水性（水中 30 天）	1.03	0.89
干湿循环（30 次）	0.93	0.82
抗冻融循环（5 次）	0.97	0.92
耐硫酸盐侵蚀（5%$Na_2SO_4$30 天）	1.33	1.13
耐氯盐侵蚀（5%NaCl 中 30 天）	0.93	0.92

抗干湿循环能力试验结果可知，经过 30 次干湿循环后，水洗浆改性粉煤灰三渣混合料的强度损失仅 0.7%，其明显小于普通粉煤灰三渣的强度损失 2.3%，并且其抗干湿循环指数达 0.93，优于普通粉煤灰三渣混合料的 0.82。

粉煤灰三渣混合料的抗硫酸盐侵蚀性能是其耐久性的一个重要方面。由于地下水及一些土壤中常含有一定浓度的 SO_4^{2-},使三渣混合料经常受到硫酸盐侵蚀。硫酸盐对三渣混合料的侵蚀是一个复杂的物理化学过程。从整体上看，硫酸盐侵蚀可以分为两个过程，即由扩散控制的物理过程，包括环境中的 SO_4^{2-}等扩散剂三渣混合料内部，三渣混合料中的 OH^-,Ca^{2+}等从三渣混合料内部向外环境扩散。SO_4^{2-}扩散到三渣混合料内部是产生硫酸盐侵蚀的先决条件，而扩散只能通过三渣混合料中的连通孔和微裂缝进行，所以三渣混合料的孔隙和微裂缝对其抗硫酸盐侵蚀能力影响很大。本文主要讨论水洗浆改性粉煤灰三渣抗硫酸盐侵蚀能力。由试验结果可以发现在 5%（wt）Na_2SO_4 溶液侵蚀后，经水洗浆改性的三渣混合料强度并没有下降而且有一定强度提高，因此可以认为水洗浆改性三渣混合料具有十分强的抗硫酸盐侵蚀能力。

4 试点工程应用

二 00 四年初在上海市某一市政道路采用水洗浆改性粉煤灰三渣混合料进行试点，路面结构示意图如图 2 所示。

上面层	細粒式沥青混凝土（3cm）
下面层	中粒式沥青混凝土（6cm）
基层	水洗浆改性三渣混合料（35cm）
底基层	土路基

图 2 水洗浆改性粉煤灰三渣基层路面结构图

十天养护各路段的弯沉检测结果见表 7。

表 7　三渣混合料基层弯沉检测结果（mm）

	十天	二十八天
普通三渣	/	1.98
废石膏三渣	0.68	0.43
水洗浆三渣	0.42	0.35

由表中结果可以发现水洗浆改性粉煤灰三渣基层的弯沉值最小，仅为 0.42mm，废石膏改性三渣次之，为 0.68mm，普通粉煤灰三渣无法测试。经过七个月的通车运行，道路面无裂缝、沉降现象，清楚地表明了水洗浆改性粉煤灰三渣混合料路用可行性。

5　结论

（1）本试验粉煤灰三渣混合料采用水洗浆等量置换粉煤灰可以提高其早期强度，当置换量为60%时，7 天强度可达 2.59MPa，能够满足粉煤灰三渣材料的技术要求。

（2）水洗浆改性粉煤灰三渣混合料无安定性不良现象发生，因此使用水洗浆置换粉煤灰生产三渣是安全的。

（3）耐久性试验结果表明，水洗浆改性三渣混合料抗冻性、耐水性和抗干湿循环能力、抗硫酸盐侵蚀性能等长期性能均优于普通粉煤灰三渣混合料。

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建筑水再生处理工艺路线初探

——“ 绿色建筑 ”水课题 01 子项系列研究之三

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摘　要　本文为“ 绿色建筑关键技术研究 ”项目的“ 降低建筑水耗的综合关键技术研究 ”课题中 01 子项“ 绿色建筑水循环安全保障综合性技术 ”的系列研究之三“ 水再生处理工艺路线研究 ”的初步综述性成果。本文简单概述了建筑"中水”类别，针对不同类别重点介绍了再生处理工艺及工程实例。

关键词　再生；处理；工艺；技术；中水；水质安全保障

1　概述

绿色建筑水循环安全保障的重要环节之一是水质安全保障。保障用水水质的安全，就是要保证水的理化指标和卫生学指标达到用水标准，符合用水水质要求。理化指标能否符合标准，是通过物理、生物、化学等再生处理工艺来实现的，而卫生学指标则是通过消毒处理工艺来实现的。因此，本文就涉及到建筑用水水质安全保障的再生工艺、消毒工艺分别进行介绍。

2　“ 中水 ”的概念与类别

目前业内有许多关于再生水、中水和回用水的概念，说法不一。为了便于研究工作的进行，特在此统一纷纭的“ 众说 ”，追根溯源，定义中水的概念。“ 中水 ”的概念源于日本，是指水质次于“ 上水 ”（市政供水），优于“ 下水 ”（市政排水）的水，实际上是一种再生水；《建筑中水设计规范》中对中水的定义是指各种排水经处理后，达到规定的水质标准，可在生活、市政、环境等范围内杂用的非饮用水；本研究中，中水是指采用非传统水源，即再生水、雨水、海水，作为建筑供水，取代部分传统水源——市政供水，用于非人体直接接触或频繁接触的冲厕、景观环境、街道浇洒、绿化、车辆冲洗、消防等用途，其水质介于下水与上水之间，这样的供水可称为“ 中水 ”。

目前中水的水源有五种，即：市政污水、建筑污水、相对洁净的工业废水、雨水和海水，其中建筑污水又可分为优质杂排水、杂排水和生活污水。

3　中水的再生处理工艺

中水的再生处理工艺与水源水质、利用途径等密切相关，针对上述提出的几种主要的中水水源，分别介绍它们目前的再生处理工艺。

3.1　市政污水

市政污水的再生处理工艺取决于城市污水处理厂的出水水质及再生水的用途。一般城市污水处理厂的二级处理出水作为再生水的原水，目前国内城市污水处理厂二级生物处理出水水质一般

为：

BOD_5 10～30mg/L

COD 30～100mg/L

SS 10～20 mg/L

总大肠菌群 10^5～10^6 个/100 mL

可知，作为再生水原水的城市污水处理厂的二级处理出水的有机物含量偏低，可生化性较差，一般适宜采用物化再生处理工艺。

（1）传统处理工艺

二级处理出水－消毒－中水

二级处理出水—过滤—消毒－中水

二级处理出水—混凝—沉淀（澄清、气浮）—过滤—消毒－中水

以上几种再生处理工艺，一般当原水水质较好且对出水水质要求不十分严格的情况下采用，出水水质可用作道路清扫、绿化等用途。

（2）膜过滤工艺

二级处理出水—预处理－膜过滤（微滤膜或其它膜）—消毒－中水

二级处理出水—预处理－双膜过滤（微滤膜＋反渗透或其它膜）—消毒－中水

这种再生处理工艺一般适用于对出水水质要求较严格，而且当地经济条件较好的情况。出水水质可用作冲厕、消防、洗车等用途。

国外市政污水的再生处理工艺也包括传统处理工艺和膜过滤工艺，一般应用膜过滤的较多。

（3）其他

二级处理出水—景观型人工湿地—建筑景观环境水体

这种再生处理工艺同样适宜于后面提到的建筑污水、雨水的再生处理，已有较为成熟的污水再生处理的实用技术，如何将这种景观湿地与景观娱乐性水体的有机复合生态系统移植与应用在绿色建筑中，将成为“降低建筑水耗的综合关键技术研究”课题中 02 子项的重点研究内容。

3.2 建筑污水

（1）生活污水和杂排水

这种污水作为中水的原水，污染程度相对来说较严重，不同地区其水质情况各不相同。一般为：

BOD_5 230~300mg/L

COD 455~600mg/L

SS 155~180mg/L

有机污染物含量较高，因此一般要采用生物处理法。

1）生物＋物理工艺

原水—格栅（栅网）—调节池—生物膜法—沉淀—过滤—消毒—中水

原水—格栅（栅网）—调节池—活性污泥法—沉淀—过滤—消毒—中水

原水—格栅（栅网）—调节池—膜生物反应器—消毒—中水

2）物化＋生物工艺

生活污水—格栅（栅网）—调节池—混凝沉淀或气浮—生物处理—沉淀—过滤—消毒—中水

这种处理工艺一般适用于悬浮物浓度较高、后续的生物处理工艺对水质有特殊要求时。

3）生物＋膜工艺

生活污水—格栅（栅网）—调节池—生物处理—预处理—膜处理—消毒—中水

这种处理工艺的出水水质较好，可用在对水质要求较高的场所。

（2）优质杂排水

优质杂排水污染较轻，一般易于处理，其水质亦存在地区差异，一般如下：

BOD＜80mg/L

COD＜100mg/L

SS＜100mg/L

总固态物＜220mg/L

pH7.2~8.0

阴离子表面活性剂 5~8.5mg/L

可知有机污染物浓度较低，不适宜采用活性污泥法。一般采用物化处理法或采用较适合低有机物浓度生物处理的生物转盘或生物接触氧化法。

1）物理处理

优质杂排水—格栅（栅网）—调节池—过滤—消毒—中水

优质杂排水—格栅（栅网）—调节池—过滤—活性碳吸附—消毒—中水

2）物化处理

优质杂排水—格栅（栅网）—调节池—混凝沉淀或气浮—过滤—消毒—中水

优质杂排水—格栅（栅网）—调节池—混凝沉淀或气浮—过滤—活性碳吸附—消毒—中水

3）生化处理

优质杂排水—格栅（栅网）—调节池—生物转盘—沉淀—过滤—消毒—中水

优质杂排水—格栅（栅网）—调节池—生物接触氧化—沉淀—过滤—消毒—中水

4）膜处理

优质杂排水—格栅（栅网）—调节池—预处理—膜处理—消毒—中水

3.4 雨水

建筑屋面及道路雨水污染程度较轻，非常适宜作为中水原水。城市建筑屋面及地面之下均设有雨水排水管，若配以雨水贮水池，成为“地下水库”，简单处理后，可用于冲厕、景观环境、道路清扫、绿化、洗车、消防等多种用途。

目前常见的做法是收集屋面雨水作为中水原水。由于屋面径流污染较严重，初期雨水水质较差，一般要考虑初期弃流，而且屋面雨水的可生化性较差，BOD/COD 的值在 0.10~0.15 之间，不宜采用生化法处理，宜采用物化方法。常见处理工艺如下：

（1）屋面雨水—初期弃流—调节池—压力滤池—消毒—中水池—中水

（2）屋面雨水—初期弃流—调节池—涡流絮凝池—贮沉池—消毒—中水

（3）屋面雨水—初期弃流—筛网过滤—旋流分离器—滤沉贮水池—消毒—中水

3.5　海水

海水用来冲厕在日本已得到成功的应用，我国青岛、塘沽都有进行海水冲厕的试点。我国沿岸和近海海水水质较好，平均一般不超过《海水水质标准》中的二类水质标准，这种水质应该说较适宜作冲厕水源。其处理利用工艺一般为：

海水—进水渠—吸水井—消毒—进水泵房—贮水池—送水泵房—海水供水管道—用户

海水—取水头部—吸水井—进水泵房—输源水管道—消毒—澄清池—贮水池—送水泵房—海水供水管道—用户

4　中水的消毒处理工艺

再生水必须经过消毒处理工艺才能作为中水使用，以保障用户的人身安全。消毒处理工艺一般采用次氯酸钠、液氯等消毒剂，近年来也有采用臭氧和紫外线消毒的。

消毒效果的好坏通常用生物灭活效率、实用性、可靠性、投资与运行成本、环境影响、职业健康和安全等指标来评价。液氯、二氧化氯、臭氧和 UV 消毒这几种消毒工艺各有优缺点。下面就这些消毒工艺进行分析比较。

常见消毒工艺的分析比较

需考虑的因素		液氯消毒	二氧化氯消毒	臭氧消毒	UV 消毒
需要的处理时间		30min	≤30min	5-10min	30-60s
投加量（mg/L）		2-20	5-10	1-3	30-40Mw/cm^2
对细菌的灭活效率		高	高	高	高
对病毒的灭活效率		中等偏下	中等	高	高
水质影响因素		受 pH、温度影响大	受 pH、温度影响大	受 pH 影响大、温度影响小	受 pH、温度影响小
技术复杂程度		简单到中等	中等	高	简单到中等
经济性	运行费用	中等偏下	中等	中等偏上	中等偏下
	投资（小规模到中等规模）	中等	中等	高	中等
	投资（中等规模到大规模）	中偏下	中偏下	高	中偏上
	占地面积	大	较小	小	小
	维护工作量	大	较小	大	小
不利影响	运输过程中的危险	有	有	无	无
	现场的危险	相当大	中等	中等	较小
	对鱼类和大的无脊椎动物的毒害	有毒	有毒	无	无
	是否存在有毒的副产品	有	可能存在少量	有	无
	清洗产物的处置	无	无	无	有
	是否增加溶解性固体含量	是	是	否	否
	有无腐蚀性	有	有	有	无

通过上表可看出，就职业健康和安全风险而言，UV 消毒的风险最低，对环境的潜在风险最小；就对细菌、病毒的灭活效率而言，UV 和臭氧消毒系统较高；就受水质等外界环境的影响而言，UV 和臭氧消毒系统较小；另外，UV 消毒系统简捷，运行管理简单。但 UV 和臭氧消毒投资较大。

尽管目前液氯消毒有逐渐被 UV 消毒取代的趋势，但对于非现场回用的情况而言，还要投加氯，以保证中水输送管道中有一定的余氯量来抑制水中残余病原微生物，并防止二次污染的发生。

5　中水利用综合工程实例

中水利用的实例目前有很多，天津梅江小区中水回用就是一个比较典型的实例。

梅江小区的中水来源于纪庄子再生水厂，中水供作居住区生活杂用水和景观环境用水，工程规模为 20000m^3/d。其设计原水水质和中水水质分别见下表。

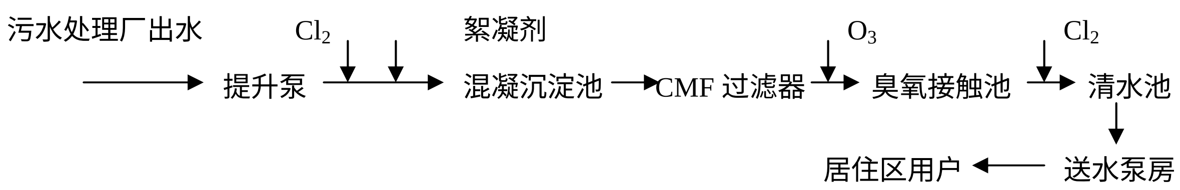
梅江小区中水原水设计水质

项目	水质指标	项目	水质指标
COD	≤120mg/L	TP	≤1.0mg/L
BOD_5	≤30mg/L	色度	≤80 倍
SS	≤30mg/L	pH	6-9
氨氮	≤25mg/L		

梅江小区中水设计水质

项目	水质指标	项目	水质指标
浊度, NTU	≤5	Cl^-, mg/L	≤300
SS, mg/L	≤5	Fe, mg/L	≤0.2
色度，度	≤15	Mn, mg/L	≤0.1
pH	6.5～9.0	LAS, mg/L	≤0.5
嗅味	无异味	游离余氯, mg/L	0.2
BOD_5, mg/L	≤10	挥发酚	≤0.1
COD, mg/L	≤50	石油类, mg/L	≤1.0
氨氮, mg/L	≤10	细菌总数，个/mL	≤100
TP, mg/L	≤1.0	总大肠菌群，个/L	≤3
TDS, mg/L	≤1000	污染指数(SDI)	<3
总硬度($CaCO_3$ 计), mg/L	≤300		

中水再生处理采用的是连续流微滤膜和臭氧氧化的联合工艺，工艺流程如下：



梅江小区中水处理工艺流程图

从 2002 年 12 月开始运行以来，整个工艺系统运行稳定，CMF 设备系统运行正常。处理出水中浊度值均低于 1NTU，细菌总数的去除率在 96%以上，总大肠菌群的去除率在 99%以上，一般不超过 3 个/L，理化指标和卫生学指标均达到了用水水质要求。

6　结语

水质安全保障是通过再生处理工艺和消毒处理工艺来实现的，各种工艺的综合集成不仅取决于中水的水源，还取决于建筑的类型、利用途径、地域特点，需要进行系统的综合分析和经济核算后才能做出正确的决策。

中水回用装置自动运行与监测水质试验研究

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摘　要　本文在现有 ICAST 处理装置[1]基础上，采用 PLC 与上位机组成的两级结构，结合水质在线监测仪器，并运用 Delphi 语言编制动态监控程序，通过监测水质指标，自动修改调整运行参数，对装置进行了高层次自动控制研究，以保证出水达到中水回用标准（CJ/T 95-2000），经济安全可靠地实现小区污水回用处理运行和水质监测的自动化。

关键词　PLC；自动运行与监测水质；动态监控程序；中水回用标准（CJ/T 95-2000）

中图分类号：X703　文献标识号：A

Test investigation of automatic running and monitoring water quality in the device of water reuse

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Abstract This article is based on the device of ICAST (Intermittent or Cyclic Activated Sludge Technology). It uses two levels of structure between the Programmable Logic Controller (PLC) and the computer, and several on-line measuring instruments. With the Delphi language, dynamic monitor routine is established on the sewage treatment system. Automatically modifying the running parameters during each technical phase according to the index of water quality, the quality of effluent can meet the National Water Reuse Standard（CJ/T 95-2000）, and then the automating of the water reusing treatment and the water quality monitoring can be realized economically、safely and reliably.

Key Words PLC; automatic running and monitoring the water quality; dynamic monitor routine; National Water Reuse Standard（CJ/T 95-2000）

1998 年英国“整合计划公司”在沃特福德推出的“千禧房屋”,1999 年英国私人住宅市场先后推出的两批绿色环保房屋——“未来房屋”和“贝丁顿零化石能屋”，以及澳大利亚、加拿大、美国、日本、意大利、德国、以色列及香港地区等国外经济发达国家和地区[2，3]，生态小区内的中水回用率都在 80%左右，其中严重缺水的以色列，回用率接近 100%。显然，中水回用已成为控制治理水污染和保护水资源的重要手段，是解决水资源危机的一种重要途径，同时也是生态小区可持续发展的要素[4]。

目前，污水回用处理技术的国内外研究主要集中在活性污泥法，膜生物法和强化一级处理法等，可以说从水处理单元技术方面已无关键技术问题。但这三者均存在一定的缺陷[1,2]:（1）小区污水每天的水质水量变化较大，且含较高浓度的 COD_{cr}、BOD_5 和 NH_3-N 污染物，这就要求活性污泥法的生化处理器内保持较强活性的污泥和良好的微生物生态平衡系统，才能保证高效低成本处理，但当前该两方面问题均没有解决；(2) 膜生物法的膜成本很高，处理水量少，膜易堵塞需清洗；(3) 强化一级处理法，很难去除 NH_3-N 污染物。此外，这三种工艺技术共同存在以下不足[1~4]：(1) 处

理过程产生的污泥、臭味和噪声等二次污染，目前还没有很好解决；(2）处理装置占地面积大、一次投入和日常运行费高，国内已有中水系统，中水成本要远高于当前自来水价格；(3）国内已有中水系统，仅简单采用了自动控制系统实现半自动运行，但还不能根据水质水量和处理效果等变化因素随时调节运行参数，也即无法达到运行调控参数选择、自动控制和监测、维护管理等各个系统之间的最优化集成，因而无法保证出水经济可靠地达到中水标准。

因此，在文献[1]的 ICAST （Intermittent or Cyclic Activated Sludge Technology，间歇 / 循环活性污泥技术）装置基础上，本文采用 PLC 与上位机组成的两级结构，运用 Delphi 语言编制动画监控程序，并采用水质在线监测仪器，依据水质监测指标，通过上位机自动修改运行参数，保证出水达到中水回用标准（CJ/T 95-2000），从而经济安全可靠的实现生态小区污水回用处理运行和水质监测的自动化。

1　ICAST 处理装置

ICAST 处理装置[1]，间歇运行时的处理流程为：格栅→ICAST 生化处理→过滤→消毒→中水，连续运行时需在 ICAST 生化后设置二沉池，如图 1 所示。为防止生化池曝气产生的气溶胶飞沫和飞沫所夹带细菌的污染，以及消除污水处理过程中产生的异味气体，在 ICAST 池顶部设置废气收集管道，通过抽风机将废气抽入废气处理器，并进行生物脱臭达标后排放；处理过程中产生的极少量污泥通过管道回流至生化池；由空压机产生的噪声，其消音措施由隔音材料、抽风机和管道组成。因此，ICAST 处理装置不会产生二次污染的问题。

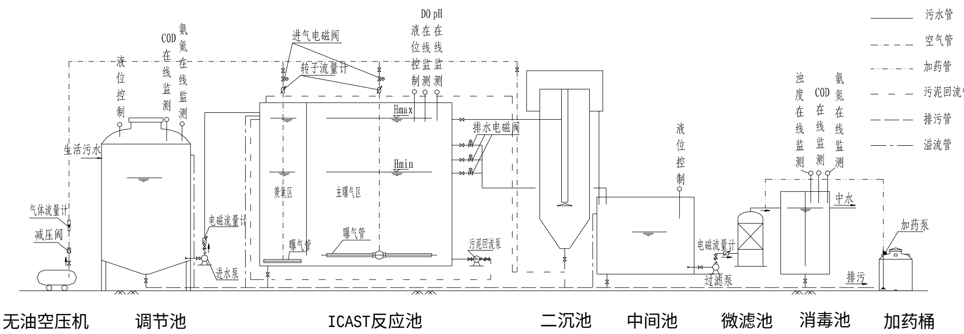

图1 污水回用处理系统

Fig.1　System of living sewage reusing treatment device

2　自控系统

传统工艺的连续运行方式为空间上的变化，污水顺序自然流到下一个处理单元，因而不需要太多的运行操作，而 ICAST 工艺为时间上的连续运行，需要进行多次开停操作，包括控制进水泵、空压机、过滤泵、污泥回流泵等设备的启动，运行和停止等，而这些操作均为时间顺序控制，故特别适用于自动控制，并且通过适当改变运行程序可实现生物脱氮和除磷。因此，在现有 ICAST 处理装置基础上，本文自行设计并建立了一套自控系统，该系统可通过 PLC 与上位机的连接实现间

歇式或连续式的 ICAST 处理流程的自动运行，并可在线监测水质,当各工艺阶段的水质指标不能达标时，通过上位机调控 PLC 可改变运行参数，如 ICAST 生化池的运行时间或曝气量等，确保出水水质达到中水回用标准。

整个系统分为三层（表 1），其中中央控制层和现场执行层主要负责装置系统的自动运行，数据采集层则进行在线监测[5~7]。

表 1 自控系统结构表

控制层名	设备构成	具体实现的功能
中央控制层	中控计算机（上位机）	监视控制装置运行过程及数据等
数据采集层	各类水质分析仪表及流量计	采集水质水量指标数据
现场执行层	PLC、水泵、风机、电磁阀等	驱动现场设备

2.1 自控运行

采用 PLC 与上位机组成的两级结构，进行自动控制处理运行。下位机选用 OMRON 公司的 CPM2A 型 PLC，通过 RS232C 端口与上位机链接，在其扩展连接器处连接两个 CPM1A 模拟量扩展单元，每个单元有四个模拟量输入端子和一个模拟量输出端子。

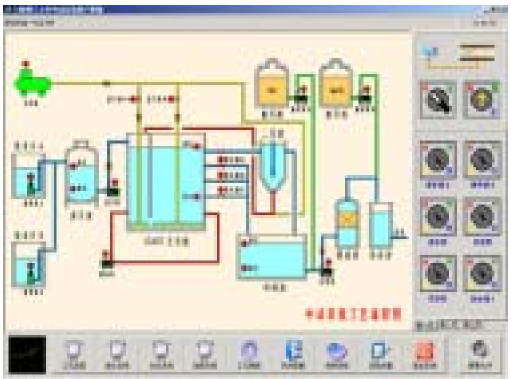

图 2 上位机主画面

上位机操作系统为 Windows XP，采用 Delphi 语言设计平台程序，通讯程序则采用由台湾小猪工作室推出的串口通讯控件 SPCOMM，后台数据库采用 Borland 公司的 Inter-base 数据库。上位机具备的功能为如下：(1) 显示设备的运行状态、工艺流程的动态参数、相关参数的趋势、历史数据和历史纪录；(2) 打印过程回路控制的参数给定值，报警记录和班报表等；(3) 报警设有优先级管理，任意管理均在屏幕上显示；(4) 操作进程中设有启动、停止和选择等软手动操作功能；(5) 上位机编程软件可方便、直观地实现编程、组态和修改等[5]。

图形界面分为 2 大部分：主画面和各个工艺阶段、报表报警的分画面。图 2 为上位机主画面，显示整个工艺流程的设施设备和管道流向，通过动画编程动态显示其当前的工作状态，同时也可显示通讯过程是否正确。在此画面中，通过观察动画显示的有无，可以判断通讯是否中断；通过观察右边的通讯状态栏，可以评估实际通讯的品质。

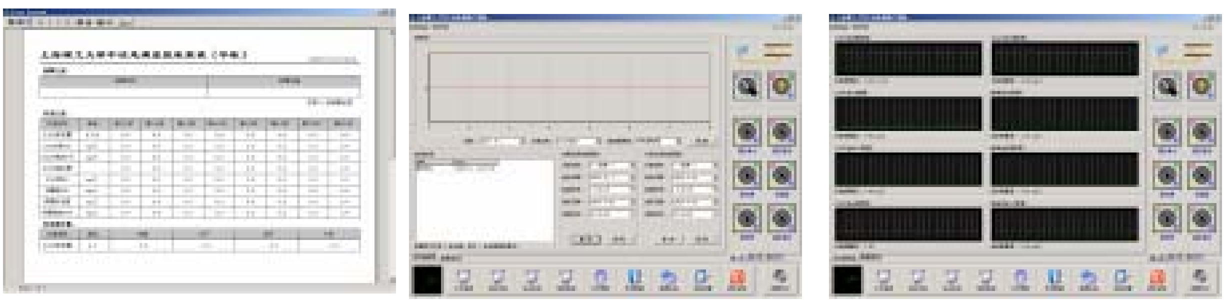

图 3 分画面

当通讯报告发生错误时，首先由 PLC 自行检查设备故障，并反馈信息给上位机，若 PLC 不能排除故障，则上位机继续进行故障检查和处理，当两者都不能解决故障时，发出声光报警，此时可通过手动强制开停操作控制某台设备的开关，进行故障的检修，待设备正常后再次投入运行。同时，自控运行还设有若干个分画面，分画面可实现报表记录，历史数据查询，故障记录以及各工艺段的详细参数和测量值记录等，当上位机与打印机连接，还可以进行报表打印，如图 3 所示。此外，PLC 通过串口发给上位机的数据以及上位机通过串口发给 PLC 的数据在这些界面中都可以查询到。

2.2　水质水量在线监测

根据 ICAST 工艺的特点，要实现自动控制，除了控制泵开停的电磁阀外，还需配置在线监测仪器，本文选用电磁流量计、溶氧仪、温度计和压力计等必备仪表进行水质监测[6]。

电磁流量计通过水流切割磁力线所产生的感应电动势的大小，反应出流量的大小，并进行累加，最终得到污水处理量。溶氧仪和温度计采用复合式仪表。其中温度是反映微生物活性的一个重要参数，通过适宜的温度控制可以使微生物处于最佳活性状态并获得较好的出水。溶氧仪用于监测 ICAST 生化池的溶解氧值（DO）。不同的 DO 值，ICAST 生化池内微生物种群存在差异，这些差异会对处理效果产生较大影响，适宜的 DO 值可确保生化池内硝化和反硝化反应的正常运行，从而可保证获得既经济高效又稳定的处理效果，因此当 DO 值过大或者过小时，上位机通过 PLC 控制空压机的曝气时间或曝气量，进而改变 ICAST 生化池的 DO 值。压力计则用于监测空压机出口端的风压。

由于这些仪表都属于非电量仪表，因此需要进行 A/D 转换，转换成 PLC 可识别数据传输给上位机，以备数据存贮和历史数据的查询打印等。

2.3　工艺流程

自控系统的工艺流程为进入自控监测界面（图 4），选择 ICAST 处理工艺运行方式（间歇式或连续式），并输入密码及相关原始设定值，如进水泵间歇启动时间、曝气时间、沉淀时间、排水阀延时启动时间等。开始运行，实现过程控制自动化。

图 4　自控监测界面

生活污水经提升泵从集水井输送到调节池，根据调节池中的液位信号控制开停泵的时间，调节池低位时开泵，高位时停泵。经调节池出水，由进水泵输送到 ICAST 生化池，进水泵根据调节池和生化池的液位信号以及设备运行状态一同控制，生化池低位调节池高位时开泵、生化池高位或调节池低位时停泵，当生化池处于曝气、沉淀、出水期间则不开泵。在 ICAST 池曝气过程中：(1) 空压机的运行根据处理流程的间歇式或连续式有所不同，若间歇式运行，进水泵运行时延时启动空压机，而进水泵关闭后，空压机继续运行一段时间后停止；若连续式运行，空压机与进水泵联动；(2) 2 个进气电磁阀与空压机联动；(3) 间歇式运行中回流泵不运行，连续式运行中回流泵与进水泵联动；(4) 间歇式运行中 3 个排水电磁

阀依次延时打开，ICAST 池排水到低位时关闭所有排水电磁阀，连续式运行中排水电磁阀不受控制。

经间歇式 ICAST 处理后的出水，通过自流至中间池，而经连续式 ICAST 处理后出水则自流至二沉池去掉细小颗粒，再溢流至中间池。中间池内蓄水由过滤泵输送至微滤池进行过滤，过滤后出水加消毒剂送至消毒池停留一段时间即为中水。其中过滤泵依据中间池水位控制，高位开泵、低位停泵；加药泵与过滤泵联动。

当系统出现故障时，由 PLC 先进行故障检查，并且每隔一定时间发送错误报告给上位机，若不能排除故障，则可进行手动强制开停操作，待故障排除后重新投入运行，可保证出水水质达标，也使得整个设备的运转更加完善。

3　试验结果

采用上述设计的 ICAST 处理装置自动运行和监测水质系统，本文针对某 18 高层住宅污水（污水量 40m^3/d），进行试验加以验证。经过 2004 年 1 月～6 月半年的试运行，其试验结果的平均值如图 5 所示，其中 COD$_{cr}$ 去除率在 95%以上，BOD$_5$ 去除率在 96.6%以上，SS 和色度的处理效果也令人满意，出水水质略呈酸性，嗅觉上无任何不快感，完全符合中水标准（CJ/T 95—2000）。NH_3-N 的去除也达到了中水处理水质要求，NH_3-N≦20mg/L。

通过试验结果分析可得，自控系统根据在线监测的进水水质和溶解氧（DO）值，可自动改变运行参数，如曝气时间（间歇运行）和曝气量（连续运行），以保证出水水质达到中水回用标准。

