AALBORG UNIVERSITY
DENMARK

State-of-the-art Review : Vol. 1. State-of-the-art Report

Aschehoug, Øyvind; Andresen, Inger; Andresen, Inger; Haghighat, Fariborz; Heiselberg, Per Kvols; Li, Yuguo; Olesen, Bjarne W.; Perino, Marco; Principi, Paolo; Silva, Fernanda Marques da; Yoshie, Ryuichiro; Zhang, Jian

[Link to publication from Aalborg University](#)

NNEX 44

INTEGRATING ENVIRONMENTALLY RESPONSIVE ELEMENTS IN BUILDINGS

State-of-the-art Review
Vol. 1. State-of-the-Art Report
Øyvind Aschehoug, Inger Andresen (editors)
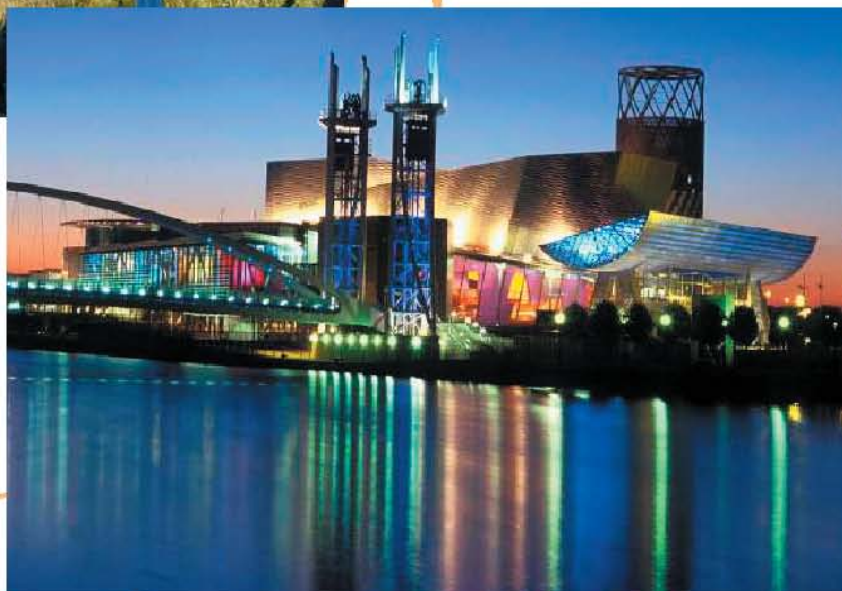
International Energy Agency
Energy Conservation in Buildings and Community Systems Programme

Annex 44 Website: www.civil.aau.dk/Annex44

Foreword

This report summarizes the state-of-the-art review of IEA-ECBCS Annex 44 "Integrating Environmentally Responsive Elements in Buildings" and is based on the contributions from the participating countries.

The publication is an official Annex report. With a focus on innovative building elements that dynamically respond to changes in climate and user demands, the report describes materials, components and systems that have been tested in laboratories and buildings around the world.

This report is aimed at researchers in the field and gives an overview of how these elements work together with available performance data.

It is hoped, that this report will be helpful for researchers in their search for new solutions to the problem of designing and constructing sustainable buildings.

Øyvind Aschehoug
Editor

Acknowledgement

The material presented in this publication has been collected and developed within an Annex of the IEA Implementing Agreement Energy Conservation in Buildings and Community Systems, Annex 44 "Integrating Environmentally Responsive Elements in Buildings".
The report is the result of an international joint effort conducted in 14 countries. All those who have contributed to the project are gratefully acknowledged. A list of participating institutes can be found on page 7.

Some Annex participants have taken the responsibility of collecting information and writing the chapters in this booklet. They are:

Inger Andresen
Fariborz Haghighat
Per Heiselberg
Yuguo Li
Bjarne W. Olesen
Marco Perino
Paolo Principi
Fernando Marques da Silva
Ryuichiro Yoshie
Jian Zhang

On behalf of all participants the members of the Executive Committee of IEA Energy Conservation in Buildings and Community Systems Implementing Agreement as well as the funding bodies are also gratefully acknowledged.

Table of Content

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster co-operation among the twenty-four IEA participating countries and to increase energy security through energy conservation, development of alternative energy sources and energy research, development and demonstration (RD&D).