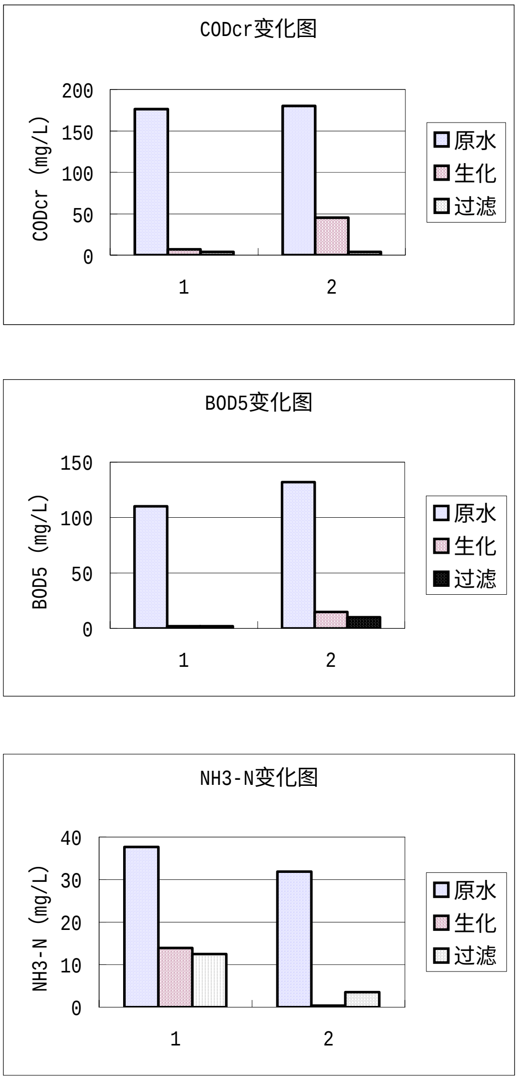

图 5　试验结果

图 6 为半年试运行中 DO 随时间变化曲线的平均值。该曲线表明溶解氧在进水期间基本保持不变，曝气时随着曝气量的增大溶解氧呈上升趋势，这时微生物处于最佳活性期，保持较高的 DO 值有助于微生物获得充足的氧，但过高的 DO 需要更多的曝气量，从而使曝气效率降低，相对稳定的 DO 值一般保持在 2.0mg/L 左右。此外，沉淀和排水时逐渐下降，在厌氧反应段接近为 0，随后上升到初始状态进入下一个周期。

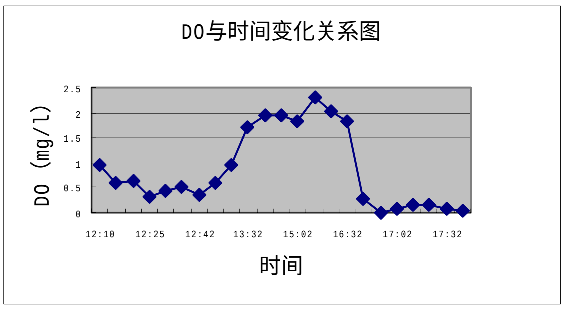

图 6　DO 随时间变化曲线

4 结论

本文采用可编程控制器（PLC）与上位机组成的两级结构，运用 Delphi 语言编制的污水处理系统动画监控程序，可动态显示整个处理过程，经济安全可靠的实现了处理运行和水质监测的自动化。同时，依据进水水质水量和 ICAST 生化池内 DO 值，自动改变曝气时间（间歇运行）和曝气量（连续运行）等运行参数，确保出水能经济高效地达到中水标准（CJ/T 95—2000）。半年试运行的结果表明，本文设计的生态小区污水为中水装置
自动运行与监测水质的系统是正确可行的。

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建筑供排水体制初探

——“绿色建筑”水课题 01 子项系列研究之二

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摘　要　本文为“绿色建筑关键技术研究”项目的“降低建筑水耗的综合关键技术研究”课题中 01 子项“绿色建筑水循环安全保障综合性技术”的系列研究之二“供排水体制研究”的初步综述性成果，总结和分析了国内外现有的集中与分质供排水体制的运行情况，并针对系统中的输送、储存等环节的实际状况与存在问题进行了分析总结。
关键词　建筑供排水；质供水；质排水；质杂排水；排水

1　概述

随着人民生活水平的提高和水资源短缺问题的日益严重，在传统的集中供排水体制的基础上逐渐衍生出分质供排水，即：供排水由单一系统直接供给/排放（市政供水由净水厂直接到用户；市政排水统一接入市政排水管网，送至污水处理厂处理达标后排放）发展成依据水质不同分别供给/排放。分质供水可以分为优质饮用水、传统市政供水和中水（包括再生水、雨水和海水）三种，依据用途的不同分别供给；分质排水主要可以分为优质杂排水、杂排水、生活污水和海水冲厕水，依据收集、再生与排放的不同目的而分别设置排水系统。

有效地利用雨水也是解决城市水资源短缺的重要措施之一，沿海地区还可以利用海水来解决淡水资源不足的问题。

2　供水体制

2.1　常规供水系统

目前常规市政供水系统有以下几种：

（1）共用低压供水系统——当给水管网水量、水压经常满足要求时，采用生活和消防共用的低压给供水系统，由城镇给水管网直接供水，不设水泵房及高位水箱。

（2）分散加压供水系统——当给水管网水量、水压不能满足小区内的建筑物要求时，小区内的各建筑分别设置加压水泵房，每个水泵房只负责一栋楼或几栋楼的给水，通常下面几层由市政给水管网直接供水，上面几层由水泵加压后供水。

（3）集中加压供水系统——当给水管网水量、水压不能满足小区给水要求时，整个小区由一个集中设置的加压泵房供水，当小区内各建筑物的高度相近时，应根据最不利点所需压力确定供水压力。

（4）集中加压与分散加压相结合的供水系统——对建筑物高度相差较大的小区，给水管网水压不能满足小区给水要求，集中加压站的供水压力只满足高度相近的建筑物对水压的要求，而另一

部分较高的建筑物，则另外进行加压的给水系统。

2.2　分质供水

为了合理、有效地利用宝贵的淡水资源，实现建筑中水资源的可持续利用，分质供水不失为一种经济的策略，已开始在我国一些城市建筑一定范围内实施，通过分质供水可以保证水资源的优化配置，实现水的优质优用、低质低用，避免水资源的严重浪费。

分质供水就是根据使用目的的不同，分别供应水质不同的水，一般分为中水、市政供水和优质饮用水三种。

（1）中水

中水属于低品质、非饮用水，水源主要取自生活污水和冷却水，分为 A、B、C 三类：A 为不含厨、厕排水，以冷却水、雨水、洗浴水为主的优质杂排水；B 为含厨房排水的杂排水；C 为杂排水和厕所排水的混合水。中水单设管网供应，用于冲厕、景观环境、绿化、洗车、道路清扫和消防等用途。

我国单体建筑、大型综合建筑群都有中水利用的实例，中水供水亦采用常规供水方式：利用管网压力供水、单设屋顶水箱供水、水泵水箱联合供水。

（2）市政供水和优质饮用水

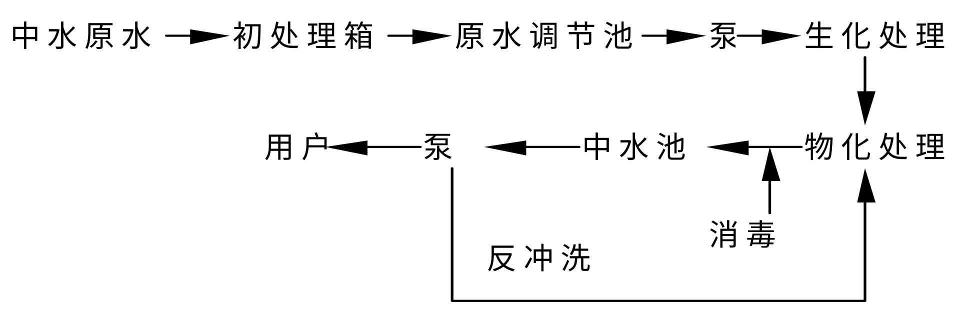
将传统的市政供水和优质饮用水分质供应，即前者主要用于洗涤、盥洗和洗浴等，后者是经一定区域内的净水站，将市政供水进一步深度处理、加工和净化，在原有供水管道系统上，再增设一条独立的供水管道，将优质饮用水输送至用户，供用户直接饮用，这种方式是否经济合理，在业内存在较大争议，不属于“ 绿色建筑 ”课题的研究范畴，在此不予细述。

（3）案例分析

河北省邯郸市滏阳河畔一花园小区，建筑面积 5 万平方米，居民 2200 人，中水主要用于冲厕、绿化和洗车，杂排水水量 168 立方米/天。

杂排水经初级处理（隔除毛发和固体物质），主处理（生化处理）再经深度处理（物化处理），以确保储水质量。

中水处理站设计为部分二层的带地下室建筑，采用一级提升重力流处理，最后加压供水。流程如下.



该工程设备工艺简单，各处理单元运行状态稳定，出水水质良好，满足回用要求。处理设备投资 38.5 万元，中水收费 1.18 元/立方米，低于目前邯郸市自来水水价。

3 排水体制

3.1 常规排水系统

目前我国普通居民住宅室内排水设计大多数采用污废水合流制，即粪便污水与其他生活污水一同经化粪池处理后排入市政管网，只有少数的高层住宅及一些智能型大厦采用污废水分流制，即只让粪便水进入化粪池而其他生活污水单独排放。根据我国目前的国情，化粪池作为一种污水予处理设施在现阶段是否必不可少，业内尚存在争议。如果采用污废水分流制，就可以大大减少化粪池的容积及数量，这样既有助于小区管线布局的合理性，也减少了日常维护、管理的费用，同时还可以降低工程投资。单独排放的生活污水可以经过适当的再生处理后进行二次利用。

3.2 分质排水

随着水资源短缺的加剧，污水再生利用受到越来越多的关注，与中水利用直接相关的建筑分质排水已逐步在全国范围内不同程度上被采用。分质排水系统是指按排水的污染程度分别收集、排放的方式，根据不同的再生利用需要，可以有多种分质方法。一般的做法是在建筑内设两条管道：一条为杂排水管道，收集除粪便污水以外的各种排水，如淋浴排水、盥洗排水、洗衣排水、厨房排水等，输送至中水设施作为中水水源，再生处理后可用于绿化、洗车、道路清扫、冲厕、消防和景观环境等用途；另一条为粪便污水管道，收集便器排水，经小区化粪池处理后排入市政管网。

3.3 案例分析

北京中海馥园小区采用分质排水系统：冲厕污水、厨房排水管道汇集后排至室外，经化粪池处理后排入市政管网；盥洗及淋浴废水回收至 2、3 号楼地下 2 层的中水处理站，经处理后回用于室外环境绿化、浇洒道路、地下车库地面冲洗，并且预留余量供二期使用。中水处理工艺采用接触氧化法。

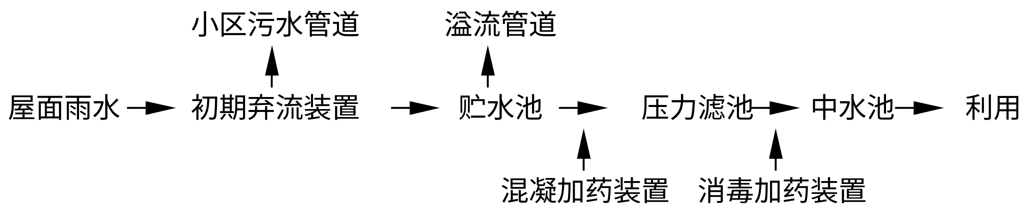
4 雨水利用

雨水利用也是建筑水循环中分质供水的一种，由于不同于常规意义上的分质供水，单列本节加以叙述。

对于建筑区雨水而言主要有屋面、道路、绿地三种汇流介质。在这三种汇流介质中，地面径流雨水水质较差，道路初期雨水中的 COD 通常高达 3000mg/L~4000 mg/L；而绿地径流雨水又基本以渗透为主，可收集雨量有限；比较而言屋面雨水水质较好、径流量大、便于收集利用，其利用价值最高。雨水处理后可作为中水应用在很多方面。

低层或多层建筑一般采用水落管外排水方式，而高层及大型综合型建筑多采用内落水方式。

屋面雨水收集及处理工艺流程如下：



城市雨水是城市可利用水资源的重要组成部分，雨水的收集利用不仅可以减轻城市暴雨洪涝的危害、降低城市雨水管网的投资，还可以补充建筑用水、替代部分新鲜淡水资源，甚至回灌地下、补充地下水资源，具有显著的经济与环境效益。

5　海水利用

海水利用亦属沿海城市建筑水循环中分质供水、混合排水的一种，由于不同于常规意义上的分质供水，故单列一节加以叙述。

利用海水作为大生活用水是一项综合技术，它涉及海水取水、前处理、双管路供水、地下和屋顶贮水、卫生洁具、及系统的杀生、防腐、防渗和防生物附着技术；大生活用海水与城市污水系统混合后含盐污水的生化处理技术；合理利用海洋稀释自净能力将大生活用海水进行海洋处置的技术等。防腐技术和防生物附着技术已基本成熟，大生活用海水技术的重点是高含盐量污水的生化处理技术和海洋处置技术。

香港海水冲厕起源于 50 年代末，历经 40 年的发展，海水冲厕已形成体系，占总人口的 78.5%。每天冲厕用水约为 52 万立方米。像淡水供水系统一样，在香港另有一个完全独立的海水供应系统，为市区和新市镇提供冲厕用水。现在，已有 76%的人口采用海水冲厕，海水用量达 $1.99\times108\mathrm{m}^3/\mathrm{a}$。由于广泛使用海水冲厕，因而节省了大量淡水。

海水冲厕系统主要由供水站(泵房)、配水管、调蓄水池等组成，自成一套独立的配水管网体系，供水站就近取海水并适当处理后供用户使用，该供水网络由 37 个抽水站、42 个配水池及约 1050 km 长的水管组成。

6　总结

解决城市化进程的加快和水资源紧缺之间的矛盾，必须研究传统水源之外的其他各种可供水源的水量与水质的特点，通过经济分析与对比，建立合理的供排水体制来实现水资源的优化配置，保障用户的供水安全。

建筑可供水源综合利用潜力初探

——“绿色建筑”水课题 01 子项系列研究之一

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摘　要　本文为“绿色建筑关键技术研究”项目的“降低建筑水耗的综合关键技术研究”课题中 01 子项“绿色建筑水循环安全保障综合性技术”的系列研究之一“可供水源综合利用潜力研究”的初步综述性成果。通过对住宅建筑的各种可用再生水水源的综合分析，结合案例，针对水量、水质、适用用途等不同方面，系统论述了不同水源在建筑中的综合利用潜力。
关键词　建筑；水循环；再生水；雨水利用；海水利用；水量安全保障

1　概述

目前我国城市水的综合利用程度较低，安全保障措施不够过关。近几年发展了一批具有绿色建筑特点的生态小区，其关注的热点主要是绿色建材的应用与能耗的降低，诸如如何有效地解决采暖和消暑，如何使用各种各样的新材料如无污染涂料以及可降低热辐射的特制玻璃窗材料等问题；而对于水的综合利用缺乏统筹考虑，并没有真正地将各种可能的传统水源与非传统水源纳入到水的大循环概念中，在水量安全保障方面缺乏系统的规划。

从发达国家发展的轨迹中可以看出，在建筑中建立水的大循环概念，市政供水、再生水、雨水、海水等，均要统一列入考虑范围，进行系统优化设计，实现多水源分质供水，以中水替代并节省宝贵的新鲜淡水，保证水量安全，已成为绿色建筑发展的必然趋势。概括起来，可作为中水水源的有市政污水、建筑污水、相对洁净的工业废水、雨水和海水，将其进行适当处理再生后可以用作非人体接触或接触较少的用途。

2　建筑用水

根据用途分类，建筑用水可分为生活用水和公共用水。其中居民生活用水包括饮用、烹调、淋浴、洗涤、冲厕。公共用水包括景观环境、道路清扫、绿化、洗车、消防等。

建筑中的冲厕、景观环境、道路清扫、绿化、洗车、消防等非人体接触的用水，其水质要求低于饮用水，可考虑由中水取代，已节省宝贵的新鲜淡水。表 1 给出各类建筑物生活用水的百分比。

表 1　各类建筑物分项用水百分率（%）

项目	住宅	宾馆、饭店	办公楼、教学楼	公共浴室	餐饮业、营业餐厅
冲厕	21.3～21	10～14	60～66	2～5	6.7～5
厨房	20～19	12.5～14	—	—	93.3～95
沐浴	29.3～32	50～40	—	98～95	—
盥洗	6.7～6.0	12.5～14	40～34	—	—
洗衣	22.7～22	15～18	—	—	—
总计	100	100	100	100	100
注：沐浴包括盆浴和淋浴。					

其中冲厕用水量可根据上表中的百分率计算确定；道路清扫用水定额可按浇洒面积 2.0～3.0L/m^2·d 计算；绿化浇洒用水定额可按浇洒面积 1.0～3.0L/m^2·d 计算（干旱地区可酌情增加）；洗车用水定额应根据车辆用途、道路路面等级和沾污程度以及采用的冲洗方式，按下表确定；消防用水量和水压及火灾延续时间，应按现行的《建筑设计防火规范》及《高层民用建筑设计防火规范》确定。

表 2　汽车冲洗用水量定额(L/辆·次)

冲洗方式	软管冲洗	高压水枪冲洗	循环用水冲洗	抹车
轿车	200～300	40～60	20～30	10～15
公共汽车 载重汽车	400～500	80～120	40～60	15～

建筑中这类用水的最大特点是时变化系数大，普通住宅的用水时变化系数都在 2.0~3.0，因此无论是从收集杂用水角度，还是用水角度，都存在一个水量稳定的问题。

3　市政污水

在管网系统完善的地区，市政污水作为中水水源具有规模大、水源稳定、管理水平高、供水保障程度高的优点，但由于工业废水的排入，其水质与建筑污水相比要复杂得多，因此更适宜于景观环境、道路和绿化这些与人体接触频率较低的用途。

天津纪庄子市政污水处理工程日处理规模 50000m^3，其中再生水厂规模为 20000m^3/d，采用连续流微孔膜过滤＋臭氧氧化的再生处理工艺。再生水部分用于梅江小区的景观水体补充、道路清扫和绿化，其余作为工业用水。梅江小区内人工湖泊的水面面积为 28500m^2，水深 1.8~2.0m，自建成以来陆续换水和补充水体的蒸发，已经使用了近 20000 m^3 的再生水。

4　建筑污水

建筑污水可分为：优质杂排水（洗浴排水为主）、杂排水（冲便器以外的生活排水为主）和生活污水（包括冲便器在内的全部排水生活)。建筑污水作为中水水源，与市政污水相比具有水质单纯、易生化、水量时变化大的特点，其水质依建筑类型的不同而变化，见下表。

表 3　各类物各种排水污染浓度表　(mg/L)

类别	住宅			宾馆、饭店			办公楼、教学楼			公共浴室			餐饮业、营业餐厅		
	BOD5	COD	SS	BOD5	COD	SS	BOD5	COD	SS	BOD5	COD	SS	BOD5	COD	SS
冲厕	300～450	800～1100	350～450	250～300	700～1000	300～400	260～340	350～450	260～340	260～340	350～450	260～340	260～340	350～450	260～340
厨房	500～650	900～1200	220～280	400～550	800～1100	180～220	—	—	—	—	—	—	500～600	900～1100	250～280
沐浴	50 ～60	120～135	40 ～60	40 ～50	100～110	30 ～50	—	—	—	45 ～55	110～120	35 ～55	—	—	—
盥洗	60 ～70	90 ～120	100～150	50 ～60	80 ～100	80 ～100	90 ～110	100～140	90 ～110	—	—	—	—	—	—
洗衣	220～250	310～390	60 ～70	180～220	270～330	50 ～60	—	—	—	—	—	—	—	—	—
综合	230～300	455～600	155～180	140～175	295～380	95 ～120	195～260	260～340	195～260	50 ～65	115～135	40 ～65	490～590	890～1075	255～285

建筑污水经过不同的再生处理工艺后，适宜于冲厕、景观环境、道路清扫、绿化、洗车等用途。

北京西单东南商业大厦总建筑面积为 5 万平方米，主要由三部分组成：三星级宾馆，工商银行营业部，综合商业及餐饮娱乐设施。根据北京市的相关法规和规范，结合当地现状的市政条件，该建筑中建设有中水回用工程，主要包括中水收集系统、中水处理设施、中水回用管道。中水的原水

主要是客房淋浴盥洗优质杂排水，设计水量为 183m^3/d，收集系统管道使用优质 UPVC 管材。该系统的中水主要用于厕所冲洗、室外绿化、洗车等。中水工艺采用生化处理和沉淀结合的再生工艺，前设调节池，其作用是对原水流量和水质起调节均化作用，保证后续处理设施稳定和高效运行。

5　工业废水

较清洁的工业废水如冷却水等可以作为中水使用，由于其具有地点限制、水量日变化大、水质清洁、成分单一的特点，主要适宜于厂区内建筑的冲厕、道路清扫、消防用水。

6　雨水

建筑区内雨水包括屋顶雨水和地面径流，具有季节性强、初期雨水污染重、后期雨水较清洁的特点。屋顶雨水可收集后经初期弃流，储存回用于冲厕、景观环境、道路清扫、绿化、洗车、消防的用水；而地面径流可采用渗水性地面、景观型湿地的处理方式回补地下水或收集为景观环境用水。

慕尼黑国际展览中心是近年来德国投资较大的建筑工程，由于展览中心是人员流动频繁之地，因此，这里雨水利用的总体思路是先用于构造水景观，多余雨水用于回灌地下水。为此，设计将展览大厅屋顶的雨水收集至总库容为 2500 立方米的地下蓄水池，经泵站输送至水面近 2.5 万平方米的人工湖内。湖内设高大喷泉，湖周围种植水生植物，水鸟在湖面飞翔，与高大的展览厅群交相辉映，更显现出展览中心的气派与辉煌。蓄水池的设计标准为 5 年一遇，标准内降水可满足景观用水要求，超标准降水将溢地流至地面入渗系统，入渗回灌地下水。

7　海水

经简单处理后的海水可直接用于冲洗厕所，还可作为消防用水、港口码头市政道路冲洗用水。日本发生阪神地震时，由于城市供水系统安全被破坏，其灭火的水源几乎全部采用海水；香港目前约八成人口利用海水冲厕，我国天津、青岛已将海水冲厕列入议事日程。

我国沿海大部分城市人均水资源量低于 500 立方米，其中大连、天津、青岛、连云港和上海的人均水资源量低于 200 立方米，严重缺水。我国沿海城市人口 2 亿多，据有关报道，若采用海水冲厕的人口达到 25%或 30%，则每年可节省 10.4 亿立方米到 12.5 亿立方米的淡水，会大大缓解沿海地区淡水资源紧缺的局面，具有不可忽视的环境效益和经济效益。

香港在上世纪 50 年代末开始采用海水作为居民冲厕用水，海水冲厕与淡水供应系统一样，有一套完全独立的海水供应系统，为市区和新区提供冲厕用水。达到三类海水水质标准的海水，只需进行格栅分离和加氯处理，就可用于冲厕，成本非常低廉。海水系统建立初期，是按用量收费的，在 1972 年后，改为免费。1991 年，全港使用海水冲厕的用户约有 65%，至 1999 年跃升至 78.6%，海水用量约占全港总耗水量的 23%，从 1970 年的大约 14.5 万立方米，增至 1999 年的 58 万立方米。

8　结语

随着人口的增长、经济的发展，水资源的紧缺已成为全球关注的焦点。因此，如何实现水资源的优化配置是我们必须面对和解决的核心问题。通过研究各种建筑不同用途用水的特点，在传统水源之外挖掘出其他可供水源，如市政污水、建筑污水、雨水、海水，分析这些水源在建筑中利用的可行性，在水量、水质两方面保障用户的用水安全，提高生活质量，保证水资源的可持续利用，以实现真正意义上的绿色建筑。

生态建筑雨污水 ICAST 回用处理系统设计研究

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摘　要　本文从污水处理装置及其自动控制与监测系统等方面，对各个装置的尺寸、功能、运行参数选择、设备选型、工艺设计特点以及高级自控与监测的实现等内容进行分析阐述，设计生态建筑雨污水就地回用的间歇/循环活性污泥技术（ICAST）处理装置系统。实验运行结果表明，该装置系统可经济、高效、稳定去除雨污水中的污染物，出水达到中水回用标准（CJ/T 95－2000）。
关键词　ICAST；回用处理系统；自动控制和监测；计算机
中图分类号：X703　文献标识号：A

Design investigation on the system of ICAST in reusing ecological building's wastewater

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Abstract　From aspects of sewage treatment device and auto controlling and monitoring system, sizes of each parts of system, functions, choice of running parameters, equipment selection, characters of process, realization of high-level auto controlling and monitoring are stated in this article. And a system of ICAST (Intermittent or Cyclic Activated Sludge Technology) treatment device in reusing ecological building's wastewater combined of rain water and living sewage is designed. With the actual running result, it shows that pollutants in wastewater combined of rain water and living sewage can be effectively removed to achieving the water reusing standard (CJ/T 95－2000, China) with such a system.
Key words　ICAST; reusing treatment system; automatic controlling and monitoring; computer

水污染及其水资源危机是制约我国当前城市建设可持续发展的重要因素，建立一个比较完善的、经济高效的生活污水回用处理系统，实现污水就地资源化和无害化,具有重大的社会、经济和环保价值。生态建筑雨污水回用是上海市科委 2003 年科技攻关项目专项《生态建筑关键技术研究与系统集成》的一个子项目，它主要是对示范工程——上海建科院莘庄园区，包括环境实验楼在内的几栋建筑每日所排放出的污水及雨水进行回用处理。在比较目前的国内外主流的几种污水回用处理技术的基础上，作者采用了一种装置集约化程度高、处理能力强、运行方式灵活、自动控制和监测、维护管理方便的改进型 SBR——ICAST （Intermittent or Cyclic Activated Sludge Technology，间歇 / 循环活性污泥技术）对生态建筑雨污水回用处理系统进行设计研究，为实施国家建设部和水利部 2001 年提出的“现代绿色小区 40%以上的生活污水经处理后须回用”指标，以及为逐步实现小区污水零排放打下基础[1~5]。

1　污水回用处理系统设计

1.1　处理装置

污水回用处理装置系统如图 1 所示，占地约 20m^2，污水水源为上海建科院莘庄园区包括环境实验楼在内的几栋建筑的全部建筑污水和部分幕墙测试中心的冲墙排水及雨水，设计承担处理水量为 20m^3/d。

该系统的污水处理主要装置包括调节池、ICAST 反应池、二沉池、中间池、过滤柱及消毒池，ICAST 反应池由兼氧区和好氧区（主曝气区）组成，连接管道采用 PVC 塑料管。主要处理装置及其材料如表 1 所示。

表 1　主要处理构筑物及其材料

序号	名　称	尺寸	材料
1	调节池	4.4m×0.9m×2.5m	200mm 厚钢筋混凝土
2	ICAST 池	2.9m×1.2m×2.0m	20mm 厚有机玻璃板
3	二沉池	Φ1.4m，h=2.15m	20mm 厚有机玻璃板
4	中间池	1.3m×0.8m×1.3m	15 mm 厚有机玻璃板
5	过滤池(柱)	/	外壳为 5mm 玻璃钢
6	清水池	4.4m×0.9m×2.5m	200mm 厚钢筋混凝土

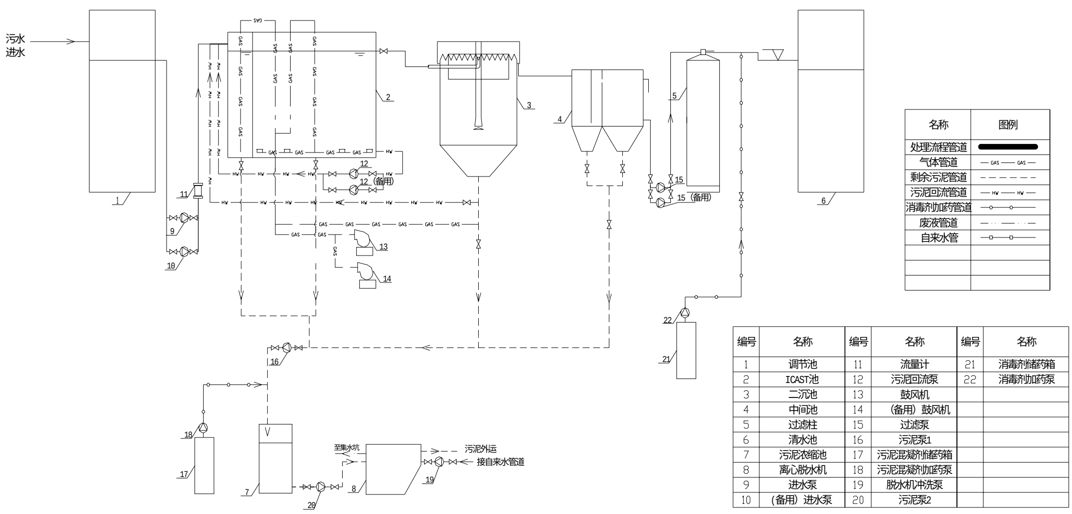

图1 污水回用处理系统

Fig.1　System of living sewage reusing treatment device

1.2　工艺流程

ICAST 是作者基于 SBR 及其衍生的 ICEAS、CAST/CASS/CASP 处理技术发明的一种改进型的活性污泥技术。该专利技术采用灵活的运行方式，可根据实际需要自由选择间歇式或连续式的运行方式。

工艺流程如图 2 所示，生态建筑雨污水经调节池进入 ICAST 反应池进行生化处理。ICAST 反应池可以采用间歇式和连续式两种运行方式。考虑到维护的方便，本次设计采用连续式运行（如图 3 所示）。连续运行为连续进水、连续出水，流入 ICAST 反应池的污水，在兼氧区与活性污泥

充分混合后进入主曝气区进行好氧分解，自然停留一段时间后溢流入二沉池，沉淀后上清液出水至中间池，处理过程中回流主曝气区内的部分污泥至兼氧区。

这里将 ICAST 反应池设计分为一个较小的兼氧区和一个较大的好氧区，目的在于兼氧区不仅可有效地缓冲进水水质波动对好氧区活性污泥的冲击，而且可起到生物选择的作用，抑制丝状菌生长，控制污泥膨胀。运行过程中，兼氧区还可减轻好氧区部分的有机物负荷，使残留有机物更有效地去除。

此外，考虑到进水水质可能有较大波动，因此在原污水污染物浓度较大时可在中间池加入微量混凝剂。由中间池出水经过滤柱进行过滤，并送至清水池，消毒后的出水水质可达到中水回用标准（CJ/T 95—2000）。在处理过程中，各工艺阶段的水质监测指标及其分析方法如表 2 所示。

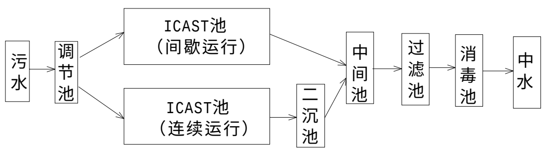

图2 处理流程示意图
Fig.2 Flow chart of ICAST treatment process

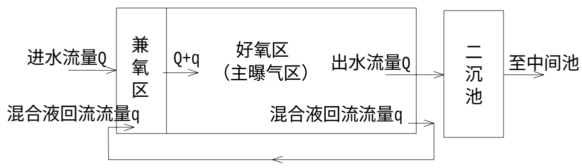

图3 连续式运行示意图
Fig.3 Sketch map of the continuing process

采用 ICAST 技术对生态建筑雨污水进行处理，装置一体化程度高，可以节省基建费用，连续式运行时，为保证在相对较短的停留时间内取得理想的处理效果，通过增设污泥回流系统，使回流混合液 NH_3-N 在兼氧区内利用原水中的碳源反硝化，提高脱氮效果，处理量较大。

表 2 水质监测指标及其方法

序号	水质指标	分析方法或仪器
1	COD_{cr}	COD 在线监测仪
2	BOD_5	Oxi-Top 压差法快速测定
3	SS	重量法
4	NH_3-N	氨氮在线监测仪
5	MLSS	过滤烘干水份后称重
6	MLVSS	600℃灼烧 30min 后称重
7	PO_4^{3-}	钼酸铵抗分光光度法
8	pH	玻璃电极法（在线监测）
9	DO	氧电极法（在线监测）

1.3 回用系统

将生态建筑雨污水经调节池处理后进入 ICAST 池生化处理并由过滤消毒后的出水（其水质达到中水回用标准）用于回用的系统，称为中水回用系统，一般由管道、水泵及喷嘴等组成。中水经回用系统可用于生态建筑楼顶平台浇灌绿化、景观水池用水、清洁道路等。

2 自动控制及监测系统

利用上述污水回用处理装置，在文献[6]的基础上，进行处理运行和监测水质的自动控制系统设计，如图 4 所示。

2.1　研究内容

a、ICAST 处理流程可以通过 PLC 和计算机进行自动控制。包括控制进水泵、鼓风机、过滤泵、污泥回流泵等设备的启动、运行和停止及不正常运行时的报警等。

b、监控污水回用处理的整个过程，监测进出水水质的主要指标 COD_{cr}、NH_3-N 及浊度；ICAST 生化反应池内的 DO 和 pH 值；当各工艺阶段的水质指标达不到预定目标时，可由计算机通过 PLC 适时调整运行参数等。

c、对污水回用处理过程中的数据进行采集和定时存贮，根据需要可查询任意时刻各种设备的故障记录及仪表的历史记录，且对历史数据进行一定的分析。

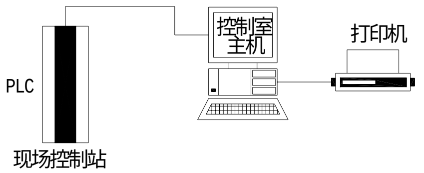

图4 自控系统功能示意图

Fig.4　Sketch map of automatic controlling system

2.2　设计原则

a、以出水水质为目标监测及控制

自控系统除了监测进、出水的水质以外，应对 ICAST 反应池内的 DO 和 pH 值作在线监测记录，通过监测的数据确定反应池内生化反应条件与处理出水之间的关系，并以此为依据在自控界面上对 ICAST 反应池的运行和曝气量大小进行调整，使出水水质可达到中水回用标准。

b、实用性与经济性

自控系统采用进口和国产设备及电器结合，设计和编程考虑主要设备的自动运行，在保证可靠的前提下尽可能节约成本。通过对系统主要设备的选型，可使其造价比国内同类型系统价格有较大幅度的降低。

c、安全性与可靠性

自控系统控制部分具有故障报警及故障处理功能。从设计到设备选型和安装施工及运行维护均应尽可能确保系统的安全可靠性。

2.3　自控硬件及软件

自动控制系统 I/O 量共计约 38 个点，目前可编程控制器（PLC）的种类有很多，如欧姆龙的 CPM2A 系列、西门子公司的 S7200 系列和 S7300 系列、A-B Rockwell 公司及三菱公司的产品等。依据作者的选型经验及比较各设备的特点，西门子公司和 A-B 公司的中小型 PLC 质量好，但对本系统而言价格较贵；欧姆龙公司和三菱公司的小型 PLC 质量及价格优势明显，其性价比较高，且在同行业中应用较广泛；同时考虑到上位机组态软件的选用，因此选用欧姆龙公司的 CPM2A 系列。它具有处理速度可满足系统要求、基本指令丰富、程序易于修改、维护工作量小、网络组态容易等特点。

监控软件是在 Delphi 软件的基础上进行编程，该软件可使系统维护人员在极短时间掌握，其

性能在国内许多企业已经得到应用检验。此外，该软件获得技术支持容易，其性能完全满足本系统需要，而价格却比其它同类型软件要低。

2.4 自控工艺

2.4.1 自控工艺流程

打开计算机，进入自控检测界面，输入密码及相关原始设定值，开始运行，实现过程控制自动化。

生态建筑雨污水经提升泵从集水井输送到调节池，根据调节池中的液位信号控制开停泵的时间，调节池低位时开泵，高位时停泵。经调节池沉淀处理后出水，由进水泵输送到 ICAST 生化池，进水泵根据调节池和生化池的液位信号以及设备运行状态一同控制。经连续式 ICAST 处理后出水则自流至二沉池去掉细小颗粒，再溢流至中间池。中间池内蓄水由过滤泵输送至微滤池进行过滤，过滤后出水加消毒剂送至消毒池停留一段时间即为中水。其中过滤泵靠中间池水位控制，高位开泵、低位停泵；加药泵与过滤泵联动。

2.4.2 控制系统结构及特点

依据国内外常用的自控系统形式，本系统采用 PC+PLC 结构，与常规智能直接数字控制仪表相比，具有投资少，寿命长，易维护且故障率低等特点。

现场控制站主要负责所有设备和过程的数据采集控制和参数调节，由 PLC 完成该功能且通过 PLC 承担事故预处理并与控制室计算机进行通讯。控制室可提供 CRT 显示及故障报警、部分参数设置、远程人工干预操作和数据存储等工作。控制室通常由 1 台工控机来完成，该管理机除含有现场操作功能外，还具备数据处理、报表打印等功能。

2.4.3 自控系统组成及功能

根据地理位置及工艺功能划分，本系统由控制室和现场控制站组成，控制室与处理装置相邻，回用系统的喷泉景观池与住宅楼相连。本系统可通过计算机界面实现数据采集、画面显示、参数修改、存储及打印等功能，具体可由 4 大部分组成。

a、工艺流程图动态显示

流程图共 5 张，包括总工艺流程图、进水部分流程图、生化处理部分流程图、中间池和二沉池处理部分流程图、过滤及加药消毒部分流程图。这 5 张流程图、管道和设备都可以动态显示当前的工作状态。设备故障时用声光报警并可作适当处理。

b、实时监测和显示有关数据

通过扩展的模拟量模块，可将相应的仪表数据传入上位机，在上位机上实现实时监测和显示有关数据，包括进水的流量、进出水的 COD_{cr}、NH_3-N 指标值、出水的浊度值、以及 ICAST 反应池中的 DO 值和 pH 值。

c、设备控制及参数设定

可以在自动控制的状态下强行控制某台设备的开关，根据处理的要求进行多种参数的设定，同时，可根据在线监测仪器的反馈值自动调整运行参数。

d、数据采集查询及处理

根据要求对处理过程中的数据进行采集和保存，可以查询任意时间各种设备的故障记录及仪表的历史数据，提供历史趋势图功能，自动生成 24 小时、1 个月、1 年的趋势图，同时提供数据报表功能，生成班报表和日报表。

2.5 试验验证

根据以上所述，作者在上海理工大学校园内，设计加工搭建了 ICAST 用于 18 高层住宅的雨污水就地回用处理的自动控制运行和监测水质的装置系统，并经 2003 年 6—8 月３个月的调试运行，其出水水质达到中水回用标准。调试运行结果表明，该处理装置、自动控制运行及监测水质的系统是可行的，为生态建筑雨污水回用处理系统的设计提供了可靠的依据。

3 结论

a、以出水水质达到中水回用标准为目的，设计了生态建筑雨污水回用的 ICAST 处理装置系统。

b、采用在线监测仪器对出水水质、ICAST 反应池内的运行条件以及系统设备的运行参数等进行监测，根据进水水质、水量和 ICAST 反应池内 DO 值，自动设定各工艺阶段的运行参数，可经济、安全、可靠地实现系统处理运行和水质监测的自动化。

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微型生物在污水回用处理中的指导作用

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摘　要　针对污水回用处理 ICAST 装置[1]，通过长期镜检观测，本文总结了 ICAST 反应池内所占优势的微型生物，对运行过程中由于工况改变致使微型生物性状发生的变化进行了分析。结果表明，微型生物、特别是原生动物对污水回用处理装置经济高效运行可起指导作用。

关键词　ICAST；微型生物；指导作用
中图分类号：X703　文献标识号：A

The guidance of microorganism in the living sewage reusing treatment

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Abstract　By the long-term microscopy, the respective dominant microorganism is summarized in the device of ICAST[1] for the reusing treatment of residential quarter's living sewage, and the variation of microbial trait is analyzed when the change of working conditions. It is shown that microorganism and protozoa can give the guidance to the economical and effective operation of the device.

Key words　ICAST; microorganism; directive function

生活污水在废水处理及其资源化利用中占有相当大的比例，建立一个比较完善的、经济高效的小区污水回用处理系统，实现污水就地资源化和无害化，具有巨大的社会、经济和环境效益。ICAST（Intermittent or Cyclic Activated Sludge Technology，间歇/循环活性污泥技术）[1]是一种适合小区污水回用处理的新型改良 SBR 工艺的处理技术。

在 ICAST 反应池中，参与污水回用处理的是由细菌、原生动物、后生动物和悬浮物质、胶体物质混合形成的具有吸附分解有机物能力的絮状体颗粒——活性污泥。是否具有良好性能的活性污泥是对污水进行生化处理最终达到资源化利用的基础，因此本文就污水回用处理 ICAST 装置，通过长期镜检观测，从活性污泥培养到正常运行的整个过程中，对微型生物进行深入研究，分析 ICAST 反应池中微生物的变化规律，以及当工况发生改变时生物相的变化趋势，利用生物指示作用为处理装置的最优化运行控制和集成化管理提供科学的理论依据。

1　研究对象

活性污泥中存在着多种微型生物，它们共同构成了相当复杂的生物相，其中数量占主导地位并起到降解污染物质主要作用的是细菌。从生物学角度了解污水处理是否达到预期效果，最直接方法是对活性污泥中的细菌进行研究，观察细菌的生长情况及在运行中发生的种类、数量等变化。目前，对细菌观察和分类鉴定的周期较长，作出诊断还没有较为简易的可行方法，不能及时地起到指导装置运行的作用。

但是，活性污泥中的原生动物与细菌之间存在着相互依存和制约的关系：(1) 原生动物对细菌的捕食，可促进细菌生长和提高细菌活性；(2) 细菌的絮凝作用提供了原生动物的生长环境，而在絮状物上生长的原生动物又能加速絮凝过程；(3) 原生动物分泌的粘液对悬浮颗粒和细菌均有吸附能力；(4)除细菌外，原生动物也能直接摄入微小的悬浮粒性有机物（DOM, dissolved organic matter），以及通过渗透性营养直接吸收溶解性有机物（POM, particular organic matter）；(5) 原生动物体积较细菌大可便于观察，周围环境发生变化时比细菌更加敏感，更及时地反映出运行状态。

因此，原生动物的种类、数量、生长状况和菌胶团等指标可以间接定性地评价污水回用处理装置运转状态的好坏，起到生物指示的作用。

2 ICAST 处理装置及运行方式

污水回用处理 ICAST 装置[1]，如图 1 所示。该装置运行方式如图 2 所示，生活污水经调节池进入 ICAST 反应池进行生化处理，ICAST 反应池采用间歇式和连续式两种运行方式。其中，连续式运行时（如图 3 所示）为连续进水、连续出水；间歇式运行时（如图 4 所示）为间歇进水、间歇出水。

本文在活性污泥培养完成后，分别采用间歇和连续两种工艺运行该装置，对 ICAST 反应池中的微型生物进行观测，在研究生物指导作用的同时，对比不同条件下该反应池中微型生物生态群落之间的异同。

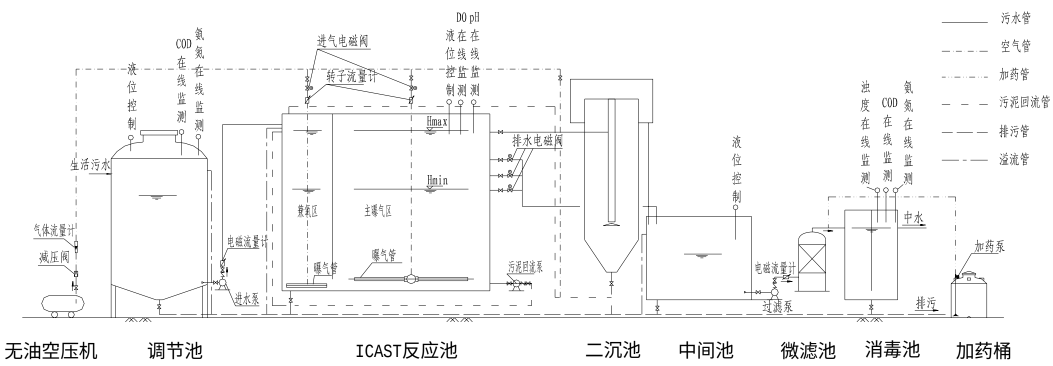

图1 污水回用处理系统
Fig.1 System of living sewage reusing treatment device

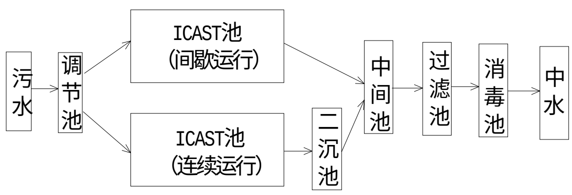

图2 处理流程示意图
Fig.2 Flow chart of ICAST treatment process

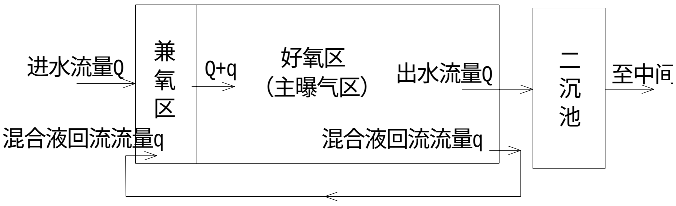

图3 连续式运行示意图
Fig.3 Sketch map of the continuing process

图4 间歇式运行示意图
Fig.4 Sketch map of the intermittent process

3 活性污泥的驯化与培养

本文接种的活性污泥菌种取自上海市曲阳污水厂二次沉淀池回流浓缩污泥，微型生物活性强，污泥絮体和沉降性能均良好，原生动物已演替到较高级的类型。起初对新进污泥进行不进水的闷曝，一段时间后对 ICAST 反应池进行间歇进水，污水为上海理工大学高层住宅每日所排生活污水（$40m^3/d$），且水量随培养时间的增加而逐渐增加，最终达到设计处理水量，实现正常的间歇运行。

在驯化与培养过程中，每天通过显微镜进行镜检，分析污泥的性状和微型生物种类和数量的变化趋势。通过三周的观测，发现由于曲阳污水厂污水水质和本装置所处理污水水质均为生活污水，有相同的水质特征，故所驯化培养的活性污泥中微型生物对新进污水的适应过程较短。最初几天的驯化过程中，原生动物类缘毛目（Peritricha）固着型纤毛虫（图 5）数量有明显减少，替代之大量出现的是全毛目（Holotricha）游泳型纤毛虫（图 6），并有部分的吸管虫（图 7）出现。随着培养时间的推进，当污泥中的微型生物逐渐适应新的水质和生长环境时，固着型的纤毛虫重新开始大量出现，伴之有少量的游泳型纤毛虫。在污泥培养后期，固着型纤毛虫已占绝对优势，相继出现漫游虫（图 8）、轮虫（图 9）等微型生物，此时污泥的培养已基本完成，活性污泥全面形成大颗粒絮团，且结构紧密，沉降性能良好。由于进水的有机物浓度不高，因此生化需氧量 BOD_5 在 150mg/l 左右。污泥沉降比 SV 在 15%左右，污泥浓度 MLSS 在 1200mg/l 左右。

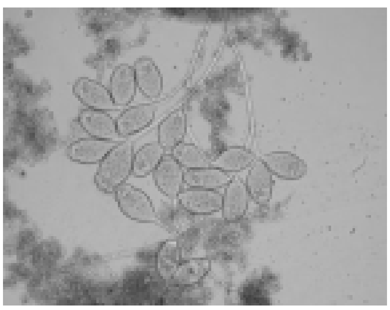

图 5 固着型纤毛虫
Fig.5 Sessile ciliates

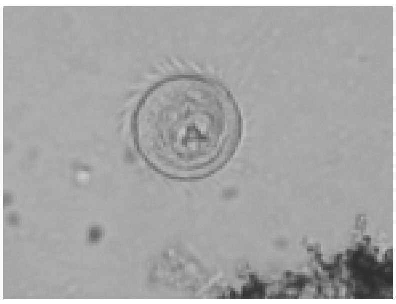

图 6 游动型纤毛虫
Fig.6 Wandering ciliates

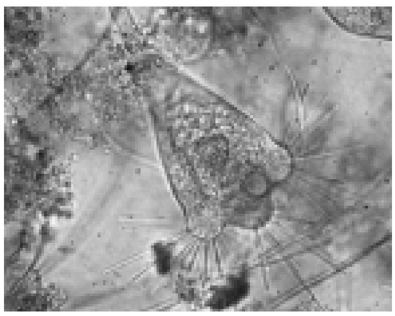

图 7 吸管虫
Fig.7 Suctoria

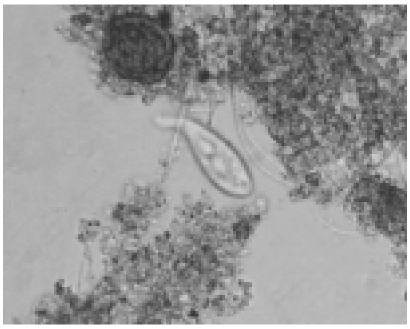

图 8 漫游虫

Fig.8 Lionotus

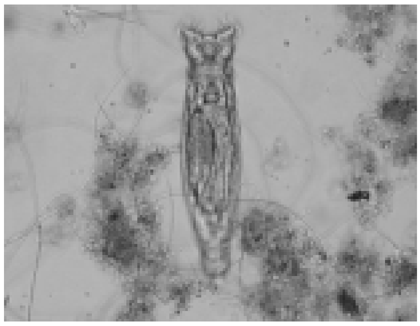

图 9 轮虫

Fig.9 Rotifer

4 ICAST 反应池中的优势微型生物

在间歇运行方式时，ICAST 反应池中经常观测到的微型生物有：湖累枝虫（Epistylis lacustris），树状聚缩虫（Zoothamnium arbuscula），水虱伪独缩虫（Pseudocarchesium aselli），瓶累枝虫（Epistylis urceolata），圆筒盖虫（Opercularia cylindrata），白钟虫（Vorticella alba），转轮虫（Rotaria rotatoria），小口钟虫（Vorticella microstoma）等。

由间歇运行改为连续运行方式时，待运行大约二周后出水较稳定，这时反应池中经常观测到的微生物有：湖累枝虫（Epistylis lacustris），彩盖虫（Opercularia phryganeae），薄漫游虫（Litonotus lamella），瓶累枝虫（Epistylis rotans），白钟虫（Vorticella alba），八钟虫（Vorticella octava），杯钟虫（Vorticella cupifera），圆筒盖虫（Opercularia cylindrata）等。

从以上微生物种类可以看出，处于正常运行的 ICAST 反应池中，生物的种类会变得比较单纯，主要以有柄的纤毛虫占优势，这与文献[2,3]获得的结论相一致。

5 微型生物在 ICAST 反应池中的指导作用

在整个污水回用处理过程中，微型生物特别是原生动物状态好坏起着至关重要的作用，活性污泥中的生物相在通常情况下是比较稳定的，但当外界条件或工况突然发生改变时，原生动物的种属和数量以及菌胶团的结构也将随之发生变化。通过微型动物的生物指示特性，可以对处理工艺起到定性的指导作用。

5.1 对出水水质的指导作用

ICAST 反应池处于正常运行中，除定期对出水进行监测之外，还应以微型生物的镜检情况，判断活性污泥净化污水的效能。通过观测 ICAST 反应池内活性污泥的生物相，发现：活性污泥系统中，以固着型的纤毛虫为主且具有较好的活性时，活性污泥易成絮体，沉降性能好，出水较清澈，悬浮物质少，水质良好；同时，通过观测有柄的纤毛虫数量，以及有柄纤毛虫占整个原生动物的百分比，都可预测出水的 BOD_5，方法十分简单，只要能认出纤毛虫是否有柄，无需做进一步的分辨；若有柄纤毛虫的数量突然下降，则出水 BOD_5 会出现波动，这时应立即追查事故原因以求尽快解决问题。

Gurds 等人通过在多家活性污泥曝气池中进行的调查，找出了原生动物种类的组成与排水水质之间的关系，在系统的运行中，只要观察原生动物构成情况就可大致预测出水的 BOD_5 值[2~4]，

Al-shahwani 等人通过回归分析法建立了出水水质和原生动物种群和数量的数学模型[5]，Madoni 等人列出了 19 种原生动物与 BOD_5、NH_3-N，NO_3^--N，MLSS、DO、SVI、SRT 等的对照关系[6]。这些结论与上述本文试验镜检状况相一致。

5.2 对工况的指导作用

当由于设备故障或其他因素导致工况突然发生不正常的变化时，污泥中的原生动物和后生动物的活性会受到不同程度的抑制。由于是处理生活污水，一般不含有毒物质，且 pH 值也不存在较大的波动，故对处理效果影响较大的是进水浓度、进水水量、温度和溶解氧的变化。通过镜检发现：原生动物和后生动物的活动会明显减少，钟虫等固着型纤毛类微型动物口缘纤毛会停止摆动，虫体收缩；正常运行时，钟虫靠体内伸缩泡的定期收缩把吞入体内的多余水分不断排除体外，以维持体内的水分平衡，但若反应池内的溶解氧 DO 浓度降至 1 mg/L 以下时，伸缩泡就会处于舒张状态，不再活动，有时钟虫还会脱去尾部的柄，在虫体的顶端还会突起一个体积和自身体积大致相当的空泡（图 10），从而导致虫体死亡，同时污泥中后生动物的线虫数量会突然增加（图 11）。

图 10 钟虫头顶空泡

Fig.10 Vorticella with low dissolved oxygen

图 11 线虫

Fig.11 Nemato

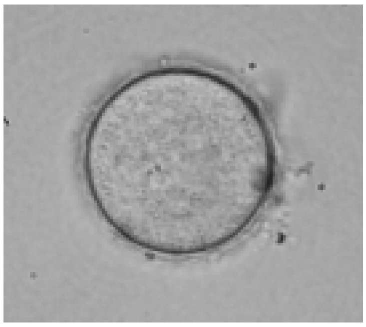

图 12 胞囊

Fig.12 Cyst

当不利的工况在一段时间内得不到有效改善时，原生动物会由于无法进行正常的新陈代谢致使虫体变圆，鞭毛、纤毛或伪足等细胞器缩入体内或消失，细胞水分陆续由伸缩泡排出，虫体缩小，最后伸缩泡消失，分泌出胶状的物质于体表凝固后形成胞壳，最终形成“胞囊（cyst）”（图 12），以渡过不良的环境。此时，活性污泥可能出现解体，导致絮体变小，甚至出现恶化的现象，出水水质会出现恶化。一旦工况恢复正常，其胞壳就会破裂并恢复虫体的原形，活性污泥的性能也会逐渐改善。

因此，若保持污水回用处理装置经济高效运行，则应避免由于活性污泥中微生物生态的长期失衡导致处理装置无法正常运行。

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建筑水循环安全保障的综合考虑

——“降低建筑水耗的综合关键技术研究”课题介绍

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摘　要　本文作者负责“绿色建筑关键技术研究”项目中“降低建筑水耗的综合关键技术研究”课题的研究。课题目的在于针对绿色建筑的水资源可持续利用这一主题，从水量安全与水质安全两个基本方面，围绕我国目前急需的水循环安全保障综合性策略与技术集成及急需突破的单项技术，就非传统水源、供排水体制、非传统水源的水处理工艺以及节水技术进行全方位的研究开发。具体研究内容包括：绿色建筑水循环安全保障综合性技术、湿地-水体复合生态系统水质净化专项研究、节水技术与节水器具专项研究。该课题组针对目前绿色建筑关注的热点主要是绿色建材的应用与能耗的降低，而对于水的综合利用及水的大循环概念缺乏统筹考虑的状况，提出在住宅建筑中建立水的大循环的概念，即：将各种可能的传统水源与非传统水源，如市政供水、再生水、雨水、海水等，列入统筹考虑范围；在水安全保障方面，将研究内容锁定在水量与水质两个基本点上，着重从这两个方面进行水循环安全保障的系统规划。

关键词　绿色建筑；水循环；安全保障；水质安全；水量安全；评估指标；再生水；雨水；海水

1　前言

水是人类生存和经济社会发展的生命线，是实现经济可持续发展的重要物质基础，缺水已是一个世界性的问题，水资源问题已成为全人类关注的话题。我国是世界上严重缺水的 12 个国家和地区之一，只有世界人均占有量的四分之一，水资源短缺已严重制约了我国的经济发展。“国民经济和社会发展第十个五年计划纲要”明确规定：重视水资源的可持续利用，坚持开展人工增雨、污水处理回用、海水淡化。

随着人口的增加、城市化与工业化程度的提高，水资源短缺问题日益突出，从不同的方面影响着人们的健康生活；同时随着经济的发展、生活水平的提高，对居住区提出了更高的要求，从追求片面的建筑空间转化到追求以山系、水系、绿系为主的生态复合共享空间。建筑消耗了近四分之一的净水，绿色建筑应把排放污水的减量化、无害化、资源化作为追求目标之一，以保护自然界珍贵的水资源；在住宅建筑中建立水循环的概念，统筹考虑市政供水、再生水、雨水、海水等传统水源与非传统水源，进行系统的规划与设计。

目前我国在围绕绿色建筑的一系列有关水资源循环利用的安全问题上尚缺乏系统的规划、设计、运行、管理的经验总结，远不能满足建筑业市场的需要。因此结合现有的示范工程和工程实例，参考国内外相关工程的经验，根据不同的地域条件和住宅建筑水的综合利用途径，制定适合绿色建筑的水循环安全保障的综合性的控制策略、规划，提出相应的成套处理工艺技术、工程实施方案与

管理措施，对我国如何降低住宅建筑中的水耗，实现人与自然的和谐共生，实现真正意义上的绿色建筑是十分必要的。

人工水体系统是绿色建筑体系的重要组成部分，它在为小区居民营造一个良好的多自然型环境的同时，也给居民提供了一个亲自然、亲水空间，对提高小区居民的生活质量，提升小区的品位有重要的作用。利用雨水和再生水作为住宅建筑人工水体的补充水源在节约水资源的同时还可以处理雨水地表径流带来的面污染源负荷，是今后发展趋势，对节约水资源，保护城市水环境质量具有重要的意义。由于建筑区内人工水体富营养化现象对景观价值的严重影响，以及因此衍生出来的卫生问题直接威胁了人身安全，因此研究开发经济、高效的人工水体水质净化和水华控制技术成为重要的课题。

在水资源供需矛盾日益尖锐的今天，只有坚持开源与节流并举、把节流放在首位的方针，才有可能实现可持续发展的长期目标。冲厕用水占建筑生活用水的三分之一，因此，以削减冲厕用水为核心，研究开发新的节水技术与节水器具对于实现绿色建筑的节水目标具有非常现实的意义。

2 国内外技术现状和发展趋势

2.1 国外进展

为了促进住宅建筑的可持续发展，在八十年代，发达国家就组织起来，共同探索这一问题，如："绿色建筑挑战"行动，美国绿色生态理事会、德国兰色天使标识等。各种类型的绿色生态建筑及绿色建材在世界各国风行涌现，很多国家的政府为了极大地推动绿色生态住宅的发展，研究、制定了相应的技术评估和产品认证体系。如美国绿色建筑理事会颁布的《绿色建筑评估体系（第二版）》和《国家康居示范工程建设技术要点》、《商品住宅性能评定方法和指标体系》。在日、美、欧这些发达国家，绿色建筑、生态建筑和可持续城市的理念已深入人心并融入实践。

日本城市的高层建筑大都采用了中水道技术，要求具有一定规模的宾馆、机关、院校或住宅小区，将生活污水处理后，作为市政用水和生活杂用水。如 60 层的三菱公司大楼，楼内设有饮用水和非饮用水两套管路，洗菜或盥洗用过的水经过处理后送入非饮用水管路，作为冲洗厕所、清洗汽车、冷却水或暖气用水等。

飞利浦梅林环境中心位于美国马里兰州首府安纳波利斯，雨水可以通过屋顶流入储水箱以满足灌溉之需，参观过这里的人都会对其极具环境亲和力的风车房式建筑留下深刻印象。

西班牙玛捷卡市的城市设计是可持续城市设计的一个典型例子。由于该地区为地中海式气候，夏季缺少降水，因而设计中首先考虑建造储水设施，收集 10%左右的冬季季节性洪水，以满足夏季饮水和灌溉需要。储水池设置依地形设在不同的标高点上，利用重力进行自流灌溉而避免使用水泵。

2.2 国内进展

总体而言，目前我国城市水的综合利用程度较低，安全保障措施不够过关。近几年发展了一批具有绿色建筑特点的生态小区，其关注的热点主要是绿色建材的应用与能耗的降低，诸如如何有效地解决采暖和消暑，如何使用各种各样的新材料如无污染涂料以及可降低热辐射的特制玻璃窗材料等问题；而对于水的综合利用及水的大循环概念缺乏统筹考虑，并没有真正地将各种可能的传统水

源与非传统水源纳入到综合利用中，在水质水量的安全保障方面缺乏系统的规划。但从发达国家发展的轨迹中可以看出，在住宅小区中建立水的大循环概念，市政供水、再生水、雨水、海水等，均要统一列入考虑范围，进行系统优化设计已成为绿色建筑发展的必然趋势。

近年来，以水生/湿生植物为主体的生态工程技术，特别是人工湿地技术在小型人工水体富营养化防治和水华现象控制方面的应用得到了广泛的关注。人工湿地系统能有效地去除水体中的氮、磷等营养物质，防止富营养化的产生，同时具有运行费用低、易管理等特点。人工湿地系统还可以营造一个半自然空间，具有美化、绿化建筑小区的作用。因此，景观型人工湿地系统的开发成为水环境领域的一个重要方向。在我国正在实施的重大科技专项 “水污染控制技术与治理工程”中，人工湿地技术作为水质净化的高效技术，被广泛地应用于河流、湖泊、地表径流、城市污水再生处理示范工程。

冲厕用水在住宅建筑用水中占有很大比例，成为节水的关键途径之一。目前国内外所用的坐便器在结构上一般为冲落式或虹吸式，由于采用存水弯式的水封，所以冲水阻力大、用水量大，一般冲水量为 6～12 升，现有节水型坐便器的节水性能已近极限，据统计，大约有 30%的生活用水通过坐便器变成了污水。所以追求外形美观，使用舒适、方便，在结构和材料上满足节水、节能、环保要求的节水器具是发展趋势。

3 “水”课题的研究内容

从水资源角度看，目前我国对资源再生利用重视不够，利用效率不高，首先表现在缺乏适合于中国国情的绿色建筑水环境发展战略与技术政策，不能够形成全国一盘棋；其次，现阶段所研究的绿色建筑技术仅仅局限在几个领域，没有形成全面的、系统的研究框架和具体的研究内容，未能形成具有实践指导作用的规划设计导则和评估体系；由于我国绿色建筑研究起步较晚，积累不够、基础较为薄弱，与发达国家相比较，存在较大的差距；此外没有绿色建筑相关技术的测试、试验平台，在绿色建筑建设上还缺乏成熟的经验。

本课题目的在于针对绿色建筑的水资源可持续利用这一主题，从水量安全与水质安全两个基本方面，围绕我国目前急需的水循环安全保障综合性策略与技术集成及急需突破的单项技术，针对非传统水源、供排水体制、非传统水源的水处理工艺以及节水技术进行全方位的研究开发。具体研究内容包括：绿色建筑水循环安全保障综合性技术、湿地-水体复合生态系统水质净化专项研究、节水技术与节水器具专项研究。

3.1 绿色建筑水循环安全保障综合性技术

该子课题针对目前绿色建筑对于水的大循环概念缺乏统筹考虑的状况，提出在住宅建筑中建立水的大循环的概念，即：将各种可能的传统水源与非传统水源，如市政供水、再生水、雨水、海水等，列入统筹考虑范围；在水安全保障方面，将研究内容锁定在水量与水质基本点上，着重从水量与水质安全保障两个方面进行系统的规划。该子课题将包括可供水源综合利用的潜力研究、供排水体制研究、水处理、再生工艺路线研究、水量安全保障策略研究、水质安全保障技术研究和水循环安全保障的综合性技术研究 6 个方面。

针对富水与缺水两种基本情况，研究包括市政供水、再生水、雨水在内的各种供水水源的水质、

水量特征及其综合利用的可能性，结合不同的用水途径，以水量安全保障为目的进行住宅建筑水环境的合理规划，提出适合不同地域生态、不同自然条件、不同水资源状况的绿色建筑水循环的规划、设计与工程实施的经济适用的方案；