Energy Conservation in Buildings and Community Systems

The IEA sponsors research and development in a number of areas related to energy. The mission of one of those areas, the ECBCS - Energy Conservation for Building and Community Systems Programme, is to facilitate and accelerate the introduction of energy conservation, and environmentally sustainable technologies into healthy buildings and community systems, through innovation and research in decision-making, building assemblies and systems, and commercialisation. The objectives of collaborative work within the ECBCS R&D program are directly derived from the on-going energy and environmental challenges facing IEA countries in the area of construction, energy market and research. ECBCS addresses major challenges and takes advantage of opportunities in the following areas:

- exploitation of innovation and information technology;
- impact of energy measures on indoor health and usability;
- integration of building energy measures and tools to changes in lifestyles, work environment alternatives, and business environment.

The Executive Committee

Overall control of the program is maintained by an Executive Committee, which not only monitors existing projects but also identifies new areas where collaborative effort may be beneficial. To date the following projects have been initiated by the executive committee on Energy Conservation in Buildings and Community Systems (completed projects are identified by (*)):

Annex 1:   Load Energy Determination of Buildings (*)
Annex 2:   Ekistics and Advanced Community Energy Systems (*)
Annex 3:   Energy Conservation in Residential Buildings (*)
Annex 4:   Glasgow Commercial Building Monitoring (*)
Annex 5:   Air Infiltration and Ventilation Centre
Annex 6:   Energy Systems and Design of Communities (*)
Annex 7:   Local Government Energy Planning (*)
Annex 8:   Inhabitants Behaviour with Regard to Ventilation (*)

(*) - Completed

Participants

Austria
AEE INTEC
Ernst Blümel
Phone: + 43 3112 5886 25
E-mail: e.bluemel@aee.at

Canada
Concordia University
Fariborz Haghighat
Phone: + 1 514 848 2424
E-mail: haghi@bcee.concordia.ca

China
The University of Hong Kong, Dep. of Mech. Eng.
Yuguo Li
Phone: + 852 2859 2625
E-mail: liyg@hku.hk

The University of Hong Kong, Dep. of Architecture
Matthias Haase
Phone: + 852 2241 5839
E-mail: mathaase@hkusua.hku.hk

Denmark, Operating Agent
Aalborg University
Per Heiselberg
Phone: + 45 9635 8541
E-mail: ph@bt.aau.dk

Technical University of Denmark
Bjarne W. Olesen
Phone: + 45 45 25 41 17
E-mail: bwo@mek.dtu.dk

France
ENTPE-LASH
Gérard Guarracino
Phone: + 33 4 74 04 70 27
E-mail: Gerard.guarracino@entpe.fr

INES - Savoie Technolac
Etienne Wurtz
Phone: +33 479 44 4554
E-mail: etienne.wurtz@univ-savoie.fr

LEPTAB - Université de La Rochelle
Laurent Mora
Phone: + 33 5 46457265
E-mail: laurent.mora@univ-lr.fr

CSTB
Faure Xavier
Phone: + 33 0476762574
E-mail: xavier.faure@cstb.fr

Italy, Leader of subtask A
DENER
Marco Perino
Phone: + 39 011 5644423
E-mail: marco.perino@polito.it

Università Politecnica delle Marche
Paolo Principi
Phone: +39 (71) 2204773
E-mail: p.principi@univpm.it

Japan
National Institute for Land and Infrastucture Management
Takao Sawachi
Phone: + 81 298 64 4356
E-mail: sawachi-t92ta@nilim.go.jp

Tokyo Polytechnic University
Ryuichiro Yoshie
Phone: + 81 (0) 46-242-9556
E-mail: yoshie@arch.t-kougei.ac.jp

University of Tokyo
Shinsuke Kato
Phone: + 81 3 5452 6431
E-mail: kato@iis.u-tokyo.ac.jp

Building Research Institute
Yuji Hori
Phone: +81 (29) 864 6679
E-mail: hori@kenken.go.jp

Ritsumeikan University
Tomoyuki Chikamoto
Phone: + 81 77 561 3029
E-mail: tomoyuki@se.ritsumei.ac.jp