跟踪示范工程，结合相关工程与资料调研，分析比较集中与分质供排水系统的适用性，对现有的水处理、储存、再生、消毒工艺进行归纳、总结，针对洗涤、冲厕、绿化、景观环境等不同的用水途径，以水质安全为目的研究各种不同的处理、再生与消毒工艺组合与集成，提出以水质安全为目的、经济适用的成套工艺技术；

以水量、水质安全保障为核心，围绕“开源”与“节流”提出适合绿色建筑的水循环安全的综合性控制策略和技术集成，最后形成推荐性评估体系，为我国如何在绿色建筑中降低水耗，合理实现人与自然的和谐共生提供技术借鉴。

3.2 湿地-水体复合生态系统水质净化专项研究

在水生/湿生植物优选和高效除磷抑藻复合填料开发的基础上，开发景观型人工湿地系统的构建技术，实现高效除磷和抑藻的效果，保证人工水体的水质；以北京地区示范工程为依托，借鉴其他地区的工程实践，研究湿地系统的水质净化效果及其季节性变化规律；在此基础上提出景观型人工湿地水质净化成套技术，用于以雨水和再生水为主要水源的绿色建筑人工水体的水质净化与水华控制；提出绿色建筑景观型人工湿地及人工水体水质净化系统的设计与运行指南。

3.3 节水技术与节水器具专项研究

以降低占生活用水三分之一的冲厕用水为目标，以坐便器新型直排节水技术为核心，研究开发适于绿色建筑的新型节水技术与节水器具。结合实际工程，研究开发浮球式水阀的替代品，解决坐便器的漏水问题，省去水箱以降低坐便器的成本和占用空间；解决存水弯造成的坐便器用水量过大的问题，达到节水、节能、保护资源和环境的目的，实现节水率在 50%以上（与现有节水型坐便器相比）的目标。

4 经济、社会与环境效益分析

2000 年初我国城镇化率已达 30%左右，预计到在今后 20～30 年内需达到 50%～60%，即每年有 1200 万人口由农村进入城镇。以每人居住 10 平方米计，则需建房一亿两千万平方米。以平均每平方米造价 300～400 元计，则仅建筑住宅一项即可持续每年拉动经济 360～480 亿元。在这样一个生态环境十分脆弱的国家进行如此大规模的住宅建设，必须走可持续发展之路，城市化必须坚持以建造绿色建筑为主题。

我国的水资源非常紧张，住宅建筑中的绿化、洗车、冲厕等用水如以非传统水源替代，则可节约自来水的 2/3。而目前绿色建筑中“水”的概念模糊、认识混乱，亟需从技术、经济、环境、能源及社会的角度加以规范，提出成套客观、科学的水循环安全保障的综合控制策略与技术，更好地引导“绿色建筑”建设的进行。因此绿色建筑水安全综合保障策略与技术的研究成果具有显著的经济、社会与环境效益，其竞争力是不言而喻的，成果应用也将具有良好的市场前景。

湿地－水体复合生态系统和节水专项技术的开发是绿色建筑水循环的重要组成，在技术上有独到之处，具有很强的竞争力和广阔的市场前景；以雨水和再生水为补充水源的湿地－水体复合生态

水质净化技术，在保证亲水空间、提高居民生活质量的同时，还能达到节约水资源和减少污染负荷的作用，是一举两得的措施；以节水型坐便器为核心的节水专项技术可大幅度削减生活用水占 30 %的冲厕用水，因此具有显著的经济、社会与环境效益。

5 结语

随着城市需水量的增大和实际可供利用量逐步减少的矛盾的加剧，降低水耗已是大势所趋。国家已逐步完善了污水再生利用方面的相关法规与标准，鼓励利用再生水。作为住宅建筑，充分综合利用各种水资源，特别是再生水，而且与周围的生态环境有机结合在一起，已是小区建设发展的趋势。可以预见，随着“ 绿色建筑 ”水研究的进展、国家相关政策的完善及各级政府的支持，建筑水循环安全问题将会从根本上得到保障，“ 绿色建筑 ” 在我国将具有光明的前景

屋顶绿化研究进展

——上海屋顶花园概论

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摘　要　本文详细分析了屋顶绿化的生态效益，探讨了屋顶绿化在设计中应注意的问题。通过对屋顶绿化特点的研究，提出了选择屋顶绿化植物和栽培基质的原则，并对坡屋顶绿化技术进行了初探。
关键词　屋顶绿化；生态效益；植物；栽培基质；绿化技术

绿色植物是人类赖以生存和发展的必不可少的条件，绿色植物与人类互为补充、互为依存达到一个生态平衡。随着现代社会的工业化进程日益加快，城市人口密集，废气污染、尘埃飞扬、噪声扰人、“ 热岛效应 ” 等，大都市环境日益恶化，严重损害都市人的身心健康。由此可见，改善日益恶化的城市生态环境，已成为当今城市问题的当务之急[1，4]。

最早的屋顶花园是 2500 多年前建在幼发拉底河岸的巴比伦空中花园。自上世纪初，英国、美国、德国、日本等国家建造了大量的屋顶花园[5，6，8]。1959 年美国建成的具有高技术含量的奥克兰市凯泽中心屋顶花园，被认为是现代屋顶花园发展史上的一个里程碑。随着建筑工程技术的不断进步、发展，越来越多的新型建筑材料的开发与应用，使得屋顶花园的建造变得更加轻而易举。

二十世纪 60 年代初，重庆、成都开始出现屋顶花园，至 80 年代末，成都市中心有 200 多座商住楼屋面绿化率达 72%；珠海、深圳都重视美化屋顶，提出“美化建筑第五面”。近年来，上海为了改善城市环境，绿地建设突飞猛进。由于上海是寸土寸金的国际化大都市，兴建绿地的拆迁成本昂贵，市中心每增添 1 平方米的绿地就要付出上万元的代价，导致地面绿化的增长空间非常有限。上海共有 2 亿平方米的屋顶面积，到 2002 年底，申城屋顶绿化面积只有 22.29 万平方米，仅利用了 0.11%的屋顶进行绿化，至今依然是大片的“空中荒漠”[7]。研究表明粗放型屋顶绿化每平方米的造价在 350 元左右，与同等级的地面绿地相差不多，而且屋顶草坪养护费用极低。因此，在不占用土地的情况下，屋顶绿化是改善上海城市环境的最佳方法。

1　屋顶绿化的生态效益

随着人类社会的进步和城市化的发展，人们对生活环境的要求也越来越高。一座现代化的城市不仅应有完美的建筑与设施，还应有一个优美的环境以消除疲劳、陶冶身心，而优美环境的最主要组成部分是绿色植物[2]。据了解，植物能够调节人的神经系统，使紧张疲劳得以缓和消除，使激动情绪恢复平静。从景观角度看，屋顶作为建筑的第五立面，是城市建设与美化过程中不可忽视的环节。屋顶花园是可以让人走进去的花园，对都市人的心理调节大有益处。屋顶绿化作为一种不占用地面土地的绿化形式，其生态效应也非常广泛。

1.补偿作用[9，13]。国际生态和环境组织调查指出：要使城市获得最佳环境，人均占有绿地面积

需达到 60m^2 以上[8.15]，而统计表明上海现有人均绿地面积仅为 9.16m^2。上海地价昂贵，建筑密度高，道路密集，高架路、立交桥纵横交错，城内地面大多是人工化的硬质铺地。如果能充分利用建筑物的屋顶、露台进行绿化，就可以大大提高人均绿地面积，起到很好的补偿作用。

2.涵养水土[9, 13]。城市中建筑林立，提供给人们户外活动的开敞空间多是硬质铺地，雨水无法被土壤所涵养、储存，必须急速地由下水道排放。若遇到排水系统受阻的情况，则会造成一雨成灾[13]。而屋顶绿化可适当缓解这种状况，因其表面的植物、土壤有利于雨水的储存，落到屋顶的雨水仅有１/３排出，２/３被留在屋面上或蒸发到空气中，从而调节了小气候。屋顶绿化可以减缓温度剧烈变化，使建筑物内部冬暖夏凉，形成舒适的人居环境[17]。

3.增加空气湿度[9, 13]。由于绿色植物的蒸腾作用和土壤的蒸发会使绿化屋面的水蒸气含量增加，致使绿化屋面空气绝对湿度增加。加上绿化后其温度有所降低，故其相对湿度增加更为明显。可见，屋面绿化对城市的“ 干岛 ”有减弱作用。

4.降低气温[9, 13]。屋顶绿化还可以改善住宅的室内气温，对改善人居环境及节能大有好处。据测算有绿化的屋面温度可下降 3-5℃，室内空调可节电 20%[2]。况且绿地生态效应的有效辐射距离是 50m，因此利用住宅建筑屋面布置绿化，更是十分珍贵。由于绿色屋面对阳光的反射率比深色水泥屋面大，加上绿色植物的遮阳作用和为满足生理所需的同化作用，使绿色屋顶的净辐射热量远小于未绿化的屋顶。同时，绿色屋顶因植物的蒸腾和潮湿土壤的蒸发作用消耗的潜热明显比未绿化的屋面大，导致绿色屋顶面的贮热量减少，绿化屋顶空气获得的热量也减少，热效应降低，从而减弱了城市的“ 热岛 ”效应。

5.形成生物气候缓冲带。屋顶花园涵养充分的水土能形成人工建筑与自然之间的生物气候缓冲带，为建筑系统提供良好的微气候环境，尽量满足居民的各种生活舒适标准；提高建筑系统生物组成的多样性，为鸟语花香提供现实的土壤，实现人与自然的和谐共处。

6.净化空气、降低噪音。一个人每天要吸收 0.75 公斤氧气，呼出 0.9 公斤二氧化碳，而自然界中唯一能制造氧气是植物的光合作用，由此推算出每人至少要拥有 10-15 平方米森林或 25-30 平方米草坪才能获得足够的新鲜空气。加上工业、交通运输的耗氧量远远大于人，这就要求拥有更多的人均绿地才能满足空气成分平衡的需要。植物还能吸收人类生产活动过程中产生大量废气如 NOx、SO_2 等有害气体和滞留灰尘微粒等。据估算，如果大城市 1%的建筑物建成屋顶花园，则城市大气中二氧化碳和硫化物可减少一半。一个城市如果把屋顶都利用起来进行绿化，那么这个城市中的 CO_2 较之没有绿化前要少 85%[16]。因此屋顶花园可降低空气中的 CO_2 浓度和飘尘含量，提高大气中氧浓度，清新空气。绿色植物除了可以减轻大气污染，还可以阻挡、吸收、滞留和过滤空气中的噪声，减轻城市噪声污染，对改善和保护城市环境很有益处。

7.有效保护屋顶、延长建筑物寿命[15]。由于夏冬温差大和干燥收缩产生屋面板体积的变化，夏季高温易引起沥青流淌和卷材层下滑，可使屋面丧失防水功能。另外，屋面在紫外线的照射下，随着时间的增加，会引起沥青材料及其它密封材料老化，使屋面寿命减短。而屋顶绿化使屋面和大气

隔离开来，屋面内外表面的温度波动小，减小了由于温度应力而产生裂缝的可能性。隔阻了空气，使屋面不直接接受太阳光的直射，延长了各种密封材料的老化，增加了屋面的使用寿命。

8.减缓风速、调节风向。屋面绿化，增加了屋顶粗糙度，增大摩擦使风速减少，同时也使风向发生偏转。另外，由于绿地降温消弱了“热岛”效应，从而也在一定程度上减弱了“热岛环流”，减小了风速。

9.影响云、雾和降水。城市人口密集，工业集中，能耗大，废气、废渣和废水排放多，凝结核充沛。再加上“热岛环流”的作用，使城区的云、雾和降水比郊区多，具有“雾岛”和“雨岛”特征。城市平顶屋面绿化后，对云、雾和降水的影响视不同的情况而异。当前者的影响大于后者时，则云、雾和降水减少，反之增加。而这两种不同的影响又取决于城市的具体情况(如城市性质、规模、布局、密度、绿被率等)。

由此可见，如果能很好地利用和推广屋顶绿化，形成城市的空中绿化系统，对城市环境的改善作用是不可估量的。

2 屋顶绿化的设计

整个屋顶绿化层包括保温隔热层、防水层、排水层、过滤层、栽培基质层、植物层等[20]。

1.保温隔热层可采用聚苯乙烯泡沫板，铺设时要注意上下找平密接。

2.防水层采用柔性(油毡卷材)防水层、刚性防水层或新材料(如三元乙丙防水布等)，但目前使用最多的是柔性防水层，如高弹性防水涂料，防水性能好，使用寿命长；国外还有采用硬塑料做防水层的实例[27]。屋顶绿化后，防水层应绝对避免出现渗漏现象，最好设计成复合防水层[24]。在柔性防水层与防根系保护层之间应加设隔离层，隔离层可用中性材料[17]。

3.排水层(蓄水层)设在防水层上，过滤层之下。其作用是排除上层积水和过滤水，但又储存部分水分供植物生长之用[17，21，31]。可与屋顶雨水管道相结合，将过多水分排出，以减轻防水层的负担。排水系统由排水层、排水管、排水口、排水沟等组成。小面积屋顶花园，一般通过屋顶坡度外排水方式排水；面积较大的屋顶花园要采用较大管径的排水管来排水，以免积水而造成植物烂根。灌溉系统有人工浇灌、自动喷灌、低压滴灌等多种，所用管道应是轻质管如塑料管[17]。可用材料主要有陶粒(100k-200mm 厚)、砾石(100k-200mm 厚)、焦碴(50mm 厚)和疏水板等轻质材料[21]。

4.为防止种植土中小颗粒及养料随水而流失，且堵塞排水管道，需在种植基质层下铺设过滤层。过滤层采用稻草层、玻璃纤维布或粗沙层(50mm 厚)、炉碴层、玻璃纤维布、稻草(30mm 厚)，所要达到的质量要求是：既可通畅排灌又可防止颗料渗漏。

5.种植层一般多采用无土基质，以蛭石、珍珠岩、泥炭、草炭土等轻质材料配制而成。

屋顶花园的设计应服从于建筑设计[17，20]。设计屋顶花园前，首先要了解建筑的结构类型，如砖木结构、钢结构屋面是不允许建屋顶花园的。混合结构的平屋面、混凝土结构的平屋面、坡屋面才允许建造屋顶花园。同时园林设计人员也要把屋顶花园设计提供给建筑、结构、水电设计人员，使园林设计的特殊要求能够在房屋设计中得到综合处理，完美结合。园林工程的一切预埋件、排水

孔、水管电缆预埋，必须与屋面工程施工一同进行，尽量避免二次浇注，造成屋面渗漏的隐患。

安全问题是屋顶花园成败的关键，其中屋顶的荷载校核与屋面的防水安全是屋顶花园建设的关键性因素[17，20，28，32]。安全应贯穿屋顶花园造园的全过程，使设计出来的屋顶花园对整个房屋建筑传力明确，结构体系达到安全、经济、合理。绿化屋顶结构增加的附加荷载，包括植物生长层、排水层等自重；植物生长后的重量；以及上人荷载。屋面假山、水池的设置，高大乔木的种植及土坡造型的整理，亭、廊、花架等小型建筑原则上都应尽量地规划到承重的梁、柱、墙上，使荷载合理分散，同时防止植物根系损害屋面防水层。

针对某一层次的特定群体，确定设计风格，并使其贯穿始终，确保某种特定内涵和品位[21，23]。根据屋顶花园的大小，合理的设置活动区域、场地及设施的位置和空间大小，使之符合人的行为模式，以方便使用者的使用。因“顶”制宜，在园路的组织、建筑小品的位置与尺度、地形的处理及植物的选择等方面，以精美为特色[28]。适当利用“障景”、“对景”等手法，达到小中见大，意犹未尽的视觉、感官效果。由于屋顶高层变化甚微，充分利用台阶、水池、花台、堆土等进行竖向设计，形成微小的地形变化，丰富造园层次。植物配置宜选用小乔木、灌木、花草等，构成层次丰富、四季变化的景观[21]。注重选择建筑周围、屋顶花园以外的景观，“佳则收之”、“俗则屏之”，用“借景”手法使其内外结合、融为一体。利用景墙装饰、植物、山石、小品遮挡的方法，对屋顶花园周边的女儿墙进行淡化处理，使人感到亲切、自然。

3　屋顶绿化的类型

屋面绿化的布置形式，可以说是多种多样，主要依据业主的要求来设计[19，21]。一般屋顶花园的建设形式分为三种：一是地毯式屋顶绿化，即在建筑负载能力较差层面上先在屋顶铺一层整块滤水板，再加上一层无纺布，然后在上面覆盖相适应的薄土层，种植屋顶草皮和地被植物，形成地毯式成片布置。二是花园式，多用于服务性建筑物如宾馆、酒楼等，能为客人提供游憩空间。花园式屋顶绿化可做成小游园的形式服务于游人，小游园应有适当起伏的地貌，配以小型亭、花架等园林建筑小品，并点缀以山石。有的可以采取现代的手法，用草坪、地被植物组成流畅的图案，其中点缀小水池、小喷泉及雕塑，使之充满时代气息；也可以采取自然的手法，以草坪为基底，根据生态群落组织植物景观，加假山、置石等小品，使之充满温馨情趣；也可以利用植物、花草、树木精心培育修剪成姿态各异、气韵生动的艺术形象。三是组合式屋顶花园，即沿屋顶有墙角和承重墙的地方，通过盆栽和缸栽组合成一个别具一格的屋顶花园。

4　屋顶绿化的特点

屋顶位于空中，与大地不再相连，使其生境与地面差别很大，其对绿化有利的因素有[20]：

（1）与地面相比，屋顶处光照强度大、光照时间长，有利于促进植物光合作用。

（2）受建筑的影响，屋顶吸热快，散热快，昼夜温差大，有利于植物的营养积累，也有利于植物的生长。

（3）屋顶上气流通畅清新，污染明显减少，受外界影响小；相对隔离，病虫害不易传播，有

利于园内病虫害防治，有利于植物的生长和保护。

不利因素有[20]：

（1）湿度条件差。因屋顶位于高处，四周相对空旷，风速比地面大，水分蒸发快。

（2）土温、气温变化较大，对植物生长不利。

（3）屋顶风力一般比地面大。

（4）和地面相比，屋顶花园增加了承重和防水投资，施工和养护的困难和投资也加大。

（5）对造园及植物选择有一定的局限性。因屋顶承重能力的限制，因此在设计时应避免地貌高差过大，在植物的选择上一般应避免采用深根系或生长迅速的高大乔木。边界规整屋顶形状一般为规则的几何形状且多重复出现，设计时应注意协调统一又富于变化，形成韵律。

5 屋顶绿化植物与栽培基质的选择

根据屋顶特殊生境的特点，选择喜光、耐旱、耐寒、耐贫瘠、抗风、根系浅并且水平根发达、生长缓慢、姿态优美、低矮的植物，如小乔木、花灌木和球根花卉及竹类、草坪等[20，33，36]，尤其以乡土植被为佳，这样可降低养护费。移栽的小乔木、花灌木最好是“熟活”植物，其根系抱土紧密，存活率高。因为荷载过重，深根系乔木在住宅建筑屋面一般不被考虑。考虑到土层较薄、楼顶风力大等因素，屋顶绿化植物高度应不超过 2.5 米，种植后最好能保持“两到三季常绿”。 表 1 是常用屋顶绿化材料[20，33，36]。

在实施经济粗放型屋顶绿化工程时，可以选择一些较矮植株。它们繁殖能力强、扩张速度快、有良好的耐旱性，无须过多灌溉、施肥以及修剪处理，又具备减低噪音、减小污染等功能。如狼牙草[15]，叶丛低矮、整齐均匀、适应性强，覆盖面可达 90%以上；与杂草竞争能力强，生长迅速，易繁殖；能抗寒、抗风、耐旱、耐瘠薄、耐盐碱、抗二氧化硫等污染气体以及能在粉尘、飘尘等严重危害的环境中照常生长；对光照不敏感，在蔽荫度大的乔木下绿化效果也较好。佛甲草需要的土层薄，重量很轻，不会影响屋顶结构且有耐干旱、抗严寒、四季常绿、管理粗放的特点，是屋顶绿化较理想的植物材料。

为使植物生长良好，又尽量减轻屋顶的附加荷载，种植土一般不采用普通的土壤，而是采用含各种植物生长所需元素，又比自然土壤容重更小的介质材料。如以泥炭、堆腐的木屑、谷壳、蛭石、膨胀珍珠岩、粉煤灰等配制的栽培基质，容重控制在 1000～1500ｋｇ/m^3。对于荷载能力差的屋顶绿化，目前还可以采用无土草坪技术，用织物加多种营养物质形成培养基质，同时加入保水剂，减少浇水次数和浇水量，一举多得。在选择栽培基质时，尽量减少栽培基质更换次数，厚度要控制在最低限度，尽可能减少荷载。屋顶花园绿化植物正常生长要求的最小土层厚度分别为：草坪土层厚度为 10-15cm，低矮的草花需 20-30cm，灌木需 40-50cm，小乔木需 65-70cm[19]。

6 坡屋顶的绿化

为使住宅建筑屋面形式多样化，对住宅建筑屋面采取“坡屋面”及各种变形体等传统或

表 1　常用屋顶绿化材料[20，33，36]

k	名称	拉丁文	k	名称	拉丁文
草坪植物	结缕草	Zoysia japonica	观果	木通	Akebia quinata
	野牛草	Buchloe dactyloides		枸杞	Lycium chinense
	狗牙根	Cynodon dactylon	攀援植物	爬山虎	Parthenocissus tricuspidata
	麦冬草	Ophiopogon japonica		木香	Rosa banksiae
花灌木	月季	Rosa chinensis		紫藤	Wisteria sinensis
	山茶	Camellia japonica		金银花	Lonicera gaponica
	牡丹	Paeonia suffruticosa		牵牛	Pharbitis indica
	火棘	Pyracantha fortuneana		茑萝	Quamoclit pennata
	连翘	Forsytia suspensa		凌霄	Campsis grandiflora
	海棠	Malus spectabilis		络石	Trachelospermum jasminoides
观花	葡萄月见草	Oenothera biennis		常春藤	Hedera nepalensis
	长春花	Catharanthus roseus		油麻藤	Mucuna sempervirens
	马缨丹	Lantana camara	宿根花卉	美人蕉	Canna indica
	萱草	Hemerocallis fulva		葱兰	Zephyranthes candida
	蝴蝶花	Iris japonica	绿篱	黄扬	Buxus sinica
	吉祥草	Reineckia carnea		冬青	Ilex purpurea
	石榴	Punica granatum		女贞	Ligustrum lucidum
观叶	佛甲草	Sedum lineare			
	沿阶草	Ophiopogon bodinieri	抗污染树种	无花果	Ficus carica
	垂盆草	Sedum sarmentosum		大叶黄扬	Buxus megistophylla
	铺地柏	Sabina procumbens		夹竹桃	Nerium indicum
	金边万年青	Rohdea japonica		柏	Cupressus funebris
	蜘蛛抱蛋	Aspidistra elatior		木槿	Hibiscus syriacus
	红桑	Morus rubra		玫瑰	Rosa rugosa
	肾蕨	Nephrolepis cordifolia		番石榴	Psidium guajava
	石菖蒲	Acorus gramineus		海桐	Pittosporum tobira
	花叶美人蕉	Canna generalis		桂花	Osmanthus fragrans
	锦熟黄杨	Buxus sempervirens			

现代的建筑艺术处理手法，这是美化城市景观的一个大进步。为了充分利用坡屋顶，使草皮和低矮的地被植物在倾斜的屋顶上易于固定，应采用一些特殊的措施。例如，在屋顶上铺设木条网格或带钩刺的塑料垫，或使用重量轻、安全性高、便于铺设的材料作为草坪的底层结构。屋顶安装防滑槛，檐口部位装上横梁，防止种植介质滑落[2]。

在坡屋顶的植物生长层中应渗入蓄水能力好的材料，而无须铺设排水层。在自然界中，有许多可以作为坡屋顶绿化用的材料。考虑其土层较薄，楼顶风力大等因素，应选择喜光、耐旱、耐贫瘠、生长缓慢、抗风、耐寒、低矮的浅根系植物，如草皮等。草坪最好采用移植的方法。在植物生长层中间还可以铺设一层塑料网，使植物的根可以很牢固地扎在生长层中。同时利用生态学原理，形成屋顶绿化多种群落结构，多种草类和多种草花相结合，让屋顶更美丽，更丰富多彩[15，22]。

在斜坡屋顶上应用屋顶绿化滴灌技术，可以减少上人荷载，减轻建筑负担，便于管理。采用微灌，还可调节屋顶的干热气候，降温增湿，对花卉增色效果较好[37]。由于采用小流量出流，不会形成土表径流，避免了土质板结，促进植物根系发育。

随着我国城市化的不断发展，混凝土“ 森林 ”愈来愈多，人类生存的环境日趋恶化。因此，现代化城市建设不但要充分利用边角露地，以“ 见缝插绿 ”的方式增加绿地，并且要充分利用多层建筑物屋顶，建设更多的现代化“ 空中花园 ”，为城市增加绿地，构筑优美的城市景观。

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聚焦建筑沙漠中的绿洲

——小议草地式屋顶绿化

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摘　要　介绍了草地式屋顶绿化的概念、特征。与群落式屋顶绿化相比，草地式屋顶绿化具有造价低、适于大面积推广等优点。简述了草地式屋顶绿化建植的技术要点，包括植物选择标准和常用种类。屋顶绿化具有为建筑节能，有效提高城市绿化率，改善建筑硬质景观等功能。
关键词　草地式屋顶绿化
中图分类号　TU986

Extensive Roof Garden — the Oasis in the Desert of Architectures

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Abstract: The article gave the definition and characters of the extensive roof greening. By comparison, extensive roof greening costs less to build than intensive roof greening. Extensive roof greening is more suitable for spreading in more roofs include slope roofs. The structure and the plants selection are the main points for attention when green the roof. The extensive roof greening can save energy for the building, raise the greening ratio of the city, and improving the architecture landscape.
Key words: extensive roof garden　　roof meadow

近年来，屋顶绿化这一概念频繁出现于生态建筑研究及世界各大城市绿地建设之中。屋顶绿化具有为建筑节能、改善环境质量、丰富建筑景观、提高城市绿地率等重要意义，这已被世人所肯定。然而目前在世界范围内屋顶绿化仍然以群落式为主，具有造价高、维护费用高等限制性不足，制约着屋顶绿化在城市上空的大面积发展。草地式屋顶绿化——一种造价低廉，功能有效的屋顶绿化形式便应运而生了。

1　草地式屋顶绿化的概念与特征

草地式屋顶绿化是在屋顶薄层基质上种植低矮草本植物，形成贴近屋顶表面植被层的屋顶绿化形式。

草地式屋顶绿化有以下几个特征：1.种植环境恶劣，表现于基质薄、排灌条件差、维护简易；2.植物选材低矮，以常绿草本和宿根草本植物为主，植株高度一般不超过 50cm；3.草地式景观，呈现为建筑绿色外衣，绿色植被层包裹建筑，如图 1，图 2。

图 1　上海市西中学

图 2　日本石川县金沢医科大学

根据植物材料的特征和景观特点，可将草地式屋顶绿化分为单一草种式和宿根花园式。单一草种式屋顶绿化指仅应用一种植物，形成单一植物草坪景观的绿化方式，常通过植生块的方式进行种植，如图 3。宿根花园式的屋顶绿化则是将多种低矮宿根植物以及其它草本植物进行合理配置，充分利用植物的季相变化和形态变化而建造的观赏性较强的屋顶绿化形式，目前多见于欧洲和北美洲及亚洲少数国家，如图 4。

图 3　上海第九百货公司

图 4　欧洲某住宅

2　草地式屋顶绿化与群落式屋顶绿化特征比较

群落式屋顶绿化是相对于草地式屋顶绿化的另外一种屋顶绿化形式，指在屋顶绿化中选用乔木、灌木、藤本等多种植物类型，通过设计配置，形成植物层次丰富、观赏性较强的屋顶绿化形式。目前中国国内及世界其它国家的屋顶绿化大都属于此类型。草地式屋顶绿化与群落式屋顶绿化特征相比如表 1。

表 1　草地式屋顶绿化与群落式屋顶绿化特征对照表

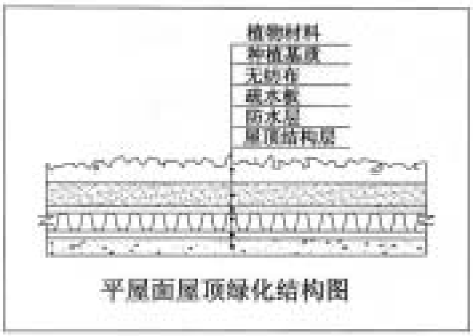
内容	草地式屋顶绿化	群落式屋顶绿化
优点	● 重量轻，屋顶一般不需特殊加固 ● 适于坡屋面及改造屋顶绿化 ● 不需要特别的灌溉系统 ● 建造成本与后期维护费用低 ● 植物可放任式生长，景观更接近于自然 ● 有效延长屋顶防水层使用寿命	● 可选择多种植物 ● 可模仿地面种植形式 ● 观赏性强 ● 可供休闲、种植或用来分隔空间 ● 为室内节能效率高，蓄水功能强 ● 有效延长屋顶防水层使用寿命
缺点	● 植物选择条件苛刻，数量有限 ● 一般不供作休闲 ● 为室内节能效率相对不高，蓄水功能相对较差	● 只能应用于平屋顶，对屋顶荷载较大 ● 系统复杂 ● 灌溉及排水系统能耗高，水及材料耗费量大 ● 建造成本高，维护费用高

从表 2 可以看出，两者在生态功能上有着相近的功效；在建造和维护费用以及其它配套设施的投资方面，草地式屋顶绿化则远远低于群落式绿化形式，而在满足景观需要与休闲功能方面，群落式屋顶绿化又有着绝对的优势。据估算，草地式屋顶绿化的造价可比群落式屋顶绿化少 50－60%，后期维护费用可少至 60－90%。由于草地式屋顶绿化能够应用于对荷载要求不高的旧式改造屋面和不能种植中大型木本植物的坡屋面上，这就决定了草地式屋顶绿化有着更强的大面积推广的价值。

3　建植技术要点

1．草地式屋顶绿化结构

不同形式的屋顶结构技术关键也有所不同，平屋顶由于排水坡度比较小，进行绿化时防水结构最为关键，一般都要特别设置排水系统；而对于坡屋面而言，由于坡度较大，在结构上则应注意基质的保持。现常采用的是槽式的疏水板和土工格室（图 5）。



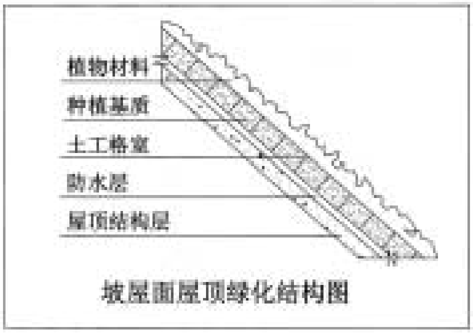


图 5　草地式屋顶绿化屋面结构图

2．植物选择

草地式屋顶绿化对植物选择有较高的要求，由于土层薄，且一般不配备专用的排灌设备，所以植物必须具有耐干旱、耐贫瘠等较强的综合抗性，详细标准见表 2。

在草地式屋顶绿化植物选择方面，欧洲国家一直走在前列，西班牙、德国、匈牙利等国在 20 世纪 70 年代末已相继就此课题开始进行研究，并选出了玉米石（*Sedum album*）、佛甲草（*S. lineare*）、垂盆草(*S. sarmentosum*)、匍匐筋骨草（*Ajuga reptans*）等以景天科植物和唇形科植物为主的多种屋顶绿化植物。日本是开发草地式屋顶绿化植物较早的亚洲国家之一，目前已经有近 40 种景天类及其它多肉植物在草地式屋顶绿化中应用。近年来中国上海、广州、厦门等城市也开始对草地式屋顶绿化进行研究，目前已有佛甲草及垂盆草等少数几种在小面积内得以应用。

表 2　草地式屋顶绿化植物选择标准

项　　目	标　　　准
抗　　性	● 综合适应性强，尤其是抗旱、抗寒、耐瘠薄性必须较好
生态习性	● 常绿草本与宿根草本最佳
形态要求	● 高度低于 50cm，以贴地面为主 ● 根系浅，穿透力不强 ● 地面覆盖能力强
其　　它	● 病虫害少，抗病虫害能力较强 ● 落叶少，易清除

4　草地式屋顶绿化的功能

1. 为建筑节能，改善室内温湿环境。

20 世纪 80 年代初人们就通过实测证明用植被覆盖建筑外表能达到良好的表面隔热效果。据测试：种植草坪屋顶比普通刚性防水屋面在中午时的温度可低至 6-8°C。植物通过蒸腾散热的直接结果是为建筑室内环境增湿降温，大大减少了空调耗能。

2. 有效偿还绿地面积。

在当今很多大中型城市里绿地常被作为一个弹性用地方式，随时被建筑和道路替代着，“ 建筑森林 ” 不如用 “ 建筑沙漠 ” 形容更为合适。寸土寸金的城市环境使得人们的目光不得不投向空中的屋顶。造价低廉的草地式屋顶绿化的大面积推广则可大大弥补这一不足，有效解决建筑占地与绿化用地之间的矛盾。

3. 改善建筑硬质景观，提供富有生气的绿色建筑环境。

建筑充塞，绿色欽失的环境容易使人产生视觉疲劳和心理烦躁，而在建筑环境里尤其是闲置的屋顶进行绿色填充，则可以为建筑高层用户提供绿色环境，消除疲劳，恢复精神，提高工作效率。

屋顶绿化的研究在全世界已引起了相当的重视，但是在中国一些用地紧张的大城市，此项工作还未真正开始，在当今 “ 人与自然，和谐发展 ” 的今天，建筑生态化研究使得屋顶绿化日益成为建筑的组成部分，研究并应用植物为建筑隔热和改善环境质量的生态功能，开发草地式屋顶绿化，完善相关技术的研究，使之得以推广和应用，无疑是对建设人性化生活和工作空间的一大贡献。

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生态建筑技术经济分析初探

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摘　要　技术经济分析是评价和推广生态建筑的一项基础性工作，但又是一项难度很高的工作，难以应用传统的经典方法。本文以上海生态建筑样板房为例，基于全局和全生命周期的思想，通过采用层次分析法和模糊综合评价模型，建立了生态建筑关键技术的技术经济评价方法。初步应用结果表明，该方法具有简便和容易应用的优点。
关键词　可持续发展 生态建筑 技术经济分析

1　引言

1987 年世界环境与发展委员会提出“可持续性发展是既要满足当代人的需要，又不对后代人满足其需求能力构成危害的发展”（United Nations, 1987）。建筑领域由于其对资源的大量消耗和对环境的巨大影响，成为贯彻可持续发展理念的一个重要方面，为此人们提出了生态建筑的概念，并积极进行实践，以取得经济效益、环境效益、社会效益的较好统一。

欧美一些国家从上世纪九十年代初就开始了对生态建筑的研究和实施（Bhatti, et al., 1994），考察对象从建筑的结构、材料、功能、效益等，到社区环境和开发形式等（Bouwmeester, 1999；Smerdon, 1997 ect.）。当前，生态建筑在西方国家处于方兴未艾的阶段，政府积极推动进行试点和示范（Edwards and Turrent, 2000）。例如，早在 1993 年，英国就在诺丁汉郡索斯韦尔小城中部建造了“自维持住宅”。温哥华相继制定和推广了“可持续发展生态居住区设计六项原则”、“绿色住区生态景观设计指导手册”、“可持续发展城市系统”等，已建成为绿色生态城市。荷兰政府制定了相应的计划和法规条例，进行了大规模的试点，不仅建成了一批示范性的住宅区，还按照生态建筑的要求改造了一批现有建筑 MHSPE, 1997；胡昊与诺兹曼，2002）。日本于 1993 年完成的 Next21 是生态建筑方面的一个十分有影响的示范项目（大阪煤气株式会社, 1999）。德国特别对节能建筑进行了大量研究，建成了一批生态节能住宅区。在联合国人居中心的帮助下，东欧各国正在进行生态建筑方面的试验和发达国家的经验推广（UNCHS, 1999）。

随着生态建筑研究与实践的不断扩展，以及相关设计与监测方式的不断更新与进步，其评价工作也受到越来越多的重视。国际上，生态建筑评价体系的发展基本上经历了三个阶段：第一阶段对建筑产品和单项指标的一般评价、介绍与展示；第二阶段对建筑方案环境物理性能的模拟与评价和第三阶段对建筑整体环境表现的综合审定和评价（刘煜与 Prasad, 2003）。

目前，我国已就生态建筑开展了一定的研究工作。上个世纪九十年代末就从国外引进了“生态建筑”和“绿色建筑”的概念(黄淘, 1998; 张暇龄, 2001 等)，在规划设计上予以采纳，并在一些项

目上进行了尝试，对生态建筑在我国的应用前景进行了较为全面的思考(Rousseau and Chen, 2002)，结合智能化技术和绿色建筑提出了“绿色智能居住小区”的发展方向(林少培，2002)，同时在专项技术上如能源利用等进行了较为深入的研究(Gglicksman, et al., 2001)。生态建筑还得到了政府部门的重视和支持，生态型住宅收到居民的极大欢迎，生态建筑更被列为 2010 年上海世博会的四大主题之一。特别是，我国以奥运工程为切入点，积极实行“绿色奥运建筑”战略，系统地提出了绿色建筑所涉及的内容和重点。总体上，我国已经接受和掌握了生态建筑的一些概念、方法和技术，但仍较缺少系统的集成和具体的范例，特别是目前的研究和应用主要集中在技术层面上，较少关注生态建筑的分析与评价问题。

生态建筑的评价包括了环境、健康和经济等诸多方面，因此对其进行评价分析有别于传统意义上的建筑，比如，为了逐步解决发展和环境所面临的问题，需要摒弃单纯以追求经济效益为中心的发展观，重视对自然资源的持续利用；在进行经济预测时，要讨论自然资源持续利用的价格问题，以一个较长的时期为考察对象，结合考虑生态环境的经济价值等多种因素来分析项目的成本和效益。对生态建筑的评价，需要建立多个评价因素或评价指标，是在多因素相互作用下的一种综合判断，仅从单个因素出发作出判断是不够的，而且容易带来片面性。这些因素往往包含不确定性因素，难以量化，而如果过多地依赖主观经验，又可能使评价结果失真。因此，生态建筑的评价是一项艰巨而复杂的工作。国际生态建筑评价经过十多年的发展，至今已形成了若干有影响力的评价体系，包括英国的 BREEAM 评估体系、美国的 LEED 绿色建筑评估体系、加拿大的 GBTool、澳大利亚的建筑环境评价体系 NABERS、德国的生态建筑导则 LNB、挪威的 ECO PROFILE、法国的 ESCALE、日本的 CASBEE 等。这些评价方法在实践中得到了较好的应用，对各个国家在城市建设中倡导绿色概念，引导建造者和使用者注重可持续发展起到了重要作用。但这些评价体系一方面需要大量的基础性工作，需要采集成百上千种数据，因而推广应用难度大；另一方面，这些方法主要是评估建筑物的整体表现，而在生态建筑的推广初期，往往需要对各种生态建筑技术进行判别和选定。本文主要关注的是后者，即生态建筑关键技术的技术经济评价问题，以便在此基础上，探求对生态建筑进行整体评价的方法。所谓技术经济分析，就是对不同技术方案实施所需投入与所取得的效果进行计算、分析、比较论证，对参选方案的成本与效益作对比分析及经济效益评价，从而做出方案取舍决策的一套方法。技术经济分析又分为静态和动态两种，动态评价方法即考虑资金时间价值的一种评价方法。

为了推动生态建筑的发展，上海有关方面通过集成现有的生态建筑技术，建设了办公和住宅两种样板房。本文以上海生态建筑样板房为例，基于全局和全寿命周期的思想，运用模糊综合评价方法，探讨生态建筑关键技术的技术经济评价问题。通过对生态建筑关键技术的综合评价，可以对不同的单项技术进行排序，在资金有限的情况下，合理选用性价比高的技术。

2　生态建筑关键技术

通过整合国内外已有的生态建筑先进技术，针对上海的地域特征、经济发展水平和市场需求，上海市有关方面正在加紧进行生态建筑的试点工作，其目标是建成具有国际先进水平、体现上海建筑风格的生态办公、住宅样板房，建立具有上海特色的生态建筑集成技术体系，推广示范生态建筑

适用技术体系，制定生态建筑设计指南、评估体系和技术经济分析等标准规范，指导工程实践，整体提高上海生态建筑技术水平，拉动相关产业发展，并推动我国生态建筑领域的科技进步。

本文选取上海生态办公楼样板房为案例进行具体的技术经济分析。该办公楼主要采用了以下几种关键技术：

（1）自然通风。确保室内有充足的新鲜空气且满足下列需求的功能：能带来必需、有质量的空气；能驱除不好的气味，有毒的气体以及各种不同的污染；能保证延长建筑物的寿命，尤其是防止建筑物的发霉；符合建筑节能规范的要求；能保证长时间连续运行，且具有高可靠性、低能耗、低噪音。

（2）低能耗建筑节能体系。包括保温隔热复合墙、节能玻璃、智能化遮阳系统等的应用。

（3）自然采光利用设计。

（4）太阳能利用和建筑一体化。

（5）地下埋管换热器冬夏联供应用技术。

（6）绿色工程建材应用。

（7）环保型化学建材应用。包括防霉、抗菌功能复合内墙涂料、木材粘合剂、排烟脱硫石膏以及石膏矿粉复合胶凝材料和高性能水性木材表面装饰涂料等。

（8）环境和节能智能控制技术。包括建立室内环境综合调控系统，同时监测包括温湿度、空气质量、室内噪声、照明等室内环境指标；应用空调系统节能的优化调节控制技术及软件。

（9）室内环境控制改善技术。主要考虑室内空气质量、建筑声环境和建筑光环境。

（10）节水技术。建立一套完整的中水和雨水的收集、处理、储存和回用设施，应用人工湿地水净化技术。

3　评价模型和方法

目前国外针对生态建筑的整体评价方法一般包括三个步骤：首先确定评价指标体系，其次是确定评价标准，最后是执行评价。本文研究的重点是生态建筑关键技术的评价。由于生态建筑涵盖了节能门窗、节能屋面、节能墙体、节能空调、太阳能、中水回收等十余种分项技术，因此如果首先完成对分项关键技术的分析和评价，就能对其进行分类排序，可以在资金有限的情况下选择应用性价比高的技术，同时有可能在此基础上实现对建筑整体表现的评价。对关键技术的评价是推广应用生态建筑的一项重要基础性工作。

本文在评估中，充分应用了“全生命周期”的思想，关注建筑项目的前期策划、中间建造活动、日常使用、维修直至拆除的整个生命周期中对资源的利用和环境的影响，同时考虑建筑评价中的多因素和模糊性等特点，利用基于模糊集理论和数学模型的综合评价方法，对生态建筑关键技术全生命周期的经济效益、社会效益和环境效益进行分析。这是一种操作简单、科学适用的评价方法，既考虑了生态建筑可持续发展的要素，又兼顾了其经济效益。

3.1　模糊综合评价模型

模糊综合评价法，就是根据给出的评价标准和实测值，经过模糊变换后对事物作出评价的一种方法。它可分为单级综合评判和多级综合评判，一般过程是：

（1）确定评价因素集（或评价指标集）：$U=\{u_1,u_2,\cdots,u_n\}$；

（2）确定评语集：$V=\{v_1,v_2,\cdots,v_m\}$；

（3）确定评价因素的各级权重 W；

（4）找出各级评判矩阵：$R=(R_1,R_2,\cdots,R_n)^T$；$R_i=(r_{i1},r_{i2},\cdots,r_{im})$，$r_{ij}$ 是评价对象在因素集上的特性指标；

（5）模糊变换 B=W〇R；

（6）解出评判指标 $B_{总}$，对结果进行说明。

本文建立的生态建筑关键技术的二级综合评价模型如图 1 所示。

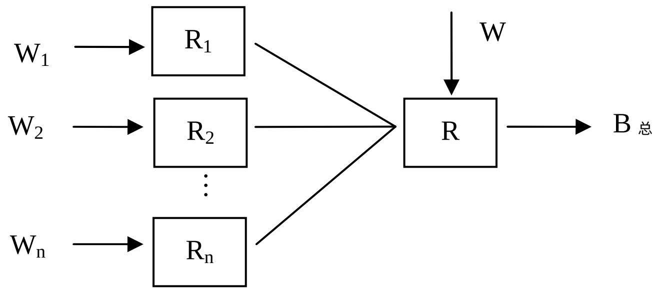

图 1 模糊综合评价模型

3.2　评价指标体系

在对生态建筑的综合评价中，往往需要确定几百乃至上千个指标项目，指标建立和数据采集的工作量非常大。本文主要对生态建筑的单项技术进行评价，从科学性、全面性、可比性和实用性出发，在征求专家意见的基础上，拟仅从社会效益、环境效益（包括周边环境、室内环境与人体健康）、技术难度、经济效益（包括初始投资和年度节能）等少数关键方面，建立如图 2 所示的评价指标体系。

环境效益：建筑全生命周期环境效益指建筑系统全循环过程中输入输出对宏观和微观环境造成的生态后果。包括：（1）宏观环境效益：现代建筑对地球环境破坏有余、建设不足，而自然环境不能用通常意义的价格概念来表示。因此在生态建筑的设计上应综合节能、使用耐久的建筑材料、设备产品以延长建筑使用寿命，减少全生命周期内建筑环境负荷，建设可持续发展的建筑。（2）微观环境效益：可持续建筑设计应将环境视为一个活跃的、具有一定功能的生态系统，生态系统的组成部分应因地制宜，兼顾景观及生态敏感性，选择对局部环境破坏最小的施工方式。（3）室内环境和健康：主要涉及与人类健康密切相关的室内环境质量等因素。本文在环境效益方面分列周边环境、室内环境与人体健康两个方面。

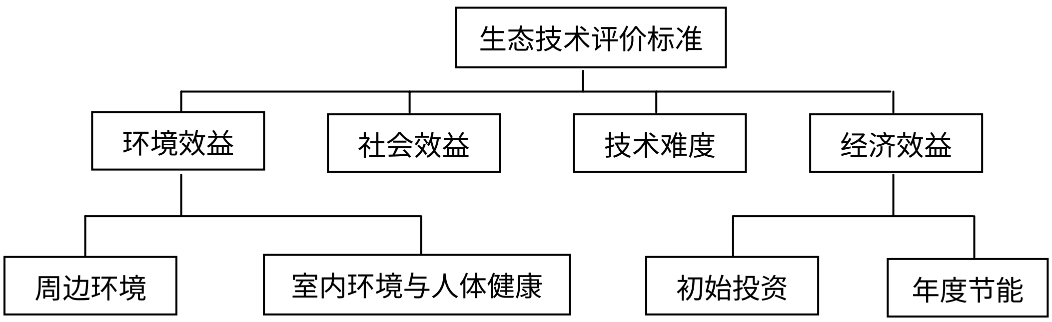

图 2　生态建筑关键技术的评价指标体系

经济效益：这是生态建筑关键技术评价中要考虑的重要方面。采用生态技术无疑会因初始投资增加而提高成本，因此，对生态建筑的评估要具有“全生命周期”的思想。“蕴能量”(Embodied Energy)包括物质材料从原材料提炼到生产过程完成所消耗的能量、转化为建筑元素和进行装配所消耗的能量的总和。据分析，建筑生命周期中其自身蕴能量只占总能源使用的 35%，高达 65%的能耗与其运营方式有关。建筑的一次造价和使用期间操作运行费用、维修费用、更换及改造费用等构成“全生命周期费用”，建筑产品的后期投入与一次造价的比例随不同时期、不同项目而不同，但后期投入始终是非常可观的。我们既不能盲目控制一次造价而不顾后期投入大量增加，也不能一味追求所谓生态高技术，造成建设投资大幅超标。相反，应充分考虑到全寿命周期中各阶段的投入及其在全寿命费用中的比重，综合平衡一次投资与后期投入的关系，从整体上降低全生命周期成本。一般而言，全生命周期经济效益控制包括以下几个阶段：建筑材料选择阶段，建筑构造设计、设备选择阶段，建筑后期处理阶段。本文对经济效益的评估考虑了初始投资和年度节能两个方面，将因采用生态技术而产生的效益用年度能源节省这一指标反映出来。

社会效益: 建筑的社会效益指建成环境在与人类互动中对其产生的生理、心理健康影响，包括使用者的健康、相关者的健康、示范作用、对树立可持续发展观的正面促进作用等。

技术难度：该项技术在规划设计、施工和使用管理中的难度，影响到建筑项目投资者和使用者对该项技术的接受程度。

3.3 评价指标权重确定

确定评价指标权重的方法很多，常用的有专家估测法、频数统计分析法、主成分分析法、层次分析法、模糊逆方程法等。层次分析法（Analytic Hierarchy Process, AHP）是一种整理和综合人们主观判断的客观方法，也是一种综合定性分析和定量计算的系统分析方法，它将决策者对复杂系统的决策思维过程数量化，为选出最优决策提供了依据，适用于多准则、多目标复杂问题的决策分析，对于处理分析社会经济系统问题很有效。

AHP 法首先通过分析复杂问题包含的各种因素及互相关系，将问题分解为不同的要素，再将这些要素分为不同的层次，建立一个多层次的分析结构模型。在每一层次中按一定的准则，对该层各要素进行逐对比较，建立成判断矩阵。通过计算判断矩阵的最大特征值及相应的特征向量，得出该层要素对于上一层某一要素的权重，进而计算出各层要素对总体目标的组合权重。AHP 的具体步骤参加文献（赵焕臣等，1986）。

3.4 生态建筑经济效益评估

本文拟用现值成本法来比较生态建筑关键技术的经济效益，具体步骤如下：

（1）确定拟比较的关键技术内容。即在第二部分中所确定的 10 项关键技术。

（2）用现值成本法计算单项技术的成本

生态建筑某项技术的成本 PC1＝技术投入成本(研究费用+设备价值)

＋年运行费用× A(P/A, i, n)

－(可回收利用材料价值+残值)×F(P/F, i, n)

－政府补帖或税赋减免现值

－处理污染得到的副产品收入现值

传统建筑某项技术的成本 PC2＝设备价值＋年运行费用×A(P/A, i, n)

－残值× F(P/F, i, n)

＋支出的生态环境治理费现值

＋政府征收的外部经济补偿费

(3)计算生态建筑单项技术横向比较经济指标 g

g=PC1/PC2

分别计算各项技术的 g 值，g 越小则该技术的经济效益越好，g 越大的技术方案建议改进或减少投入。

3.5 模糊变换

由评语集$V=\{v_1,v_2,\cdots,v_n\}$，评价因素集$U=\{u_1,u_2,\cdots,u_m\}$得出模糊评价矩阵 R 为：

$$R=\begin{Bmatrix}R_1\\R_2\\\vdots\\R_n\end{Bmatrix}=\begin{bmatrix}r_{11}&r_{12}&\cdots&r_{1m}\\r_{21}&r_{22}&\cdots&r_{2m}\\\vdots&\vdots&\cdots&\vdots\\r_{n1}&r_{n2}&\cdots&r_{nm}\end{bmatrix}$$

其中$R_i=(r_{i1},r_{i2},\cdots,r_{im})$ (i=1,2,⋯,n)为相对于评价因素 u_i 的单因素模糊评价，它是评语集 V 上的模糊子集，r_{ij} 为相对于第 u_i 个评价因素给予评语 v_j 的隶属度。而权重集合$W=(w_1,w_2,\cdots,w_n)$是因素集 U 上的模糊子集。引入 V 上的一个模糊子集 B，称评价（又称决策集），它是模糊评价，$B=(b_1,b_2,\cdots,b_m)$。那么，通过模糊变换 B=W〇 R(“〇”为算子符号)就能由 W 与 R 求得 B。由模糊数学理论，模糊变换算子〇选用时，当综合评判诸因素中某些因素权重较大时，宜选用 M（∧，∨）或 M（· ，∨）算子；当因素较多而权重分配又较均衡时，宜选用 M（∧，⊕）或 M（· ，⊕）算子（葛垆，1989）。

4 应用实例与讨论

本文应用模糊综合评价模型，对上海生态办公样板房的十项关键技术进行了初步评价。结果如下：

（1）评价指标集如图 2 所示。

（2）评语集确定为 V={好(v_1)，较好(v_2)，一般(v_3)，较差(v_4)，差(v_5) }。

（3）应用层次分析法，求得各项指标的权重如表 1 所示。

表 1 生态技术评价指标权重

<table>
<tr><td colspan="6">生态技术评价指标权重</td></tr>
<tr><td colspan="2">环境效益</td><td>社会效益</td><td>技术难度</td><td colspan="2">经济效益</td></tr>
<tr><td colspan="2">0.5024</td><td>0.0501</td><td>0.1268</td><td colspan="2">0.3207</td></tr>
<tr><td>周边环境</td><td>室内环境与人体健康</td><td colspan="2" rowspan="2">———</td><td>初始投资</td><td>年度节能</td></tr>
<tr><td>0.45</td><td>0.55</td><td>0.4</td><td>0.6</td></tr>
</table>

（4）模糊变换矩阵 R 的确定。有多种方法可以确定 R，本文采用较为简便的专家评分法，在方法的试用阶段，邀请了 10 位专家（评委）分别就各项技术，针对各项评价指标按好、较好、一般、较差和差进行评议。其中，对经济效益的两项指标，即初始投资和年度节能，先采用经典的技术经济分析方法进行计算，将结果提交专家参考，由专家在此基础上进行评分。以自然通风技术为例:

$$R_{社} = \begin{pmatrix} 0.70 & 0.10 & 0.10 & 0.10 & 0.00 \end{pmatrix}$$

$$R_{技} = \begin{pmatrix} 0.50 & 0.20 & 0.10 & 0.10 & 0.10 \end{pmatrix}$$

$$R_{环} = \begin{bmatrix} 0.50 & 0.30 & 0.10 & 0.10 & 0.00 \\ 0.70 & 0.20 & 0.10 & 0.00 & 0.00 \end{bmatrix}$$

$$R_{经} = \begin{bmatrix} 0.00 & 0.10 & 0.70 & 0.10 & 0.10 \\ 0.00 & 0.00 & 0.80 & 0.20 & 0.00 \end{bmatrix}$$

（5）求判断矩阵 B

$$B_{环} = W_{环} \circ R_{环} = \begin{pmatrix} 0.61 & 0.245 & 0.10 & 0.045 & 0.00 \end{pmatrix}$$

$$B_{经} = W_{经} \circ R_{经} = \begin{pmatrix} 0.00 & 0.04 & 0.76 & 0.16 & 0.04 \end{pmatrix}$$

（6）求 B 总

$$B_{总} = W_{总} \circ R_{总}$$

$$= \begin{pmatrix} 0.5024 & 0.0510 & 0.1268 & 0.3207 \end{pmatrix} \circ \begin{bmatrix} 0.61 & 0.245 & 0.10 & 0.045 & 0.00 \\ 0.70 & 0.10 & 0.10 & 0.10 & 0.00 \\ 0.50 & 0.20 & 0.10 & 0.10 & 0.10 \\ 0.00 & 0.04 & 0.76 & 0.16 & 0.04 \end{bmatrix}$$

$$= \begin{pmatrix} 0.4056 & 0.1664 & 0.3117 & 0.0916 & 0.0255 \end{pmatrix}$$

（7）结果说明

综合评价结果表明,“ 自然通风 ”技术被评定为好、较好、一般、较差、差的比重分别是 40.6%，16.6%，31.2%，9.2%，2.6%。由此看来，该项技术总体评价良好。如相应地用 5 分、4 分、3 分、2 分、1 分分别表示 5 个档次，即 u=（5, 4, 3, 2, 1）^{T}，于是该技术的评分为 Y=B 总⊙u，取 M（· ，+），有：Y=3.8374 分。采用同样方法，可以分别对其他各项技术进行排序，结果如表 2 所示。

表 2　分项技术综合评价汇总表

分析技术	好	较好	一般	较差	差	综合评分
A	40.6%	16.6%	31%	9%	2.6%	3.8374
B	12%	16%	50%	15%	7%	3.1184
C	37%	27%	27%	6%	3%	3.8815
D	55%	19%	19%	7%	0	4.2212
E	9%	18%	50%	16%	7%	3.063
F	35%	25%	34%	4%	2%	3.843
G	33%	20%	35%	12%	0	3.736
H	3%	11%	49%	31%	6%	2.7381
I	8%	17%	42%	28%	5%	2.9552
J	35%	32%	25%	8%	0	3.934
注：A－J 分别表示本文第 2 节中所列的 10 项生态建筑关键技术。						

本文试图建立对生态建筑单项技术的评价方法，在上海生态办公样板房的初步应用表明，太阳能利用、绿色建材、自然通风、自然采光设计、节水技术等受到专家的充分肯定，具有较高的性价比。当然，这种方法还不完善，有不少需要改进的地方。以确定权重的层次分析法来讲，其核心是将系统划分层次且只考虑上层元素对下层元素的支配作用，同一层次中的元素被认为是彼此独立的。这种递阶层次结构虽然给处理系统问题带来了方便，但也限制了它在复杂决策问题中的应用。在许多实际问题中，各层次内部元素往往是依存的，低层元素对高层元素亦有支配作用，即存在反馈。此时系统的结构更类似于网络结构。在这种情况下，最好应用由 AHP 延伸发展的网络分析法 ANP。ANP 将系统元素分成两大部分，第一部分称为控制因素层，包括问题目标及决策准则，它们彼此独立，只受目标元素支配，控制层中每个准则的权重均可用传统 AHP 方法获得。第二部分为网络层，其内部是互相影响的网络结构。图 3 是典型的 ANP 结构图。ANP 与建筑评价时诸多因素有反馈作用的实际情况较为符合。

5　结论

生态建筑的评价是一项关系到生态建筑健康发展的重要工作，世界许多国家和地区都开始和继续在这一领域积极研究、探索和实践。本文以上海生态建筑样板房为例，应用全局和全寿命周期的思想，运用层次分析法和模糊综合评价模型，试图建立生态建筑关键技术的初步评价方法。试用结果表明，该方法可以用来对生态建筑的单项技术进行综合评价，比较简洁易用。

生态建筑评价体系的建立，是一项重要而又复杂艰巨的课题，涉及面广，牵涉要素多，需要通过多领域专家的合作来建立一套科学全面、简明易操作的评价标准和方法。如何进一步改进现有的模型和方法，如何在单项技术评估的基础上，在全生命周期内评价整个建筑物，是我们下一步研究的重点。

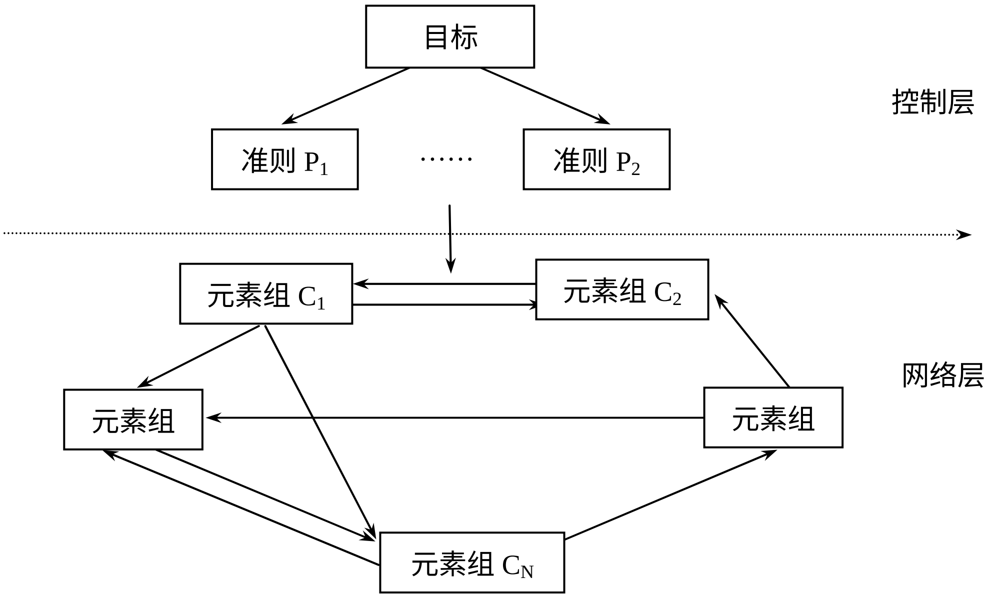

图 3　网络层次分析法示意图

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生态建筑的全寿命周期技术经济评价方法

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摘　要　本文以提高人们对生态建筑经济性的关注为目的，从全寿命周期角度出发，为一系列经济指标建立评价模型，并辅以对环境、社会等领域影响的综合评估，为今后发展推广生态建筑提供一种技术经济评价方法。
关键词　生态建筑；建筑节能；技术经济评价
Abstract　The purpose of this paper is to make people pay more attention to the economy of sustainable building. Considered life-cycle costing, the economical analysis of sustainable building covers the model of some economical targets, and associated with the integrated assessment in some fields, such as environment and society. This article is to provide an approach of economical analysis for sustainable building’s development in the future.
Key words　sustainable building，energy-saving for building，economical analysis

1　引言

随着可持续发展成为世界上许多国家的发展战略以及生态学、社会学等学科向建筑学领域的逐渐扩展，生态建筑的观念应运而生。生态建筑在实践过程中遵循 3R 原则，即 Reuse（再利用、重复利用）、Reduce（减少消耗和污染）、Recycle（循环使用），研究开发生态建筑技术和产品,目前采取的有节能环保措施，保温隔热墙体降低室内空调能耗；特殊结构设计达到自然通风、采光效果，减少室内照明；利用工业废渣制成的绿色建材减少水泥用量等。生态建筑的环境效益和社会效益毋庸置疑是有利于社会可持续发展的，但由于其初始投资成本高，通常不被投资商所看好。若期望企业能够自愿投资建设生态建筑，那么就必须将从全寿命周期的角度出发，检验各项生态技术带来的效果，包括对其在使用过程中运行费用的降低、节能效益，甚至对人体健康、社会可持续发展影响，做出全面、客观评估。因此，本文拟对生态建筑通过建立建筑全寿命周期内各项经济指标（比如：净现值、投资增额回收期等）的评价模型，结合生态建筑所特有的建设、经济和技术要求，从而达到分析各项生态、环保技术以及生态建筑的经济可行性的目的。本文着重对评价方法和评价模型进行研究和探讨。

2　生态建筑技术经济评价的基本原则

生态建筑的技术经济评价采用全寿命周期现值成本法。该方法中项目的成本支出并不片面考虑初始投资，而是大量收集建筑物全寿命周期内，包括运行、维修等后期费用的信息，均列入成本计算范围，将其折现到评价初期，根据实际需要选择评价指标，做出评估。

生态建筑是由各项节能、环保的关键技术与建筑融合在一起，从而达到与生态环境相协调的效

果。单一强调项目的总体评价，不足以体现技术经济评价的全面性，因此各项关键技术的经济性评价也是必不可少的。一方面，这些关键技术是生态建筑的核心所在，可行性势必与总体的经济合理性息息相关；另一方面，各项技术的效果参差不齐，通过比较，为投资者技术的选取提供参考依据。

生态建筑的评价不同于常规项目。这是由于生态建筑的优势或者说是节能效益，只有通过与传统建筑的对比，才得以显现。多项评价指标，比如说差额净现值、投资增额回收期等，均建立在对比差值的基础上。相互对比的思路贯穿于评价过程始终。

评价过程中指标与参数的选择，根据项目的实际情况，结合相关的建筑行业规范和经济评价的国家标准，充分考虑社会各个层次上的利益追求，并且参考国内外多项案例的实际操作，从而在此基础上进行合理的确定。