Kobe Design University
Yuichiro Kodama
Phone: +81 78 796 2571
E-mail: y-kodama@kobe-du.ac.jp

Nikken Sekkei Ltd
Tatsuya Hayashi or Takashi Yanai
Phone: + 81-3-5226-3030
E-mail: hayashit@nikken.co.jp

Misawa Homes Institute of Research and Development Co., Ltd.
Isamu Ohta
Phone:
E-mail: Isamu_Ohta@home.misawa.co.jp

Tateyama Aluminum Industry Co.,Ltd.
Yasuo Takahashi
Phone:
E-mail: y_takahashi@sthdg.co.jp

FUJITA Corporation
Akinori Hosoi
Phone: +8146 250 7095
E-mail: ahosoi@fujita.co.jp

Norway, Leader of subtask B
SINTEF Civil & Environmental Engineering
Inger Andresen
Phone: + 47 92207049
E-mail: inger.andresen@sintef.no

Norwegian University of Science and Technology (NTNU)
Øyvind Aschehoug
Phone: + 47 73 59 50 46
E-mail: oyvind.aschehoug@ark.ntnu.no

Poland
Cracow University of Technology
Marian Hopkowicz
Phone: +48 (12) 628 28 96
E-mail: hopkowic@usk.pk.edu.pl

Portugal
LNEC, National Laboratory for Civil Engineering
Fernando Marques da Silva
Phone: + 351 218 443 862
E-mail: fms@lnec.pt

Sweden
SP Swedish National Testing and Research Institute
Åsa Wahlström
Phone: + 46 33 16 55 89
E-mail: asa.wahlstrom@sp.se

University of Gävle
Mats Sandberg
Phone: + 46 26 64 81 39
E-mail: Mats.Sandberg@HiG.se

The Netherlands, Leader of subtask C
Cauberg-Huygen Consulting Engineers
Ad van der Aa
Phone: + 31 10 4257444
E-mail: a.vanderaa@chri.nl

Technical University Delft
Hans Cauberg
Phone: + 31 152283174
E-mail: J.J.M.Cauberg@citg.tudelft.nl

United Kingdom
The University of Aberdeen
Mohammed Salah-Eldin Imbabi
Phone: + 44 (0) 1224 272506
E-mail: m.s.imbabi@abdn.ac.uk

Brunel University
Maria Kolokotroni
Phone: + 44 1895 266688
E-mail: maria.kolokotroni@brunel.ac.uk

Buro Happold
David Warwick
Phone: + 44 113 204 2200
E-mail: David.warwick@burohappold.com

USA
Purdue University
Qingyan Chen
Phone: +1 765 494 2138
E-mail: yanchen@purdue.edu

Chapter 1 Introduction

Energy use for room heating, cooling and ventilation accounts for more than one third of the total, primary energy demand in the industrialised countries, and is in this way a major polluter of the environment. To successfully achieve the targets set out in the Kyoto protocols it is necessary to identify innovative energy technologies and solutions for the medium and long term which facilitates the implementation and integration of low carbon technologies, such as renewable energy devices, within the built environment. Deployment of low carbon technologies still faces major barriers in the built environment especially in relation to costs, building logistics, technological challenges, lack of understanding and knowledge and absence of requisite skills.

Research into building energy efficiency over the last decades has focused on efficiency improvements of specific building elements like the building envelope, including its walls, roofs and fenestration components (windows, daylighting, ventilation, etc.) and building equipment such as heating, ventilation, cooling equipment and lighting. Significant improvement have been made, and most building elements still offer opportunities for efficiency improvements.

But the greatest future potential lie with technologies that promote the integration of responsive building elements with the building services. Responsive in this context means ability to dynamically adjust physical properties and energetic performance according to changing demands from indoor and outdoor conditions. This ability could pertain to energy capture (as in window systems), energy transport (as air movement in cavities), and energy storage (as in building materials with high thermal storage capacity).

With the integration of responsive building elements and building services, building design completely changes from design of individual systems to integrated design of integrated building concepts, which should allow for optimal use of natural energy strategies (daylighting, natural ventilation, passive cooling, etc.) as well as integration of renewable energy devices.