3　生态建筑技术经济评价指标方法

生态建筑的技术经济评价主要被分为项目关键技术评价、项目总体评价以及综合效益评价三个部分，前两者是建立在与传统建筑对比的基础上，运用一系列指标进行具体评价。后者是综合生态建筑对各方面的影响程度而进行的等级评定。详细描述如下：

3.1　项目关键技术经济评价

一幢生态建筑往往综合运用了多项生态、节能技术，各项关键技术的效果，对于整体建筑的作用都是评价过程中不可或缺的内容。同时，关键技术评价更可以为投资者在技术方案的选择上提供科学的参考依据。

1. 净现值

它是以节约的能耗支出作为节能收益，将其与后期费用以某一折现率折现到评价初期，和初始投资求差值，由此来判断此项关键技术是否具有经济合理性。

$$NPV_{(k)} = F \cdot p(P/A,i,n) - I - f_1(P/A,i,n) - [f_0(P/F,i,m) + f_0(P/F,i,2m) + \cdots] + S(P/F,i,n)$$

其中： F——关键技术产品的年产值效益值，如 Q1-Q2、Q 和 V 等

Q1-Q2——采用节能技术后年耗能量与通常情况下年耗能量的差额，即节约年耗能量

Q——新能源技术的年产量，如太阳能屋面的年发电量

V——可再生能源技术的年产量，如中水回收的年回收水量

p——关键技术能耗单价

I——初始投资

f_1——日常运行、维修费用

f_0——每次大修费用

n——关键技术的寿命期

m——大修年限，m<n

S——残值

i——基准折现率

由于折现率 i 是反映资金随时间变化的增值率或报酬率，是衡量资金时间价值的相对尺度，

在很大程度上影响到了 NPV 的值，相关值的确定尚待进一步研究，可考虑在技术经济评价中采用以下几种值分别计算，并进行综合分析：

⑴ 会折现率 i_1——表示社会可接受的最低投资收益率的限度。

⑵ 准收益率 i_2——某行业基本建设所达到的最低投资效果。

⑶ 期望投资收益率 i_3——投资者根据企业需求而确定的最低收益率。

一般情况下，净现值函数 NPV（i）是单调递减函数，随着 i 的增大，同一现金流量的 NPV 可能将会由正值递减到负值，通常 i1≤i2≤i3，在 NPV 指标的评价过程中可能将会出现以下 4 种情况：

⑴NPV（i_3）≥0——说明该项技术具有较强的经济合理性，易于被投资者接受。

⑵NPV（i_2）≥0，NPV（i_3）<0——说明该项技术的经济性达到行业标准，但离投资者的期望值有距离，政府可以采取一系列对策来吸引投资者的参与。

⑶NPV（i_1）≥0，NPV（i_2）<0——说明该项技术虽然无法达到行业标准，但对社会的贡献仍然不可或缺。

⑷NPV（i_1）<0——该项目在经济上不具备合理性。

2. 生态技术投资增额回收期

它是以生态关键技术在运行过程中的节约的能源支出抵偿建筑物采用该项技术的投资增额所需的时间。由于尽快地收回投资、减小投资成本是投资者极为关注的问题，回收期法简单直观、易于理解，与现值法一起使用，帮助决策者做出合理的投资决策。

计算公式：

$$P_{d(k)} = n - 1 + \frac{\left|\sum_{t=1}^{n-1} NCF_t\right|}{NCF_n}$$

其中：$P_{d(k)}$——某项关键技术的投资增额回收期

n——累计净现金流量出现正值的年份数

$\sum_{t=1}^{n-1} NCF_t$——第 n-1 年累计净现金流量

NCF_n——第 n 年净现金流量

净现金流量——该年某项关键技术节约能耗费用与所增加投资成本的差值

投资增额回收期越小，说明此项关键技术用节约能耗的收益来弥补所增加投资成本的时间越短，在此之后节约的能耗费用作为相较于传统建筑的节能净经济效益。我国《民用建筑节能设计标准》中规定节能投资回收期不超过 10 年，可作为其评价指标，但对不同产品的投资回收期应分别进行研究确定，以达到合理的评价和衡量。

3. 节约单位能源的增额成本现值

它是关键技术节能效益的评价指标，由某项节能、环保技术所增加的初始成本和后期费用折现所得的成本差额现值与寿命周期内能耗节省两比值所决定的。

$$\Delta C_{(k)} = \Delta Ip \div [F \cdot n]$$

其中：n——关键技术的寿命期

ΔIp——有无采用节能、环保技术的差额成本现值

在各项关键技术的平行比较中，ΔC（k）值越小，该项技术的节能效率相对也就越高。

综上所述，在对各项关键技术的评价过程中，净现值 NPV 是各项技术自身的经济性的评判指标；投资增额回收期针对有无采用生态关键技术做出比较，由此反映资金的获利能力和回收速度；节约单位能源的增额成本现值这一指标更是对生态技术资金使用效率的评定。此部分的评价着眼于多个角度，全方位测算，为投资者技术项的选择提供参考依据。

3.2　项目总体技术经济评价

生态建筑总体技术经济评价主要分为三部分，一是对生态建筑与传统建筑在造价方面进行对比，第二部分是运用差额比较法对项目的净现值和投资回收期两项指标进行估算，第三部分是关键技术选取的多方案评价与选择。

据资料介绍，在英国生态建筑的初始成本（即造价）要比传统建筑高 5%～10%。在我国目前这些生态节能技术尚在推广期产品价格偏高。但考虑到这些技术今后在国内广泛推广之后，成本会降低。因此不仅要在现行价格下进行造价对比，而且要以远期价格再次对比，为推广生态建筑更添说服力。

差额比较法是指主要经济指标均采用差值。在生态建筑中所谓的节能收益，实质上是节能措施有无的情况下能耗支出的差值。既然能耗支出使用差额指标，遵循评价指标的可比性原则，初始投资额以及运行过程中的其他费用支出也相应采用与传统建筑相比的差额。在此基础上，制定一套评价方案。

1. 差额净现值

差额净现值反映生态建筑在生命周期内节能收益能力的动态评价指标，它的计算是依据生态节能措施实现后的年实际节能收益额与后期费用差额，按选定的折现率，折现到评价期的现值，与初始投资增额求差额。

$$\Delta NPV = (Q_a - Q_b)\cdot p(P/A,i,N) - (I_b - I_a) - \left|\sum_{k=1}^{t} P_{a_{(k)}} - \sum_{k=1}^{t} P_{b_{(k)}}\right|$$

其中：Q_a-Q_b——生态建筑与传统建筑年耗能量的差值

p——能源单价

I_a-I_b——生态建筑较传统建筑的初始投资增额

i——基准折现率

N——建筑寿命期，《夏热冬冷地区居住建筑节能设计标准》（JGJ134-2001）中规定建筑的设计基准期为 50 年

$P_{b(k)}$——生态建筑中某项关键技术后期费用的现值，计算公式如下：

$$P_{b_{(k)}} = f_1(P/A,i,n) + [f_0(P/F,i,m) + f_0(P/F,i,2m) + \cdots] - S(P/F,i,n) + \{I_0 + f_1(P/A,i,n)$$
$$+ [f_0(P/F,i,m) + f_0(P/F,i,2m) + \cdots] - S(P/F,i,n)\}(P/F,i,n) + \cdots$$

其中：f_1——日常运行、维修费用

i——基准折现率

n——某项关键技术的寿命期，$n<N$

f_0——每次大修费用

m——大修年限，$m<n$

S——残值

I_0——更换投资额

$P_{a(k)}$——传统建筑中某项关键技术后期费用的现值计算方式同 $P_{b(k)}$

$\Delta NPV \geq 0$，说明生态建筑具有经济合理性。ΔNPV 越大，说明生态建筑的经济净收益越高。

在建筑寿命周期过程中，需支付的费用主要分为两部分：一部分是为了建造建筑而支付的金额，另一部分是为了使用和运行而支付的金额。前者被称为建设成本，后者被称为运行成本，建筑全寿命周期费用应该是这两者之和，而其与建筑的技术功能更为密不可分。

生态建筑初始投资与所有关键技术后期费用的净现值之和可以被认为是某一特定的功能水平下的全寿命周期费用。如图 1 所示，在一般情况下，建设成本随技术功能水平的提高而上升，运行成本随技术功能水平的提高而下降，寿命周期成本就随技术功能水平的变化而呈开口向上的抛物线型变化。

总体经济分析的目的是通过科学的分析研究确定生态建筑在一个适当的功能水平下，该建筑的寿命周期费用最低，即寻求建筑节能、环保效果与投资成本的最佳契合点（如图 1）。

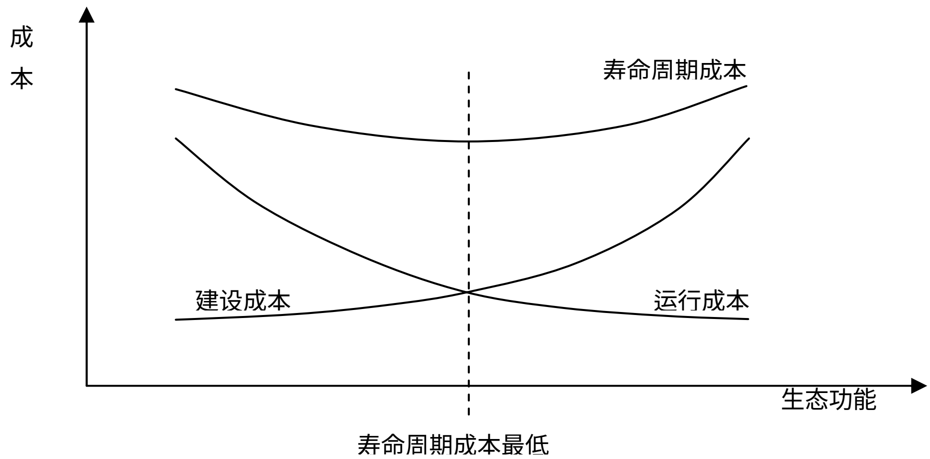

图 1　生态建筑全寿命周期成本

2. 投资增额回收期

它是以生态建筑使用过程中的总体节能收益抵偿生态建筑物总投资增额所需的时间。总体节能收益是通过具有相同节能效果的各项技术节能收益的分类叠加，再汇集各类产生不同节能效果技术的总和。除了所取数据不同,其计算方法与关键技术评价中该项指标的计算方法基本一致,其研究的关键是生态项目整体投资增额基准回收期的确定。

3．综合项目多方案的评价

⑴ 在投资资金无限制的情况下，技术的采纳与否，只取决于技术自身的经济效果如何。投资者可以选择所有符合 $NPV_{(k)}$≥0 要求的关键技术，进行方案组合。

⑵ 在有明确资金限制的情况下，即受投资资金总量的约束，不可能采用所有经济上合理的技术，即不得不放弃一些技术。可以采用以下方法来确定方案的最优组合。首先计算各项关键技术节约单位能源的成本现值 $C_{(k)}$，公式如下：

$$C_{(k)} = Ip \div [F \cdot n]$$

其中：n——关键技术的寿命期

Ip——成本现值，计算公式如下：

$$Ip = I + f_1(P/A,i,n) + [f_0(P/F,i,m) + f_0(P/F,i,2m) + \cdots]$$

按照 C（k）值的大小依次排序，排序规则为 C（k）值越大，序号越小，根据序号的次序选取方案，直至所选方案组合的投资成本总额最大限度地接近或等于投资限额内所能获得的节能效益也就越大。

项目的总体技术经济评价通过对生态建筑的差额净现值 ΔNPV 与投资增额回收期两个指标进行测算，从而判定项目总体的经济合理性。多方案的评价更为投资者在关键技术选取与组合上提供了选择方法。除此之外，还就传统建筑和生态建筑的造价成本以现行价格和远期价格分别进行对比。在肯定生态建筑的优越性同时，也不忽视其自身劣势，客观、辨证地对整个项目进行评定。

3.3　项目综合效益评价

1．评价目标

生态建筑的重要意义在于资源利用最佳、能源消耗最少、环境负荷最小、经济合理。因此应充分考虑生态建筑对经济、社会、生态环境等诸多领域的影响程度，综合评价其等级水平，为大力推广生态建筑提供科学依据。

2．评价指标和标准

指标集 E={建筑功能的满足，全寿命费用，经济效益，资源合理利用，能源节约，环境保护，健康影响}

等级集 F={优良水平，中等水平，基本合理，不合理}

3．指标权重的确定

在整个评价系统中，各个指标的重要性程度不一样，需要通过加权加以修正，对较重要的指标，赋予较大的权重，相对次要的指标赋予较小的权重。可以采用层次分析法确定指标权重向量 W（W1，W2，…，W7）。层次分析法（The Analytic Hierarchy Process 简称 AHP 法）是一种能有效地处理复杂问题的方法，是美国运筹学家 T.L.Satty 于 70 世纪中期提出的,被广泛地应用于确定指标的权重，大致可分为四个步骤，分述如下：

⑴建立递阶层次结构（见图 2）

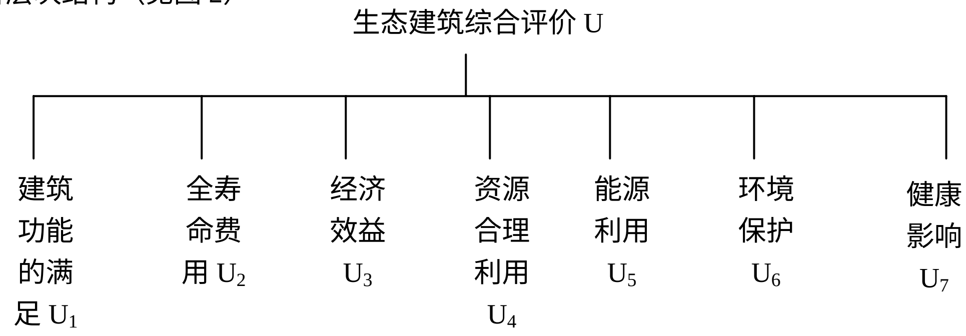

图 2　生态建筑综合评价递阶层次结构

⑵ 构造两两比较判断矩阵

通过两两比较指标的相对重要性，给出相应的比例标度（见表 2），构造判断矩阵 A

$$A=\begin{pmatrix} a_{11} & a_{12} & \cdots & a_{17} \\ a_{21} & a_{22} & \cdots & a_{27} \\ \cdots & \cdots & \cdots & \cdots \\ a_{71} & a_{72} & \cdots & a_{77} \end{pmatrix}$$

其中判断矩阵 A 必须符合以下性质：①aij>0；②aij=1/a；③aii=1；

表 2　判断矩阵的比例标度

标度内容	定　义
1	a_i 和 a_j 具有同样的影响程度
3	a_i 和 a_j 影响程度稍大一些
5	a_i 和 a_j 影响程度明显大一些
7	a_i 和 a_j 影响程度大得多
9	a_i 和 a_j 影响程度大很多
2，4，6，8	a_i 和 a_j 影响程度介于相应两相邻奇数之间

⑶ 计算指标的相对权重

采用排序权向量计算的特征根方法。在精度要求不高的情况下，可以用近似方法计算，常用求根法。步骤如下：

Ⅰ.将 A 的元素按行相乘；

Ⅱ.所得的乘积分别开 n 次方；

Ⅲ.将方根向量归一化后得排序权向量 W。

⑷ 判断矩阵 A 一致性的检验

在 AHP 法中 A 须为一致性矩阵，即 $a_{ij}\cdot a_{jk}=a_{ik}$。但由于客观事物的复杂性和人的认识的多样性，要求判断矩阵具有完全的一致性是不可能的。特别是当比较的指标较多时更是如此。因此要求具有大体的一致性，只要判断没有偏离一致性过大，排序权向量计算结果还是具有一定意义。在这种情况下，必须进行一致性检验。

检验指标为: $C.I.=\dfrac{\lambda_{\max}-n}{n-1}$

其中 n——判断矩阵阶数

$$\lambda_{\max} = \sum_{i=1}^{n} \frac{(AW)_i}{nW_i}$$

一般当 C.I.≤0.10 时，判断矩阵 A 有满意的一致性，计算所得的 W 可以接受。

4．评价方法的选择

采用模糊综合评价法，进行综合评价时可综合考虑指标体系中各因素对建筑的综合影响。但在指标权重及评价矩阵的确定上存在许多主观的因素，评价时一般采用群决策的方法并配合必要的数学处理。

5．综合评价

⑴ 组织多位专家对各指标的等级进行评定，评定结果经统计后记作隶属度矩阵 R（7 行 4 列），且对矩阵作归一化处理，符合 $\sum_{j=1}^{4} r_{ij} = 1$。

$$R = \begin{array}{c} \\ \text{建筑功能的满足} \\ \text{全寿命费用} \\ \cdots \\ \text{健康影响} \end{array} \begin{pmatrix} \text{优良水平} & \text{中等水平} & \text{基本合理} & \text{不合理} \\ r_{11} & r_{12} & r_{13} & r_{14} \\ r_{21} & r_{22} & r_{23} & r_{24} \\ \cdots & \cdots & \cdots & \cdots \\ r_{71} & r_{72} & r_{73} & r_{74} \end{pmatrix}$$

式中 rij 为指标 Ei 的评价对等级 Fj 的隶属度,即从指标 Ei 来看生态建筑被评为 Fj 的可能程度。

⑵ 求出向量 W 与矩阵 R 的合成

$$S = W \circ R = (W_1 \quad W_2 \quad \cdots \quad W_7) \circ \begin{pmatrix} r_{11} & r_{12} & r_{13} & r_{14} \\ r_{21} & r_{22} & r_{23} & r_{24} \\ \cdots & \cdots & \cdots & \cdots \\ r_{71} & r_{72} & r_{73} & r_{74} \end{pmatrix}$$

其中矩阵的合成 S 的计算方式类似于普通矩阵的乘积，但略有不同，被称为模糊运算法，计算原则为相乘换为“ 取小 ”，相加换为“ 取大 ”。

计算结果作归一化处理后得 $S = (S_1 \quad S_2 \quad S_3 \quad S_4)$

⑶ 根据最大隶属性原则，在 S 中确定生态建筑的等级，以及今后发展的对策。

等级描述：

优良水平——对各个领域的正面影响程度大，社会认同度高，易于大力推广；

中等水平——利大于弊，大力推广难度不小，需政府配套措施协助；

基本合理——基本符合推广要求，但仍需进一步改进；

不 合 理——不适宜推广。

生态建筑的推广是一项系统工程，除了技术、经济之外，仍有许多因素不容忽视的，比如：资源合理利用、环境保护、人体健康等。综合评价在充分考虑这些因素的基础上，通过专家评分，运用一系列数学处理，确定生态建筑的等级水平，从而为今后的发展提供有利依据。

4　结束语

本文旨在介绍生态建筑技术经济评价方法以及评价模型的建立，由于项目的多样性，在具体评估时，可以结合实际需要，完成对生态建筑实际技术的经济分析。根据本文的方法对上海生态建筑样板房工程所采用的节能门窗生态技术进行了实例计算和分析，获得了业主和产品开发商的认可。

本文在模型建立的过程中，在考虑了包括全寿命周期成本等多项影响因素，将生态建筑的技术经济评价作为一种从专项的生态、环保技术拓展到融入各项技术的建筑总体，与传统技术的对比分析和综合评价，对生态可持续发展的综合效益评价做了些有益的探索。

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Developing Life Cycle Assessment Tool for Buildings in Hong Kong

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Abstract Life Cycle Assessment (LCA) in many ways is a methodology which building industry is looking towards to give the answers on how to assess sustainability of buildings. In Hong Kong, like many other countries, its application is limited by the availability of credible assessment tools in the market. This paper provides the details on the processes and findings of a comprehensive study initiated by the Government to derive a LCA tool for the use of the local building industry, addressing on researches that are needed to really make LCA part of the answer to sustainability assessment.

1.0 INTRODUCTION

1.1 Global Perspective of Sustainability and Life Cycle Assessment

Global recognition of the need to strive for sustainable development began with the 1987 Report of the World Commission on Environment and Development: "*Our Common Future*", and subsequently manifested by the 1988 United Nations Environment Programme (UNEP), the 1992 Earth Summit at Rio de Janeiro, the 1997 Kyoto Protocol and the 2002 Earth Summit at Johannesburg. The Rio Earth Summit has led to the emergence of Agenda 21, the action plan for achieving sustainable development. The Malmö Declaration emphasised the importance of the life cycle economy as the overall objective for the development of cleaner and more resource efficient technologies. LCA is identified as a quantitative tool to support decision making for a sustainable development.

1.2 What is Life Cycle Assessment (LCA)?

LCA can be used both as a tool for assessments and a concept in discussions and evaluations. As a tool, LCA makes it possible to study which raw materials and energy types are used in producing products or providing services; to identify which discharges arise from a specific source to air, water and soil; and to assess the environmental impact of the identified discharges. As a concept, it represents a way of thinking about and looking at products and materials from cradle to grave, to categorise problems and assign priorities in finding a solution, and to foster consensus and international co-operation.

The multi-criteria study done in 1969 for Coca-Cola on the choice between glass and plastic bottling is believed to be the first LCA study ever conducted (Ecobilan, 2003). As a topic in environmental management, the history of LCA dates back to the early 70's (Guinee, 2002). However, active development and application of LCA has only a relatively short history. It is not until recently that a standardized LCA framework was established by ISO Standard 14040. The procedures involved are summarized in the following diagram.

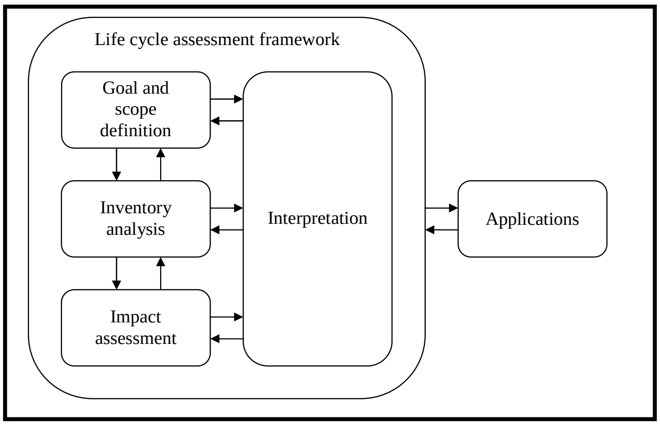

Figure 1 Framework of LCA study.

1.3 Scope of LCA

A product system comprises a collection of unit processes, each of which performs one or more defined functions, connected by flows of intermediate products, as depicted in Figure 2. The system boundary defines the unit processes to be included in the system to be modelled, which is to be determined taking into account the intended application, assumptions made, cut-off criteria, data and cost constraints, and the intended audience. As an LCA is meant to be a cradle-to-grave analysis, the original sources of raw materials; distribution and transportation processes; use and maintenance of products; process wastes; and product reuse, recycling, energy recovery and product disposal are processes and flows that should be included in the LCA.

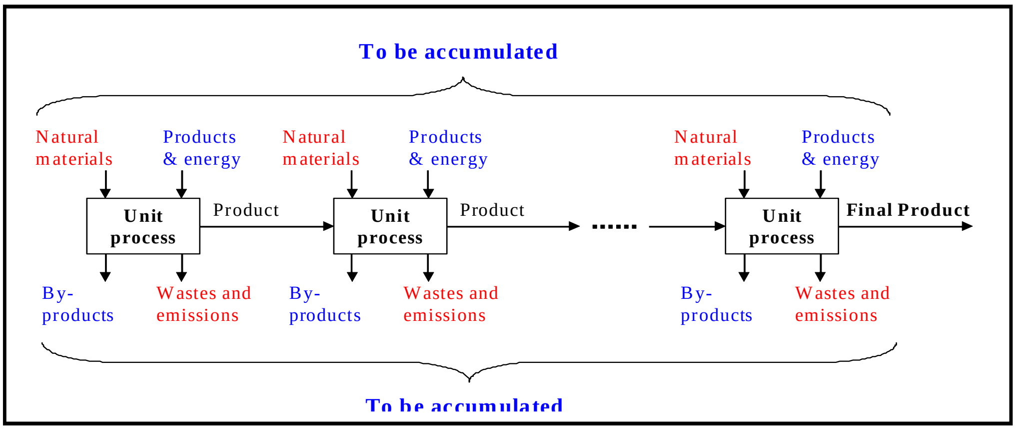

Figure 2 Scope of LCA analysis

The type of inputs and outputs that an LCA should embrace, and data for which should be collected, include:

- Energy inputs, raw material inputs, ancillary inputs, other physical inputs;
- Products; and
- Emissions to air, water and land, and other environmental aspects.

The inputs and outputs of a process may also be classified into economic flows and environmental interventions, as depicted in Figure 3.

The criteria used in LCA practice to decide which inputs and outputs are to be studied include:

- Mass - All inputs/outputs that cumulatively contribute more than a defined percentage to the mass input /output of the product system
- Energy - Those inputs/outputs that cumulatively contribute more than a defined percentage of the product system’s energy input/output
- Environmental relevance - Inputs/ outputs that contribute more than an additional percentage to the estimation quantity of each individual data category (e.g. sulphur oxides) of the product system.

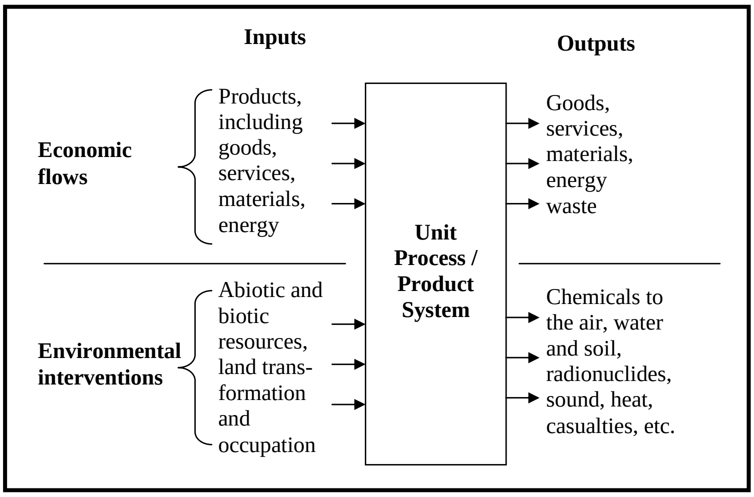

Figure 3 LCA process

1.4 Importance of Local Database

Due to the vast amount of data and processes involved, LCA practitioners need to be equipped with an appropriate calculation and data management tool for conducting LCA studies. The LCA tool should have access to databases that provide data for relevant systems and processes such that a model can be conveniently assembled for the product system under concern, and the inventory data made available for the impact assessment and interpretation of results. Expert knowledge is required for gathering inventory data and quantification of impacts. It embraces a diverse range of subject areas, such as environmental science, ecology, organic and inorganic chemistry, medical sciences, construction, economics, mathematics, mechanical, electrical, manufacturing and chemical engineering, etc. Even an LCA practitioner would need to be equipped with relevant and accurate inventory and cost data for all the materials and products involved, and an adequate LCA calculation tool, for conducting an LCA study. The current study, initiated by EMSD of HKSAR, was conducted with this background.

2.0 METHODOLOGY OF LCA TOOL FOR HONG KONG

To illustrate the essential features required of the LCA model to be developed in this study, a building is regarded as a product and the product life cycle is divided into the following phases (USEPA, 2003):

- Cradle to entry gate
- Entry gate to exit gate
- Exit gate to grave

The cradle to entry gate phase starts from extraction of raw materials and embraces all the processes for producing the construction materials and components required and bringing them to the site for constructing the building. The inventory data required include all the economic flows which embrace, in addition to the raw materials, any recycled and reused materials, intermediate products, and the energy and ancillary inputs required for the production and transportation of the construction materials and components. All the impacts (emissions or releases) incurred in these processes, which are the environmental interventions, are another essential part of the inventory data.

The entry gate to exit gate phase corresponds to the construction phase of a building. During this phase, materials and energy are consumed and construction wastes generated, which add to the inventory. However, data relevant to the local construction industry are at present lacking. Survey studies would, therefore, need to be conducted to collect data specific to local construction activities (see later descriptions on survey methods devised for data collection). To facilitate comparison studies on alternative designs or material uses, the material and energy use during the construction phase would need to be broken down into those incurred by individual types of materials and components.

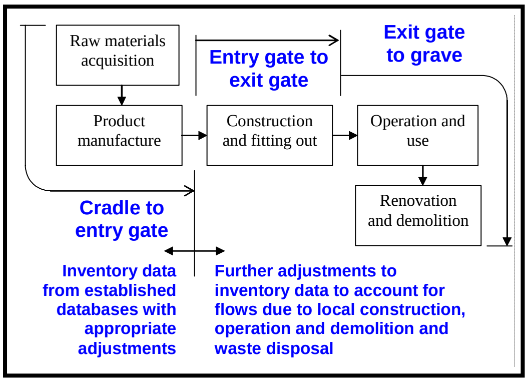

Figure 4 Stages of Building Life Cycle.

To address the need for an efficient tool for predicting the recurrent energy use in commercial buildings in Hong Kong for use in LCA assessments, a novel building energy prediction model will be developed for predicting the annual energy use for air-conditioning in buildings. Al alternative model will retain the theoretical rigour required for accurate prediction of building cooling load and plant energy use, but seeks to substantially enhance the computational efficiency such that prediction of the annual energy use can be accomplished within much shorter time than what would be required if a conventional detailed building energy simulation program was used. Figure 5 compares the calculation methods used in a conventional detailed simulation program and in the alternative method.

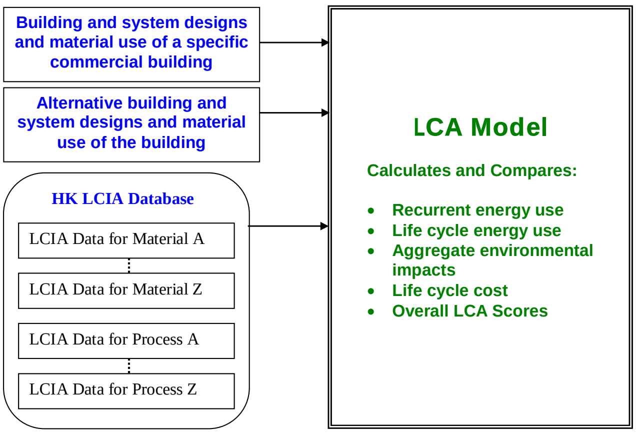

Figure 5 Model of LCA for Buildings in Hong Kong

The results of these studies will allow a database that contains the LCI data (the economic and environmental flows) for the major building materials and components, and building services equipment and materials to be established. Calculation routines will be developed for performing the classification, characterisation, normalisation and weighting processes.

3.0 PROCESSES OF DEVELOPING LCA TOOLS

3.1 Survey of Building Materials and Services in Hong Kong

A LCA model relies on a life cycle inventory (LCI) database to provide data about the economic flows and environmental interventions that would be incurred by consumption of materials and energy for construction, operation and demolition of buildings. A sample of representative commercial buildings has been selected as a basis for identification of the most commonly used building and building services components and materials among commercial buildings in Hong Kong. To ensure the obtained data would be representative of the current local building construction practices and reasonably comprehensive, the sample buildings are selected from a random list of commercial buildings on the basis of the following criteria:

(i)The selected buildings must be either completed within the past ten years or are under construction at the moment for completion. This is to forecast a meaningful indication of potential impacts for future buildings form latest development;

(ii)Information and details for any selected building should be complete, readily available and accessible;

(iii)The sample must represent a wide range of built forms, scale, grades, designs and specifications;

(iv)The sample must embrace buildings equipped with different types of building services systems.

Four Government office buildings have also been included in the survey for comparison of different purpose-built office buildings. In total, the building samples include 28 buildings, among which there are 16 private office buildings, 4 government office buildings, 4 retail centres and 4 hotels.

In this inventory study, four private commercial buildings of medium to small scale were selected in order to obtain an indicative picture about the potential outcomes and refine the methodology. In general, the major sources of information are the priced bills of quantities for the successful bids, technical specifications, tender documents and relevant materials submitted by the contractors in their tenders. Given that LCI data relevant to Hong Kong are basically unavailable, supplementary questionnaire surveys and interviews will have to be conducted with material suppliers, design consultants, contractors and building management companies to find out the countries of origin of the materials, components and equipments; the means used for their transportation to Hong Kong; and the common local practices of using material, equipment and systems in buildings, including for the maintenance and refurbishment work during the occupied stage.

3.2 Survey of Building Services in Hong Kong

This part of the Study aims to enable the impacts of services systems in commercial buildings to be estimated at the design stage to facilitate comparisons of alternative designs. The life cycle impacts to be evaluated should include the impacts of using resources for the production, transportation and installation of services systems and equipment, the total operating energy use of services systems and equipment during the occupied stage of a building, and the impacts of demolition and disposal of equipment and materials.

At the stage of building design where alternative services system designs are being considered, details of the system designs would not have been made available. For an instance, when a designer is considering using either fan coil systems or VAV systems for the office floors in a commercial building, the exact quantities, dimensions and capacities of air ducts, fan coil units or air-handling units and VAV boxes would not have been determined. Therefore, figures based on best engineering design would need to be established as default values for use in an LCA study to facilitate design decision-making. Nonetheless, the LCA software should allow the user to change the default values to better reflect the system designs under concern.

Similar to building components and materials for constructing buildings, a statistical analysis of design information pertaining to existing building development projects should be conducted to find out the types, quantities and key characteristics of services systems and equipment that are in common use in commercial buildings in Hong Kong. The study should proceed with identification of commonly used types of services systems and equipment in commercial buildings in Hong Kong, based on all buildings in the sample, to unveil the relation between building/premises types and choices of system designs. The study should identify also special system/equipment being used for enhancing environmental performance or energy efficiency of basic services systems, e.g. PV panels, air-to-air heat recovery wheels, light pipes etc. A list of common services systems that can often be found in commercial buildings in Hong Kong is shown in Table 1.

3.3 Adjustment for local and on-site construction processes

For ascertaining the energy uses and the local environmental impacts that are incurred during the construction stage, the survey will include interviews with and data collection from main contractors and sub-contractors of building projects, and companies providing local transportation services for materials and components. The survey will also cover companies responsible for off-site work, e.g. production of ready-mix concrete and pre-fabricated components. Although it would be difficult to obtain comprehensive and accurate data from such surveys, it should be possible to obtain estimates for various major construction processes that take place at different phases of the construction project by conducting necessary work studies to collect critical information, e.g. number of truck-loads, travel distances and data on fuel use per km for trucks, and the types and patterns of use of major construction equipment, for estimating the environmental impacts associated with different onsite construction processes.

Table 1 List of common building services systems and equipment

Basic installations:	
Heating, ventilating and air-conditioning (HVAC) installations Lighting installations Power distribution systems (Electrical installations), including essential power supply systems Vertical transportation (lift and escalator) installations Plumbing and drainage systems Fire detection and protection systems Automatic refuse collection systems Grey water recycling systems	
HVAC systems:	
Air-side systems:	All air systems, including: - Constant air volume systems - Variable air volume systems with and without variable speed drives - Dual conduit systems (CAV/VAV systems) - Dual duct systems (with mixing VAV terminals) Air-water systems, basically primary air fan coil systems
Water-side systems:	Heat rejection methods, including: - Direct air-cooled systems - Indirect air-cooled systems (water cooled chillers with radiators) - Direct seawater-cooled systems - Indirect seawater-cooled systems (with seawater/fresh water heat exchangers) - Evaporative cooling (water cooled chillers with cooling towers) Chilled water pumping systems, including: - Single-loop pumping systems - Two-loop pumping systems with and without variable speed secondary pumps Space/water heating systems, including: - Electric duct heaters - Electric water heaters - Reclaimed condenser heat (for space heating or water pre-heating) - Air and water-source heat pumps (for space heating or water pre-heating)
Lighting installations:	
Additional devices:	Various types of lamps, including T8 and T5 fluorescent lamps with and without electronic ballast, compact fluorescent lamps, GLS lamps, tungsten halogen lamps, LED lighting, etc. Dimming control using light sensors and/or occupancy sensors On/off timer control (discrete or through building management system) Zonal wiring Light pipes
Electrical installations:	
	Major equipment, including transformers, switch boards, cables, busbars, wiring, conduits, sockets etc. Standby generators Power factor improvement devices Power quality control devices Renewable sources, e.g. photovoltaic cells

4.0 LOCAL DATA OF BUILDING MATERIALS AND SERVICES SYSTEMS

4.1 Building Material Usage

According to the survey findings, concrete, rebar, plaster, render & screed together would contribute more than 83% of the total weight of building materials used in these buildings. Concrete alone would already contribute more than 70% of the total weight of building material in a building; rebar would contribute 6-7%, and plaster and render 5-6% of the total weight of a building. Other materials, including structural steel and bricks and blocks together, would only contribute up to 17% of the total building weight in all types of buildings (Table 2).

Table 2 Summary of Quantity Factors by Material Group for the Selected Buildings

Construction Floor Area (CFA)	Range From	To
Total Weight of Building Materials Used per m^2 CFA	1,903 kg/m^2	3,313 kg/m^2
Material Group		
Acoustic Insulation	0.04 kg/m^2	6.61 kg/m^2
Aluminium	5.65 kg/m^2	12.85 kg/m^2
Asphalt and Bitumen	0.00 kg/m^2	3.22 kg/m^2
Bricks and Blocks	9.74 kg/m^2	37.60 kg/m^2
Concrete	1,358.38 kg/m^2	2,650.90 kg/m^2
Formwork	3.13 $m2/m^2$	4.21 $m2/m^2$
Galvanised Steel	3.37 kg/m^2	23.59 kg/m^2
Glass	10.82 kg/m^2	14.67 kg/m^2
Paint	1.08 kg/m^2	2.59 $m2/m^2$
Plaster, Render and Screed	93.45 kg/m^2	151.34 kg/m^2
Plastic Laminate	0.05 kg/m^2	0.42 kg/m^2
Plywood	0.16 kg/m^2	0.79 kg/m^2
Reinforcing Bar	101.76 kg/m^2	255.95 kg/m^2
Stainless Steel	1.19 kg/m^2	15.99 kg/m^2
Stones	0.33 kg/m^2	36.77 kg/m^2
Structural Steel	49.04 kg/m^2	102.77 kg/m^2
Thermal Insulation	0.12 kg/m^2	1.16 kg/m^2
Tiles	3.12 kg/m^2	38.36 kg/m^2
Vinyl Tiles / Vinyl Sheet	0.00 kg/m^2	0.03 kg/m^2
Acoustic Tiles	0.00 kg/m^2	0.11 kg/m^2
Calcium Silicate Board / Fibre Reinforced Calcium Silicate Board	0.00 kg/m^2	0.26 kg/m^2
Firestop Insulation	0.00 kg/m^2	0.38 kg/m^2
Plasterboard	0.00 kg/m^2	2.18 kg/m^2
Plastic, Rubber, Polymer	0.09 kg/m^2	4.17 kg/m^2
Solid Surfacing Material	0.00 kg/m^2	0.04 kg/m^2
Cement Board	0.00 kg/m^2	1.08 kg/m^2
Durasteel	0.00 kg/m^2	0.25 kg/m^2
Special Aggregates (Dynagrip; in non-skid finish)	0.00 kg/m^2	0.15 kg/m^2
Access Floor Panel (Chipboard Core & Galvanised Steel)	0.00 kg/m^2	13.39 kg/m^2
Fireproofing Coating / Paint on Structural Steel	0.00 kg/m^2	0.00 kg/m^2
Photovoltaic System	0.00 $m2/m^2$	0.01 $m2/m^2$

The impacts in respect of the embodied energy, CO_2, SO_2 and dust emissions per square meter of CFA contributed by the building materials of the studied buildings were also determined. The embodied energy content per square meter of CFA for a building ranges from 9,448-10,907 MJ/m^2; the corresponding ranges of CO_2, SO_2 and dust emissions are respectively 639.96-783.22 kg/m^2, 0.89-1.22 kg/m^2, and 43.8-45.27 kg/m^2. The differences in the overall values of the four types of impacts among the four buildings are relatively small, generally less than 13% from their means.

4.2 Building Material Usage

Figures 6 shows the embodied energy content, CO_2, SO_2 and dust emission impacts of various building services systems installed in the four buildings. The HVAC systems contribute the greatest impacts, followed by electrical services and fire services systems.

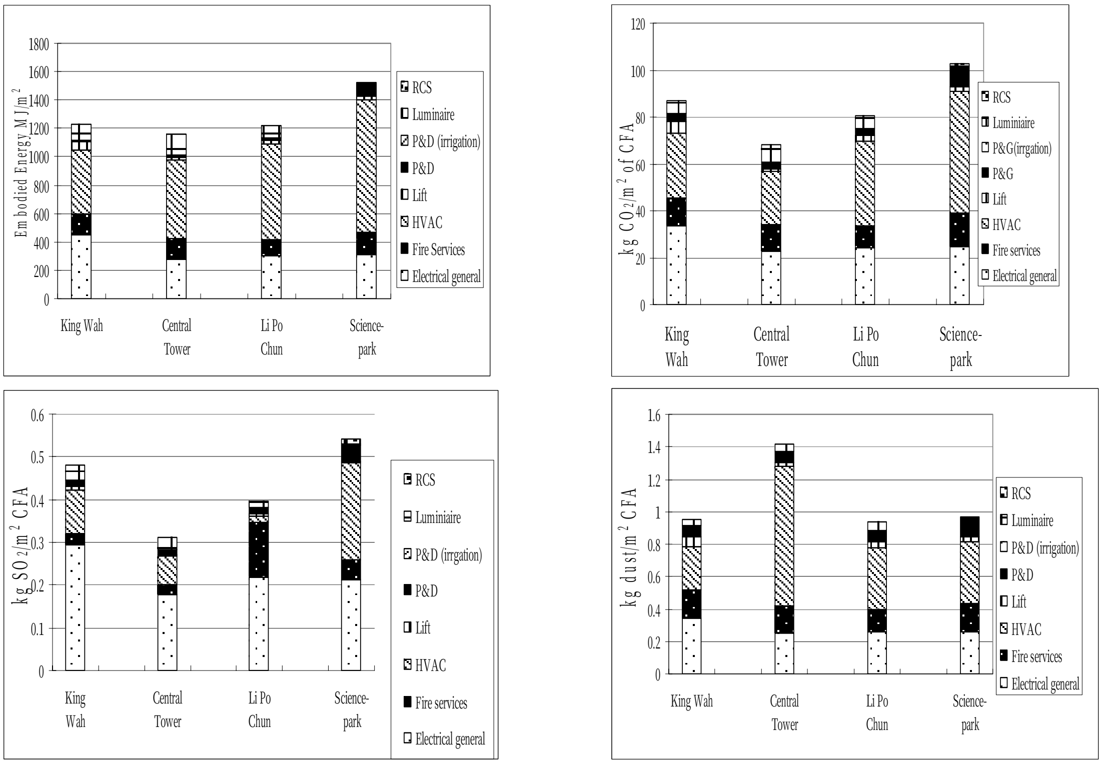

Figure 6 Impacts of various building services systems installed in buildings

From the survey of the different components within the Electrical Services, Fire Services, HVAC, and Plumbing and Drainage Systems, the main and submain cables in conjunction with lighting and power system contributed to majority of the impacts (76% of overall CO_2 emission impact; 83% of overall SO_2 emission; 79% of overall dust emission); pipes of the Fire Services Systems contributed to the majority of the impacts (97% for CO_2; 80% for SO_2; 97% for dust); water side piping together with air side ductwork also contributed to the majority of the impacts (66% for CO_2; 59% for SO_2; 90% for dust); while pipes also contribute 85% of overall CO_2 emission impact; 83% of overall SO_2 emission; 61% of overall dust emission.

5.0 Conclusions

Developing a LCA model for the use of the building industry is a complicated process. Reliable database on the usage of material and services in buildings as well as the LCI inventory of the materials used are the pre-requisite of its succeed. Extensive localization processes as discussed in this paper are necessary. The final LCA model developed can be used as a design tool for optimizing building design or a decision tool that assesses the sustainability of the buildings.

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掺杂对定形相变材料导热系数的影响

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摘　要　通过在定形相变材料中加添加剂改进定形相变材料的导热系数，用热针法对改性后的试样进行了测量,弄清了添加剂种类和含量对定形相变材料导热系数的定量影响。实验结果表明，石墨添加剂可以显著提高定形相变材料的导热系数。通过对实验数据的拟合，得到了石墨添加质量分数与材料有效导热系数间的拟合公式。

关键词　热针法；定形相变材料；导热系数；添加剂
中图分类号：TK512+.4　　　　文献标识码：A

0　引　言

相变材料由于其较大的潜热蓄热能力及蓄放热过程近似恒温等特点，在太阳能利用、区域供暖和供冷、建筑节能及纺织纤维等方面引起了广泛关注[1−7]。叶宏等对相变材料的物理化学性质进行了分析，林坤平等对相变材料在电加热采暖中的应用进行了实验测试。普通固液相变材料虽价格便宜、相变潜热大，但需容器封装，造成附加热阻，不利于传热，且易泄漏。图 1 为定形相变材料的电镜照片[2]。定形相变材料由石蜡等心材和 HDPE 囊材构成，HDPE 起微封装和支撑作用，因此既具有较大的相变潜热，又能在相变过程保持形状固定。但由于定形相变材料的组成成分均为有机物，其导热系数一般较小。这使得相变材料吸放热速率较慢，阻碍了该类材料的有效应用。

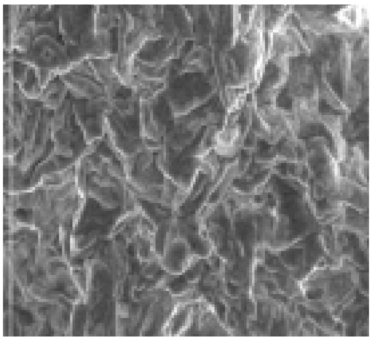
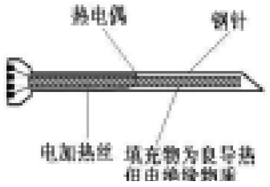


图 1 定形相变材料电镜照片(×3000 倍)

物体的导热系数和材料的成分、结构和所处的状态等有关。本文采用在定形相变材料中添加导热系数较大的固体粉末的方法，提高定形相变材料的导热系数。对各种改性定形相变材料试样，用热针法测量其导热系数，误差在 5%以内[8]。通过实验数据分析，得出了掺混石墨可明显增大定形相变材料的有效导热系数，并得到了其间的定量关系，为定形相变材料导热系数的改进提供指导。

1　测量原理和方法

本文采用热针法测量定形相变材料试样的导热系数[8−14]。热针由针管、电加热丝和热电偶组成（见图 2）。针管长 46mm，管外径 0.7mm，内径 0.4mm。电加热丝选用电阻随温度变化很小的锰铜丝，螺旋状绕制在针管中。在针管内壁中部贴有一热电偶，电加热丝与针管间填充一种绝缘导热胶。电加热丝和热电偶导线从针帽处引出，用环氧树脂与针帽固定。



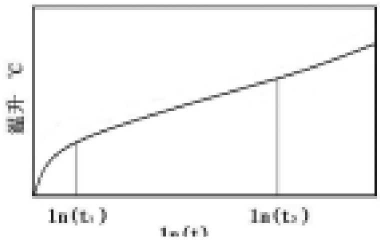


图 2　热针结构示意图　　　　　　　　图 3　热针温升与时间对数值关系典型曲线

当热针放置于被测介质中，导热可近似为一维导热时，热针温升与时间对数值关系的典型曲线见图 3[10]。时间 t1<t<t2 时，被测介质的导热系数可表示为：

$$k_m = \frac{q}{4\pi} \Big/ \frac{\partial \theta_h}{\partial \ln t} \qquad (1)$$

式（1）中 $q=I^2 Re$ 为单位长度热针的加热功率，Re 为单位长度热针的电阻，θ_h 为热针温升，t 为时间。在图 3 中表现为在时间 t_1、t_2 之间，θ_h 与 ln(t)间为一直线。实验中，记录不同时刻的热针温升，在 θ_h 与 ln(t)呈直线关系的区间，利用最小二乘法对实验数据拟合，可求得 $\frac{\partial \theta_h}{\partial \ln t}$，从而得到 k_m 值。时间 t_1 可由 $r_t^2/4\alpha t < (0.16)^2$ 确定[12]，文献[10]分析了热针长度和边界条件对瞬态热针法测量导热系数的影响，一般被测介质外径 $R_o \geq 2.61(\alpha_m t)^{0.5}$，热针长度和被测介质厚度 $L \geq 7.96(\alpha_m t)^{0.5}$ 时，边界的影响可以忽略。由此可以得到 t_2 的取值范围。为了减小热针轴向的热损失，一般建议热针的长径比大于 25，本文采用的热针满足这一条件。本实验中，电流值由数字电流表测得，单位长度热针电阻值 Re 由标准试样甘油标定得到，重复性偏差小于 1%。

表 1　按质量分数 10% 添加不同添加剂的试样成分配比与导热系数测试结果

试样编号	添加剂	导热系数 k（W/mK）	测量次数	最大相对误差（%）	比原样增加百分比（%）
原样	——	0.150	6	1.5	——
1	10%三星硅藻土 AG-WXI	0.158	6	1.6	5.3
2	10%三星硅藻土 AG-JXE	0.156	6	2.2	4.0
3	10%有机膨润土 JF-38	0.163	6	2.0	8.7
4	10%针状硅石粉 G-800F	0.180	6	1.9	20.0
5	10%有机膨润土 B5-1C	0.154	6	2.1	2.7
6	10%CaCO3 1250	0.158	6	1.9	5.3
7	10%纳米 CaCO3（未活化）	0.159	6	1.9	6.0
8	10%纳米 CaCO3（已活化）	0.159	6	1.2	6.0
9	10%石墨	0.229	6	2.3	52.7

2　试样制备

我们分两步研究添加剂对定形相变材料导热系数的影响。首先，在定形相变材料中按同样质量分数 10%加入不同的添加剂，制得不同的试样（见表 1）。接着，我们选出其中导热系数增大最明显的试样，改变其中添加剂的质量分数制成不同试样（见表 2），研究导热系数与添加剂质量分数之间的关系。为了适合热针法测量，选用试样的高度必须大于 50mm。

表 2　按不同质量分数添加石墨的试样成分配比与导热系数测试结果

试样编号	添加石墨含量(%)	导热系数 k (W/mK)	测量次数	最大相对误差 (%)	比原样增加百分比 (%)
原样	——	0.150	6	1.5	——
10	5	0.204	5	1.3	36.0
9	10	0.229	6	2.3	52.7
11	15	0.310	5	3.2	106.7
12	20	0.482	5	2.7	221.3

3　测量结果及分析

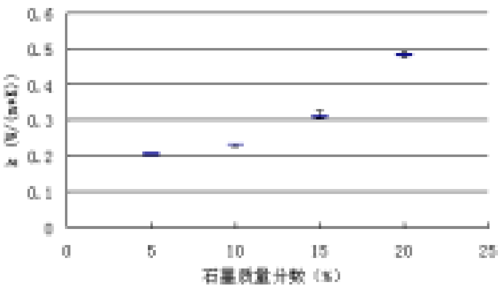


图 4　20℃时不同石墨含量试样导热系数

表 1 列出了质量分数为 10%的不同添加剂的各个试样的导热系数值，可以看出加入不同的添加剂，试样的导热系数会有较大差别，其中添加石墨的试样导热系数最大，为 0.229W/mK，比普通定形相变材料的导热系数 0.15W/mK 增加了 52.7% ;添加有机膨润土 B5-1C 的试样导热系数增加最小，为 0.154W/mK，增加了 2.7%。

表 2 和图 4 显示了添加不同质量百分比石墨的定形相变材料的导热系数值，可以看出，随着石墨质量分数的增大，试样的导热系数也随之增大，而且增长速度越来越快。基于测量结果，可拟合得到试样的导热系数 k 和试样中石墨质量分数 x 的关系为

$$k = -333.3x^4 + 213.3x^3 - 31.97x^2 + 2.187x + 0.15 \quad (0 < x < 0.2) \qquad (2)$$

公式相关度 R 为 0.99。

石墨质量分数小于 15%，相变材料试样的机械强度较好。但当石墨质量分数达到 20%时，此时的定形相变材料机械强度很差，而且相变材料泄漏严重。因此，具体应用中石墨掺杂要视应用要求而定。

4 结 论

本实验通过在已有定形相变材料中添加导热系数较大的固体粉末来提高其导热性能，并用热针法对试样的导热系数进行了测量。实验结果表明：(1) 在定形相变材料中添加不同的添加剂，可调整其导热系数。有些添加剂如石墨可以明显提高定形相变材料的导热系数，但当添加剂含量增大到某一范围时，定形相变材料的机械强度会明显下降。(2) 在石墨含量为 0-20% 范围内，掺杂定形相变材料导热系数随石墨含量的增加而增大，当石墨含量为 20%时，定形相变材料的导热系数增大 221%，由实验数据，得到了定形相变材料导热系数与石墨质量参混比 x 间关系的拟合公式：$k=-333.3x^4+213.3x^3-31.97x^2+2.187x+0.15$，公式拟合相关度 R＝0.99。

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The Influence of Doping Materials to the Thermal Conductivity of Shape-stabilized Phase Change Material

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Abstract This paper investigates the influence of doping material on the thermal conductivity of shape-stabilized phase change material(PCM). The thermal conductivities of the shape-stabilized PCM samples were measured by a thermal probe. The experimental results show that different additives have different influence on the thermal conductivities. Adding graphite can improve the thermal conductivity of shape-stabilized PCM obviously. The empirical correlation between the mass fraction of doping graphite and the effective thermal conductivity of the shape-stabilized PCM doped was obtained.
Keywords thermal probe, shape-stabilized PCM, thermal conductivity, additive

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可持续发展的建筑学

（Sustainable Architecture）

—借鉴与尝试

张宏儒　（上海建科建筑设计院）

主题词　可持续发展的，建筑学

本文从建筑的非物质层面探讨可持续发展思想的贯彻运用

The article discusses sustainable principles in architecture

SB—Sustainable Building，可持续发展的建筑物。但是，Building（建筑物）要从 Architecture（建筑学）开始，并以 Architecture 作为最终目标。所以作为建筑师，必须研究 Sustainable Architecture，才能做好 Sustainable Building。

众所周知，“ 生态化 ” 或 “ 可持续发展 ” 的目标可以概括为：

a、减少消耗；

b、减少对大环境的负面影响；

c、增进小环境的舒适与健康。

这些大都有可测量的指标进行预设与控制，例如自然材料、再生和可再利用材料的使用，节能和现场自然能源的利用，排放的控制，节约水资源，声光环境模拟，等等。建筑设计中通过选材及构造设计，配合各种专业的工作成果，可以为这些指标的实现提供工程手段的支持。

但是，只有这些是不够的。

二十世纪以前，我们认为世界由两个最基本的要素构成：物质和能量。即世界上存在的一切、发生的一切，都是物质和能量的形态及其变化与转换。到了二十世纪，我们发现还有一个基本要素不可缺少：信息。这个 “ 信息 ” 不是我们现在通常说的 “ 信息产业 ” 这个狭义的信息。从充斥宇宙的自然信息直到人类 “ 只能意会，不可言传 ” 的思想交流，都属于这个广义的信息范畴。这一洞察概括了世界的本质，更揭示出我们正是通过信息才得以感知这个世界，从而影响这个世界。

和我们整个社会的可持续发展一样，建筑的可持续发展也应该从物质、能量和信息这三个方面进行努力。技术手段（其中包括狭义的 “ 信息技术 ”）可以解决物质和能量的问题；观念革命，也就是可持续发展信息的全面覆盖，则是整个生态运动的根本。生态建筑学，或曰可持续发展的建筑学，在其中担负重要的责任。

建筑学研究建筑的使用功能与精神功能。严格地说，这两种功能都是不可测量的。我们从中可看到最多的是构成世界的第三个要素：信息。人们常引用老子《道德经》中的一句话：“ ……凿户牖以为室，当其无，有室之用…… ”，建筑中的 “ 无 ”，即空间，是其（狭义的）使用功能的载体，

这个空间是否得当、适用，甚而触动心灵、愉悦身心（广义的功能），都无法具体度量，但却能给我们明确的信息；建筑的形式更是以精神功能为要旨，是更纯粹的信息载体。形式被赋予精神功能就成了“ 形象 ”。空间给我们信息，形象也给我们信息。这些信息是否是生态的？是否包含可持续发展的思想？这就是生态建筑学需要回答的问题。

首先，建筑要符合可持续发展的规划

规划是宏观问题，不属建筑学的领域。但是生态建筑应该符合生态的规划，片面强调建筑自身，不顾区域的整体生态效益是不妥当的。可持续发展的终极目标是宏观的，因此每一级的目标都应服从上一级目标。我们在做一个生态敏感区域的规划与建筑概念设计项目时，尝试贯彻生态理念，既得到了开发方的支持，也获得了当地政府与规划部门的肯定。

案例一：黄山北驿旅游度假区概念规划设计

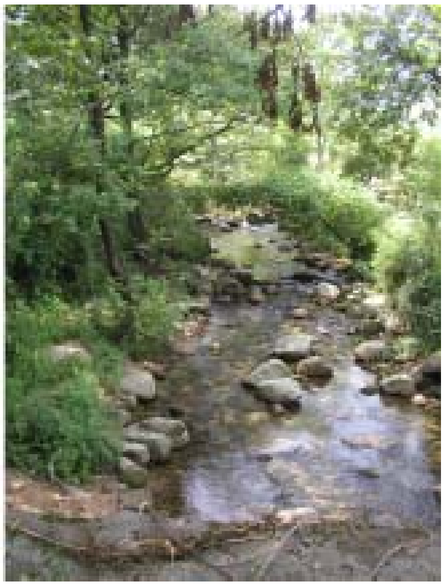
黄山作为世界自然与文化遗产，旅游负荷巨大。本项目规划意图是作为辐射黄山、九华山、太平湖等风景区的旅游集散地。游人集结于此，每天早出晚归，可以游览几个景区。这样就可以大大减少各景区内的食宿、交通等服务设施。黄山的旅游资源最为丰富，因此选址在其北麓，以利旅游者数天内多次上山，由此可以撤消山上的几个旅馆，恢复森林风貌，减少污染。

基地紧贴黄山北麓，顺着两条黄山瀑布下游形成的溪流，成狭长形状，占地 200 公顷。地势起伏，植被丰富，水系发达而涨落不定；一条直通黄山北面太平索道的公路贯穿南北。

规划方案以安徽省“ 两山一湖旅游区总体规划 ”为指导，根据地块内地势和小气候特征进行分区，并结合交通的合理化布局。南区因贴近黄山群峰，夏季风速较小；溪谷深且落差大，暴雨季节不易溢流；与黄山索道联系便捷，适合建筑密度高的旅游服务区，取名“ 山街水肆 ”；此区内按照地势水土植物等生态特征，设金、木、水、火、土五个景观节点；北区离黄山较远，夏季东南风充足，冬季寒风被西、北面丘陵阻挡，靠近小城镇，因此作为度假别墅区，是为“ 山居水寓 ”。此区建筑密度低，容许水系在一定范围内涨落变化。一些亲水别墅具有“ 两栖 ”性，也就是在雨季成为“ 水居 ”，可用小舟作交通工具，富有江南水乡特色，让游客住在风景中。

北区现状：河滩湿地，白鹭戏水。远处（南面）为黄山，右边（西面）为其余脉丘陵

现状：黄山飞龙瀑为基地内溪流之源



现状：水系支流小溪

现状：溪流上的水车是利用现场自然可再生能源的原始方式

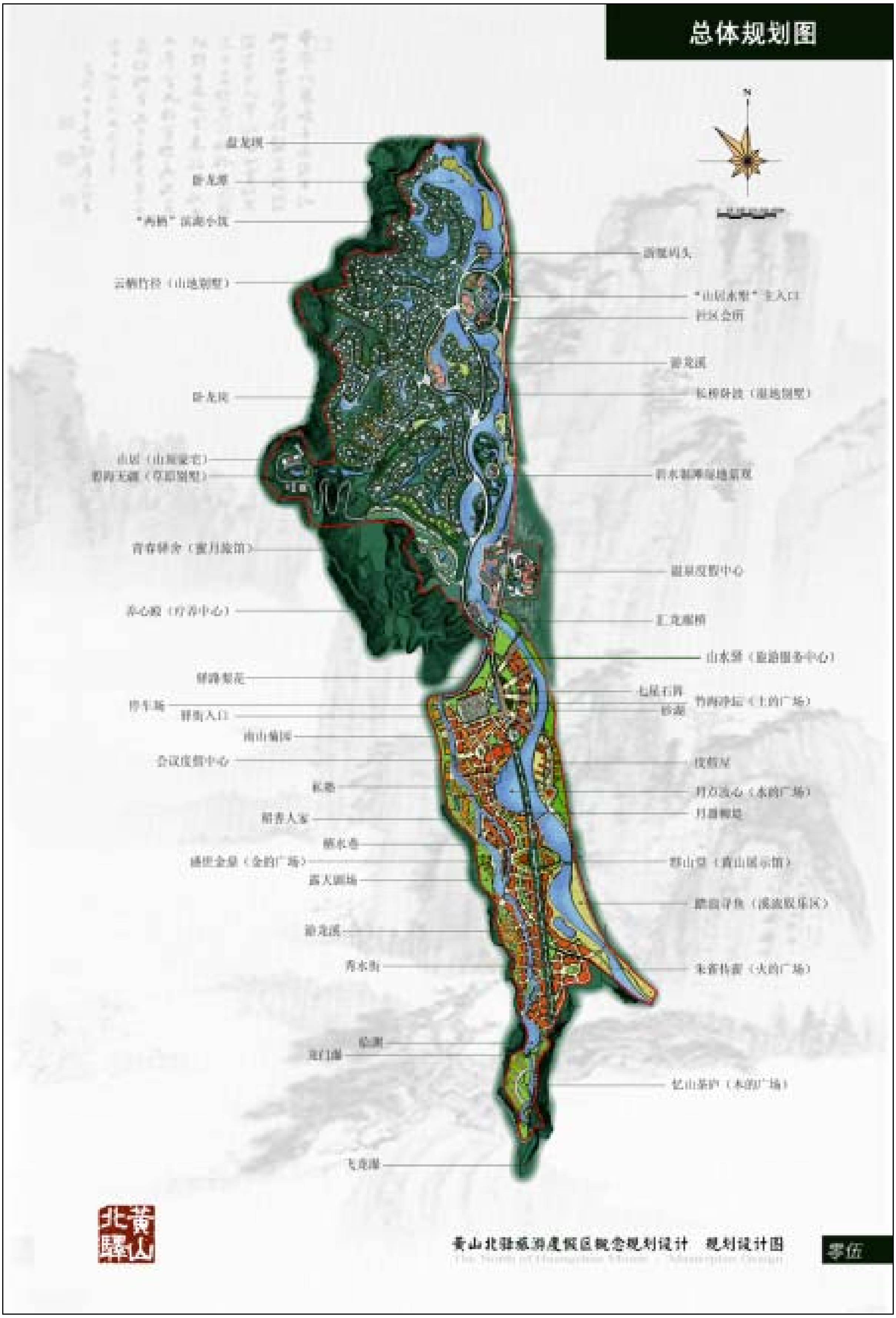
便。

现状：低层高密度的村落与大自然和谐相处

现状：竹林

现状：古树

度假区内规划的建筑密度较高，以减少耕地占用；建筑体量小，并尽量利用当地材料，如石料、竹子、基地生土、速生林木等；建筑与车场等设施均考虑原有溪流水系、植被的分布以及自然通风、自然采光、隔热保温、防晒遮阳、地势水文等因素；降低不可再利用材料（如水泥）的使用，杜绝不利于节能且产生光污染的玻璃幕墙。对原有湿地、滩涂加以重点保护，维持当地的生物多样性。根据当地水文情况在开发区上游设置水源保护区，设立小型自来水净化站。利用水流落差设置小型水电站，补充电力资源，同时用水坝稳定水平面高程，制造水景变化。自然村落中一些保存较好的建筑拟改造利用，赋予新的功能。限制机动车活动范围，为步行、骑马与非机动车交通提供最大方便。



总体规划图
停车场
会议度假中心
秀水街
飞龙瀑
黄山北驿
黄山北驿旅游度假区概念规划设计 规划设计图
零伍

第二，建筑应摈弃豪华夸张

夸张豪华的建筑，除了材料、能源和资金的过多耗费，更重要的是它将人们的兴趣引向奢华，对我们的地球生态带来的负面影响将远大于几座“ 不生态 ”的建筑物。

现在是所谓的消费时代，资本就象蚁后，向蚂蚁般的众生不断发出信息，鼓励人们追求超过自身实际需要的消费。从某种意义上来说，超消费就意味着超消耗。所谓“ 最成功的推销是为‘ 潜在的 ’顾客‘ 发明 ’需求 ”。某些发达国家人均的物资和能源消耗数倍于平均水平，这决不是发展的方向。在许多情况下，建筑也成了这种超消费信息的载体，而且是最有影响力的载体，因为它那使接近者不可忽视的体量、它给予人影响的长期性、它的实现难度，还有就是它在城市中的重要性。太多带有妄想症性质的“ 标志性建筑 ”已使我们城市失去层次感，使我们的视觉麻木，同时，更严重的是，它们发出的信息引导人们追求奢华从而给我们的地球生态造成无法估量的损害。

案例二：雷克雅未克市政厅

作为一个国家首都的市政厅，其朴实优雅的形象使我们震惊。

清水混凝土的简洁外形，亲切朴实。水面不大，且与湖泊相连，表现岛国的地理特征。

入口尺度宜人，出入自由，前后相通。采自城郊的火山岩石做成景观墙，作为攀爬植物的承体。紧急疏散楼梯置于室外，缩小了采暖空间。

底层大厅设有咖啡吧，面对水景的大窗前有供市民休息的座椅。当地居民普遍表示非常喜爱这座建筑。

西面大玻璃窗上的固定遮阳

东面外观。公园游人可从湖上小桥进入市政厅

西端的疏散楼梯

地下室紧急出口隐于水面以下

第三，尽量减少对原有环境的破坏，并充分利用现场资源

这里所说的环境，包括自然环境与历史环境。对于具有环境价值的基地，每一个新的建筑都会对原有的自然环境和历史环境带来破坏，建筑师有责任赋予新建筑充分的人文价值，以平衡这种破坏给人们的心灵造成的伤害。

案例三：某中学科教馆

基地原有一座二层四合院红砖建筑，建成于上世纪初，是该校最早的校舍之一，地处山坡。四周草深林幽，古树参天。院内有琉璃瓦砖亭，亭内有古井，还有一棵大树如巨伞覆盖砖亭。这个院落已在学校一代代师生心目中留下深刻印象，但是其安全性与适用性已远不符合需要。

原有建筑已破损不堪

四合院拆除后现场

新建筑顺山势而建，周围树木全部保留

次入口外面的小树都保留下来

透过楼梯间角窗外望

建筑设计继承这一意蕴深厚的格局，但新的四合院放大了，完整保留砖亭、古井、香樟，并将其围绕于核心。

基地上的大小树木全部保留下来，并充分利用其遮阳与景观作用。

南面遮阳与楼梯间倾斜角窗

门厅与环境的关系

案例四：某中学图书馆设计

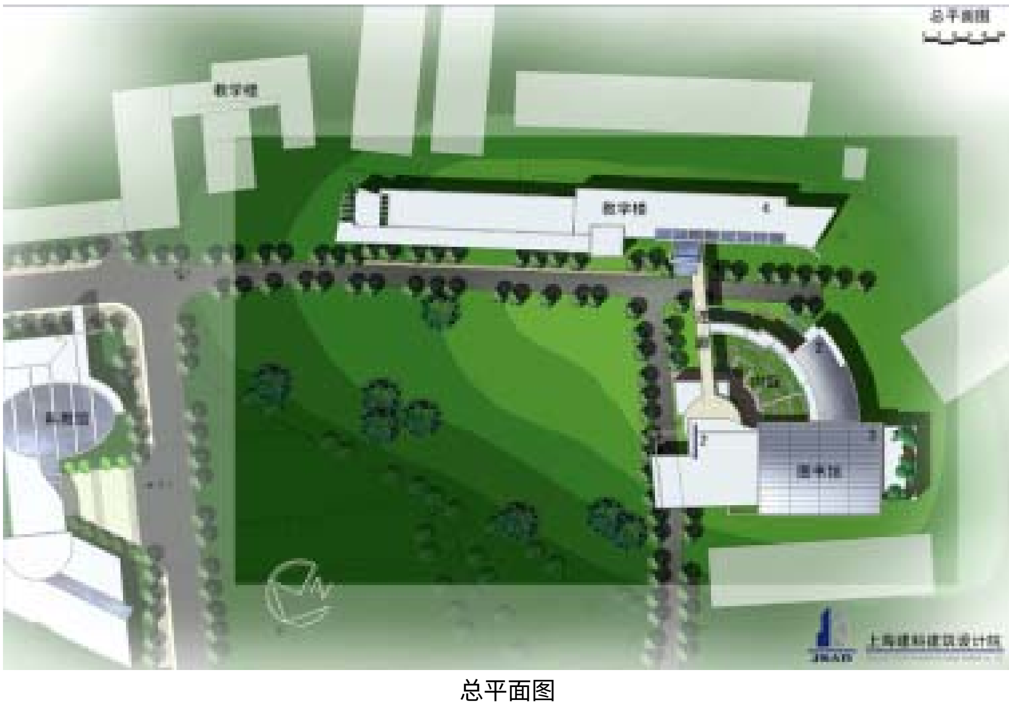
本工程为一所省级重点中学的图书馆。基地内原有一座单层工业厂房，校方原计划拟拆除。建筑师提出保留改造设想后，经检测厂房结构仍坚固可用，其钢筋混凝土屋面桁架，轻巧优美，现在的城市建筑中已十分罕见。厂房内空间高敞，桁架高 2~3 米，下弦离地高度 9 米；钢筋混凝土屋面板还具有一定的装饰效果。

原有厂房外景

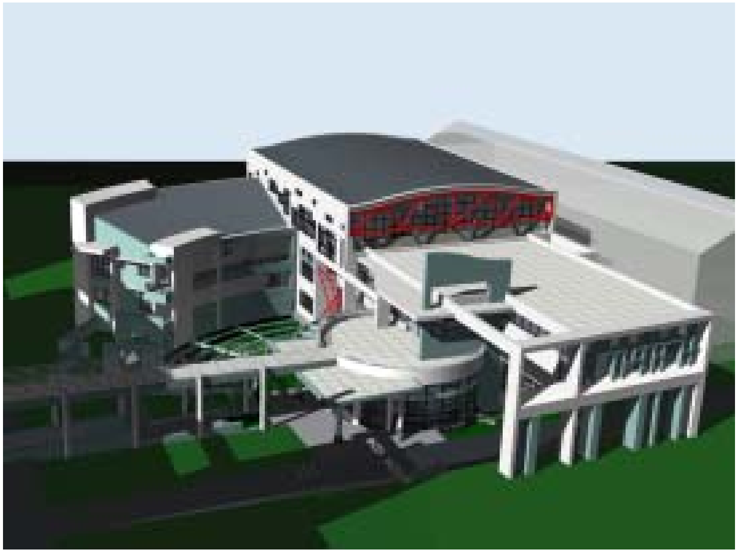
原有厂房内景：混凝土预制顶棚

设计在厂房大空间内增加二层楼板，从下至上分别形成 2.6 米、4.0 米、2.8 米三个层高。底层为书库，二、三层为主要阅览空间，其中三层 2.8 米层高指桁架下弦底面，桁架全部暴露在室内，所以实际层高达到 4.8~6.8 米，

吊灯、吊扇等均安装在 2.8 米以上；整个大厅东西长 24 米，南北宽 16 米，中间没有柱子。对于一个中学图书馆来说，这样的大阅览室是不敢想象的。



总平面图



设计中对自然通风和采光都作了精心处理。门厅、检索处、楼梯等辅助用房附着于厂房的周边，并在空间与造型上紧密结合在一起。门厅通过连廊与新建教学楼连接。

本项目已完成施工图设计。

第四，建筑要让与之有密切关系的人感到愉快，有利于其精神健康

生态目标第三条：增进小环境自身健康舒适愉快。人的一生平均约 70%的时间在建筑物内度过，如果加上在建筑物附近的时间，那么人受建筑影响的时间将达 90%。

其实，人的健康愉快还具有更长远的意义。我们提倡可持续发展，本质上是对后代负责，所谓“给后代一个健康的地球”。但是还有一件事同样重要，那就是“给后代留下健康的基因”。这两个目标加起来，才是完整的可持续发展目标。

健康的基因，来自健康愉快的身心。既然人与建筑密切相关的时间占整个人生的 70%~90%，那么使人愉快的建筑可以为这一目标作出非常重要的贡献。

案例五：奥斯陆机场。

该建筑的屋顶开天窗自然采光，白天基本不需人工照明。其天窗光线不直接射入大厅，而且是用弧形大梁的木饰板发射，光线柔和均匀，温暖明亮，效果爽朗大方。在北欧的寒冷气候中给人带来愉快的体验。

案例六：上海生态办公示范楼

确定的设计方案

这是位于上海郊区的一座实验兼办公建筑，由于作为生态示范楼，加入了一些展示和接待功能。

每天在这个楼里工作的，是一个部门的研究人员。他们大都很年轻，并且一直在市区总部工作。设计考虑为他们提供的新工作场所应该让他们感到舒适愉快，让他们喜欢这个房子，作为鼓励他们喜欢自己的工作的一种方式。这不仅是出于提高效率的考虑，更重要的是以人为本。每个工作日待在这幢楼里的时间超过八小时（包括中午的短休），几乎占一天中（平均）清醒时间的 50%。因此这个楼被设计成象一

个简化的俱乐部。里面有一个大的共享空间—中庭，其底层是室内生态绿化园，分隔展示区和交流区；中庭二层周边设一圈“ 跑马廊 ”，员工从办公室出来或坐在休息室即可欣赏中庭绿化，并有许多与同事见面和交流的机会，打破一般办公室类似旅馆客房的单调格局。大楼北部有三层办公室，所以中庭顶面为朝南倾斜面，开设玻璃天窗，冬季可为北面二、三层房间提供日照，夏季则用电动遮阳蓬遮挡辐射。

设计师衷心希望在这幢建筑里面工作的人们能够喜欢它。

按照首轮施工图绘制的效果图

8 月中旬施工现场

第五，从传统建筑文化中吸取精华

本地传统建筑中有许多生态思想和设计手法，仍然具有生命力。我们应该吸收借鉴。

江浙民居：天井，sky well，采光、通风，空间中心、交流场所

江浙民居：窄巷形成通风道，房间向巷内开窗

江浙民居：天井，绿化景观引入室内

江浙民居：起居空间与天井结合；高窗通风

江浙民居：起居空间与天井结合

江浙民居：建筑外挑与花板遮阳。在生态办公示范楼中借鉴运用，以电动铝百叶取代花板

案例七：生态别墅设计

一个大开发公司在已完成设计的别墅区内，决定将其中位置最好的两幢重新设计，作成生态别墅的试点。

设计借鉴了江浙民居中的窄巷通风、天井采光、室内绿化、植物遮阳等传统生态建筑手法与居住空间特色，并结合了其它生态建筑技术。

本项目正在进行施工图设计。

结语

生态运动不仅是一场技术运动，而且更是一场观念革命。技术的研究和拓展，是这场运动不可缺少的支撑；但只有观念的彻底更新才能使之取得全面的推进和期望的效果。我们并不追求每一座建筑都是纯粹的或者说全方位的“生态建筑”，尤其在开始阶段，这样做很容易给运动本身带来巨大的阻力。概念房或者示范楼是必要和重要的，其目的是为了倡导生态理念，而不是叫人全套照搬。在可能的条件下，尽量贯彻可持续发展思想进行每一个建筑工程的建设，选取适宜的生态技术，用生态建筑学的原理进行设计，才是推动可持续建筑运动的最好方式。

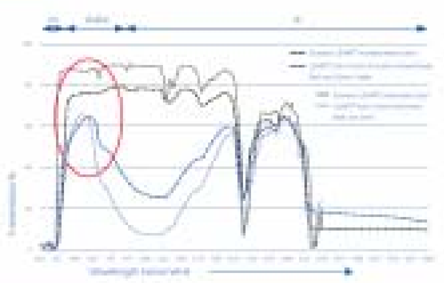
NEW LEXAN® SOLAR CONTROL SINGLE AND MULTILAYER SHEET

GE Advanced Materials has recently introduced a new family of transparent, solar-control glazing products in solid and multi-wall polycarbonate sheet that can significantly reduce solar transmission while simultaneously offering high levels of light transmission, which could help to save energy costs for cooling and lighting buildings.

The near Infrared region of the light carries the largest part of the solar heat. LEXAN® Solar Control IR sheet contains a proprietary additive which selectively absorbs this part of the light spectrum while keeping the visible part to a high level. By absorbing a large part of the near Infrared region, LEXAN® Solar Control IR sheet can significantly reduce the solar heat build-up underneath and help to maintain comfortable interior temperatures which can reduce air conditioning cost during hot days. This useful shielding property can also help to prevent discoloration of sensitive materials such as fabrics or other organic materials and help to improve comfort sensation in, for example, factory warehouses, museums or shopping centers.

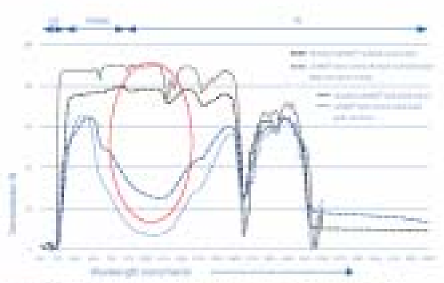
Both solid and multi-wall products can offer alternative as a glazing material that combines design freedom, light weight, high levels of light, while helping to keep excess heat to a minimum and helping to reduce energy savings, making them excellent candidates for roof domes, skylights, walkways, conservatories, and other buildings. Additionally, the solid sheet may be used for public transportation applications, such as various train and bus glazing.

Figure 1:



LEXAN® solid and multiwall sheets have the highest transmission in the visible part of the light.

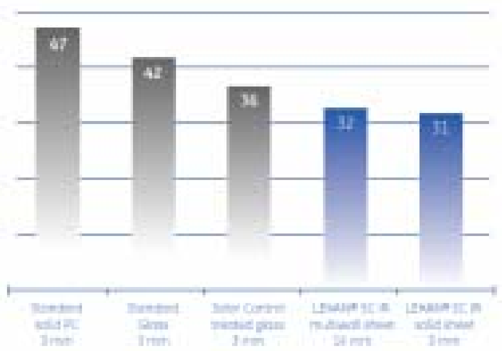
Figure 2:



LEXAN® Solar Control IR sheet selectively blocks the near infra-red region of the light, therefore reduces the heat build-up.

GE Advanced Materials ’ new heat--management glazing makes use of a new and innovative technology platform. Instead of being translucent or opaque as previous products, the LEXAN® Solar Control IR sheet materials are transparent with a light green tint, which blocks near-infrared heat but lets in high levels of light. Proprietary resin additives are used to manage heat instead of expensive and fragile coatings, which can be damaged during handling and installation. Because the additive technology, solar control properties are enduring and sheets are UV protected on both sides, which can help installers reduce losses due to installation errors.

GE Advanced Materials ’ model--scale*energy consumption studies at the Welch Technology Center in India show that by using LEXAN® Solar Control IR sheet, interior heat build up can be reduced significantly, which could result in 25%-40%energy savings in a temperature controlled environment. The relative annual energy consumption to maintain room temperature between 20 and 27 °C is shown for several materials. LEXAN® Solar Control IR sheet shows the lowest energy consumption compared to other glazing solutions.



Comparison of total annual cooling and heating energy usage in thousands of KwH in a modeled building

The result can vary with building design, climate, and heating/cooling equipment. Therefore GE Advanced Materials has developed a calculation tool to estimate energy savings as a function of several of those variables (Please contact GE Advanced Materials development engineers to get a personalized estimate of potential savings for your project).

This new heat-management glazing material range by GE Advanced Materials, offers new [or be specific as to which environmental regulations this is compliant with] solutions to architects in an era where energy savings are key.

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LEXAN is registered trademark of General Electric Company.

* GE Advanced Materials conducted a climate simulation on a model building (8 m x 6 m x 2,7 m)with an 12 m2 window (looking at north) and 48m2 roof glazing surface. ASHRAE case 600 roof-glazing model.

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中文:

LEXAN®力显™太阳能控制 IR 板材

GE 高新材料最近推出两种新型透明、太阳能控制的聚碳酸酯采光产品，分别是单层和中空的聚碳酸酯板材，这种板材在很大程度上能减少太阳能透过同时提供高程度透光率，在建筑的降温和照明中能够节省能源成本。这种单层产品名称是 LEXAN®力显™EXELL®太阳能控制 IR 板材，中空产品的名称是 LEXAN THERMOCLEAR®太阳能控制 IR 板材。

LEXAN 太阳能控制板材透明且略带绿色，它可阻挡近红外线的热量，但可以让大部分可见光通过。专利的树脂添加剂可用来管理热量，来代替在处理和安装过程中可能损坏的昂贵易碎的涂层材料。因为 GE 添加技术对聚合体来说是内在的，所以太阳能控制实质上是持久的，并且为板材的两面都提供 UV 保护，这可以防止因安装错误而造成的板材抗老化性能损失。

通过 GE 高新材料在印度的韦尔奇技术中心的模型房中的能量消耗研究，结果表明使用 LEXAN®力显™太阳能控制 IR 板材可以大大地减少室内的热量聚集,对于一个室温控制在 20 ^{o}C 至 27 ^{o}C 之间的房间,能量节约达到 25%-40%.

实心板材的产品牌号为 LEXAN EXCELL® D 太阳能控制 IR 板材,而中空板材牌号为 LEXAN THERMOCLEAR®太阳能控制 IR 板材.

这两种产品是屋顶、天窗、走道、温室以及其它需要高采光且需将热量聚集限制到最小程度的建筑物理想选择。此外，这种单层产品也瞄准了公共运输方面的应用，像火车和汽车采光部分。其它具有热能管理，基于聚合体的采光材料不可能像 GE 这种新型材料一样在高效地阻挡（吸收）红外线热量的同时容许高度的可见光的穿透过。

GE 高新材料在一个有 12m^2 窗(朝向北方)和 48m^2 采光屋面的模型房中(8m x 6m x 2.7m)进行的气候模拟实验.

结果可能会因为房屋设计,气候以及制热/制冷设备而变化.

LEXAN, THERMOCLEAR and LEXAN EXELL are registered trademark of General Electric Company.

无锡高山肖巷安置房小区规划设计

一对中国绿色生态住宅小区的实践

加拿大凯厦罗玛建筑设计事务所首席建筑师 李书谊女士

摘要:

本文是对实现绿色生态住宅小区理念这一课题的补充和追问。借助无锡南长区高山肖巷住宅小区的设计提出绿色生态住宅小区的可实现性,解释了这一理念的意义及价值,并借此呼吁社会加强对绿色生态的关注,促进可持续性发展的进程.

关键词: 绿色生态住宅　可持续性发展　人居环境质量　建筑景观城市道路”三位一体”融合化设计

一. 前言:

早在 1986 年，Bruntland 委任报告提出了“ 可持续性发展 ”这个概念。作为一个地球人，我认为应有责任去考虑人的行为对环境的影响。“ 国际化的思考和本土化的运作 ” 正是表达这种具有重要意义的原则。对于建筑设计师而言，这个原则是可以运用到我们的设计中去。

二. 概况:

该小区位于江苏省无锡市扬名镇.用地面积 114145.7 平方米,建筑面积 236245 平方米,居户 1860 户。它是依据联合国《21 世纪议程》、《中国 21 世纪议程》关于可持续发展的住区建设要点建成的安置房住宅小区.

住宅小区在实现全方位环保的绿色生态人居环境方面是参照北美 LEED （Leadership in Energy and Environmental Design）环保框架，并结合无锡自然条件，制定出一套适合中国本土的设计标准。

三. 设计指导思想:

1.合理利用土地资源

住宅建设要占用大量的土地资源，而水资源、能源又是人类赖以生存的基本要素。由于我国的土地资源非常有限，现有的土地资源能否支持住宅发展的需求，已经到了足够引起重视的地步。因此，必须研究住宅的开发模式，设法将现有的存量住宅（或存量土地）盘活并投入有效的市场;从住宅产业化方面来

考虑，应当设法提高住宅的有效使用面积。目前我国住宅的使用面积占建筑面积的 70%左右，而发达国家可达 90%，这无非是通过科技手段最有效地节约土地的办法，这需要从采用轻型结构和配套的墙体材料等方面去努力;从小区规划方面考虑，小区内部严格控制场地，采用立体式人车分流，避免场地的交叉干扰，使整个场地通而不透，连而不乱。在解决人行与车行的问题上，采用大面积的支座平台，即减少对原有场地的破坏，同时又增加了城市第五立面的丰富性，使其成为观赏景致的平台。在运用景观设计的同时，计划性设计水流的方向，使其不占用有效的行路面积，同时尽可能地汇入附近的水池，流经地又采用细草过滤等措施来净化水质，保障水流的纯净，防止泥土的流失。

小区绿化通过分区布置，在中央区域内添实地面，不做地下车库，故而可增种大型生态乔木树种，并可保留原有大型树木。基地平均每 100 平方米中有 3 颗乔木，能增加室外用地的多功能性，提高利用率，即解决了 2.1 的高容积率问题，又使绿化率保持在 42%，从而达到高品质绿色生态小区的要求。

2. 有效利用水资源

中国普遍缺水，故节约饮用水势在必行。首先，应减少饮用水在园林中的滥用，采用新型抽灌系统，结合场地原有水流和备用水池积水进行绿地浇灌；同时，由于无锡降水充足，科学采集雨水、积水均可成为浇灌的水源；其次，减少饮用水在建筑中的滥用，在建筑中使用对水质要求不高的系统设施如冲洗、室内浇灌系统尽量采用天然水；另外，应采用《上海市节水产品推荐目录》中推荐的节水器具，小区管网漏损水量应小于小区最高日水量的 1%。

3. 有效利用自然资源及材料

在对小区老建筑拆迁的过程中，可对废弃的材料作重新利用，如：废弃木材、钢材及构筑物，综合考虑与新生构筑物的合理融合，木材做拼木室外地板，钢材做主题雕塑等。

4. 合理利用绿色系统

有效管理成为可持续发展社区内环境的必要保障。

四. 规划设计特征

1.能源与生态建设

随着无锡人口增长和生活质量的提高，建筑使用能耗占总能耗的比重越来越大。同时人们的耐用消费品购买力持续增长，空调安装率据高，故能源的消费直接影响到绿色生态小区的质量，降低单体建筑的能耗至关重要。据统计，由于历史原因，无锡住宅围护结构偏薄，保温隔热性能普遍较差，其围护结构现状为：240 普通粘土砖墙，简单架空屋面，东西山墙不开窗，南墙窗户有水平遮阳，单层窗，其热工性如表:

典型城市住宅围护结构热工性能

外墙传热系数	屋顶传热系数	窗户传热系数
1.96 w/(m2· k)	1.66 w/(m2· k)	6.6w/(m2· k)

造成室内环境极差，夏季酷暑，冬季阴冷，故在新区设计中采用热工性能好的混凝土砌块，外加保温性能良好的玻璃及隔墙。在室外种植各种品种高低的植物，形成建筑物的小环境，降低人的不舒适度，减少风力及直射阳光对人造成的危害。

在社区中心，通过正面太阳能接收器，将太阳能转化为电能储存起来，供建筑的局部使用和部分室外照明；屋顶形式能最好的接受夏季凉风，利用风和室外水流的共同作用起到降低部分室温的作用；室外退台式的草坪能缓解冬天北风的侵蚀，微调社区小气候。

在规划中，运用步行轴线，以社区中心为依托，充分考虑各种功能设施，将幼儿园、办公室及配电室合理安排，减少社区的运输耗能，使达到最不利点的距离能尽量分配均匀。采用不产生氟、不导致臭氧污染的冰箱空调设施来组织社区的制冷系统，并采用可监控能源运作，随时进行调整。

2.人性与人居环境质量

在设计中，人性化的空间设想始终引导着整个思路。如何达到人与自然的和谐，如何使生态小区达到人居环境质量的标准。虽然目前国际上还没有一个统一的标准，但经过多年的实践和研究，城市人居环境可以这样定位，它是人类与其生存环境进行相互作用的时空存在形式，是在一定的地理背景下，进行着居住、工作、文化、教育、卫生、娱乐等活动，从而在城市立体式推进的过程中创造的环境。人类的生存环境，即适宜于人居住的地球自然环境，也可保护国家和地区、人类生存的社会、政治环境；狭义的人居环境是指人们日常生活、工作、学习和休息的物质、社会、文化和心里环境。国外在此方面已经进行了大量的实践，如德国战后经历大规模的住宅重建工作。第一阶段主要强调数量的增加，第二阶段则更多地强调住宅质量和居住环境质量的提高。90 年代德国开始推行适应生态环境的住区政策，以切实贯彻可持续发展战略。特别强调城市内发展，进行了包括改善居住环境为主要内容的大规模住区改造工作，特别强调居住区同城市社会的联系功能。而本设计综合考虑无锡高山肖巷的可利用环境，结合原有河道，在河道侧面设置休闲区域，种植各种调节气候的乔木，并配置有保健功能的花、灌木，利用天然河道水环境及植物环境以及微生物链，形成使游憩于此的居民心旷神怡的生态小气候。

在设计中突出建筑·环境景观·城市道路 “三位一体”，幼儿园、社区中心、办公楼、商业配套建筑齐全。立体式人车分流，人行平台上，车行平台下，部分把停车放在平台下即降低了停车库的造价又为各楼居民安全通往地下及各

种集中绿地提供安全保障，平台在通往小区住宅和集中绿地等关键部位设有无障碍坡道。结合现代园林式布局特点，使人们既能从平台上又能从平台下以不同的角度体验不同的风景。在平台上，又可以以前所未有的距离接触那伸出平台天井的大树，体验高度上的优势。

在道路流线的安排上，更是使用了融合化设计，使道路成为景观的一部分，长距短距相互参差，没有呆板，只有多变，使每几栋建筑共享一个平台限定了区域，也更有了归属感，营造了传统院落和大家庭的氛围。无论从宏观还是从微观，均从使用者的角度出发，提供宜人的适用空间，在平台上，高低错落，动静有序，既增加了人多时的热闹度和融合度，又避免了人少时萧索、孤立的心理感受。

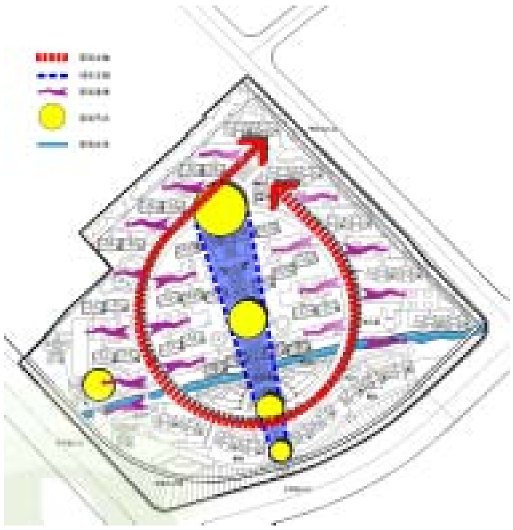
在单体组合设计中也延续了人性化场所的设计思路，注重了不同属性建筑的气质变化和空间感受的调整，没有绝对平行的公寓，各具特色的楼盘互相穿插，使大家深切感受到环境对人的关注，努力创造并维护这个场地的特色，因为它是我们的家，与别的场地不同。

从过程上看，塑造良好的人居环境应该包含两个步骤：第一是解决人们物质层面的安全和健康问题，像前面所阐述的对单体的选型、对植物的选择、交通组织等；第二就是解决人们精神层面上的需求。随着科技水平和市场条件的成熟，房产产品在物质层面做到生态、环保、安全，应该是完全没有总是的，而真正要解决的恰恰是独立的文化宗旨、独立的文化传统以及这些文化如何在我们的居住环境中得以体现，这才是最重要的。我们保留原有水文特征，保留中心区部分原有树木，希望就是能保留些旧回忆，也许就是那一颗树，它又自己的故事，自己的历史，创造了自己独特文化；也许是那一条熟悉的溪水，它造就了许多人的生活习惯，晚风习习，河边一凉席，三五知己，一轮皓月，谈天说地，这种文化的沉淀才会是最佳的人居环境。

五. 可持续性发展

作为一个“舒适、健康、文明、高效益、高自然度的、人与自然和谐以及人与人和谐共处的、可持续发展的居住社区”，它不能以某些单一的指标为测度标准，而是一系列指标体系的有机结合。生态社区也是一个不断发展、日益完善的社会－经济－自然复合生态系统。这个系统是按照生态原理和方法建立的硬件、软件和心件的有机结合。

评价一个社区是否以可持续发展为目标，主要是看能否达到小区内部、小区内外之间的平衡和循环使用，能否最高效、最少量地并有效地使用资源、能源，减少对环境的冲击，营造自然、和谐、健康、舒适的居住环境。



本方案从以下不同角度阐述可持续发展：

· **规划方面**：合理有效利用土地。保护用地周围的自然环境，不随意破坏地形、自然水系和植被，弥补不可避免的因开发而引起的环境变化的影响;充分考虑到人文环境可持续发展的需要。保护继承本地特色景观、特色空间、特色人文的精华。保持建设用地和绿化用地等各项用地的平衡。立体化交通优化区域交通网络，提高了土地利用率。方便的停车路径减少了停车噪声，部分车停在平台下，住宅在平台的声影区内，保护了声影环境，降低噪声污染。确定住宅之间的合理间距，满足日照间距的同时，避免视线干扰，保证住户的私密性。起居室和卧室布置考虑良好视觉环境，确保良好通风。

· **节能方面**：在满足建筑功能的前提下，使围护结构的总面积减少，控制建筑的体形系数和表面积系数 ;外墙的平均传热系数和门窗的热工性能及气密性满足国家颁布的节能标准；屋面坡屋顶采用保温构造型式，平屋顶采用倒置式保温构造型式，室外推台设计屋顶绿化。采用太阳能技术进行照明节能设计。而住宅节能主要包括围护结构和供热、空调系统的节能等两部分。在中国的大部分地区都存在或需要采暖、或需要空调、或二者均需要的情况，因此围护结构需要保温、隔热性能良好。为解决这一问题，不仅要积极采用新型保温墙体材料，而且门窗的保温也很重要，目前国外已广泛采用双层中空玻璃窗，今后在我国也要积极推广。

· **水环境方面**：综合利用各种水源，根据低质低用、高质高用的原则对小区用水量和水质进行估算与评价，利用雨水和地表径流雨水改善小区用水分配，达到减少节水率不低于 20%，回用率不低于 10%的要求。

· **材料方面**：社区中心外立面部分利用原基地拆迁过程中的回收木料，部分采用现浇混凝土板，强调材料的质朴和制作工艺的精美。木材和混凝土的运用与屋面的工业材料轻质铝材形成了鲜明的视觉对比。同时还有原基地的废弃钢铁、铝等金属材料用来制作主题雕塑等。新材料选用绿色建材，包括可再生、或可重复利用的塑料、粉煤灰、草板、废旧轮胎等。

社区人文环境的可持续发展：社区文化的营造和发展就好比人的发展进化，良好的社区文化除了具有自身的特色外，还必须具有开放性和可塑性。在社区开发过程中，我们为社区种下了特有的文化气息。这种基因在外部环境的影响下，也不断的进化改变，一方面，它会保有原有的一些特性，但同时社区的文化也会适合新时期的大环境，形成协调的共生关 系，达到真正意义上的可持续发展社区。