The objectives of IEA ECBCS Annex 44 is to collect information about the performance of buildings that utilize responsive building systems, and improve and optimise such system. The project participants will also develop new building concepts with integration of responsive building elements, and guidelines and procedures for estimation of environmental performance of responsive building elements and integrated building concepts.

This report gives a summary of the information gathered in the state-of-the-art stage of the IEA-project. The full information reports for responsive building elements and integrated building concepts are also available at the project website.

Chapter 2 Scope

The IEA Annex 44 will, based on the knowledge gained in earlier IEA work, address the following objectives:

- Collect state-of-the-art information about responsive building elements, of integrated building concepts and of environmental performance assessment methods, and prepare reports based on this information.

- Improve and optimise responsive building elements already demonstrated in case buildings and technical literature.

- Develop and optimise new building concepts with integration of responsive building elements, HVAC-systems as well as natural and renewable energy strategies.

- Develop guidelines and procedures for estimation of environmental performance of responsive building elements and integrated building concepts.

This report is a short summary of the state-of-the-art information gathered for Responsive Building Elements (RBE) and Integrated Building Concepts (IBC), the latter being comprehensive building systems that is based on RBEs. The "official" project definitions for RBE and IBC are given in Chapter 3.

A more comprehensive source of information is the full state-of-the-art reports for RBE and IBC available on the IEA ECBCS Annex 44 websites, http://www.civil.aau.dk/Annex44/ and http://www.ecbcs.org/annexes/annex44.htm. This shorter summary will give researchers and energy practitioners in the building sector an overview of the ground that will be covered in the IEA project. Information have been contributed by all the participants in the project, and edited by subtask leaders in the group. The full reports will have a much more comprehensive presentation of the subjects covered in this summary report.

The RBEs covered are mainly associated with the building envelope and other major construction elements: foundations, exterior walls, interior walls, floors, roof, windows etc. The RBEs are designed to work in close interaction with the building mechanical and electrical systems, such as heating, cooling, ventilation, lighting, electricity supply, and control systems, in order to reduce the demand for energy. This indicates that the principles for application of RBEs are best suited for commercial buildings that display a full range of mechanical and electrical systems. But as residential buildings now also are employing more such systems, some of the information gathered here may also be useful for such residential construction.

The responsive building element working principles identified and described in this report (Chapter 4) are:

- Advanced integrated facades, for example double facades integrating ventilation
- Thermal mass of building elements used for storage of heat and coolth
- Earth coupling of foundation elements and buried ducts and culverts
- Dynamic insulation systems in walls, for example breathing walls preheating air
- Phase change materials integrated in building elements to enhance the ability to store heat and coolth

The report also covers different applications of the RBEs, gives available data for design and performance, and discusses barriers to application and needs for more research.

The participants in IEA ECBCS Annex 44 have registered 23 buildings that have integrated different RBEs in their energy systems. A shortlist of 7 buildings that demonstrates such IBCs are presented in this summary report (Chapter 5). Also included is performance data for these buildings, and experience gained from design, construction and operation. For IBCs the report also describes 11 different design process methods and tools.

Chapter 3 Definitions

Responsive Building Elements are defined as building construction elements which are actively used for transfer and storage of heat, light, water and air. This means that construction elements (like floors, walls, roofs, foundation etc.) are logically and rationally combined and integrated with building service functions such as heating, cooling, ventilation and lighting. The development, application and implementation of responsive building elements are considered to be a necessary step towards further energy efficiency improvements in the built environment. Examples include:

- Facades systems (ventilated facades, double skin facades, adaptable facades, dynamic insulation)
- Foundations (earth coupling systems, embedded ducts)
- Storages (active use of thermal mass, material - concrete, massive wood - core activation for cooling and heating, phase change materials (PCM))
- Roof systems (green roof systems)

Integrated building concepts are design solutions of optimized responsive building elements and energy-systems integrated into one system to reach an optimal environmental performance in terms of energy performance, resource consumption, ecological loadings and indoor environmental quality. It follows that integrated building concepts are design solutions that maintain an appropriate balance between optimum interior conditions and environmental performance by reacting in a controlled and holistic manner to changes in external or internal conditions and to occupant intervention that develop from an integrated multidisciplinary design process, which utilizes a three step approach for optimisation of energy efficiency (Trias Energetica) and includes integration of human factors and architectural considerations.
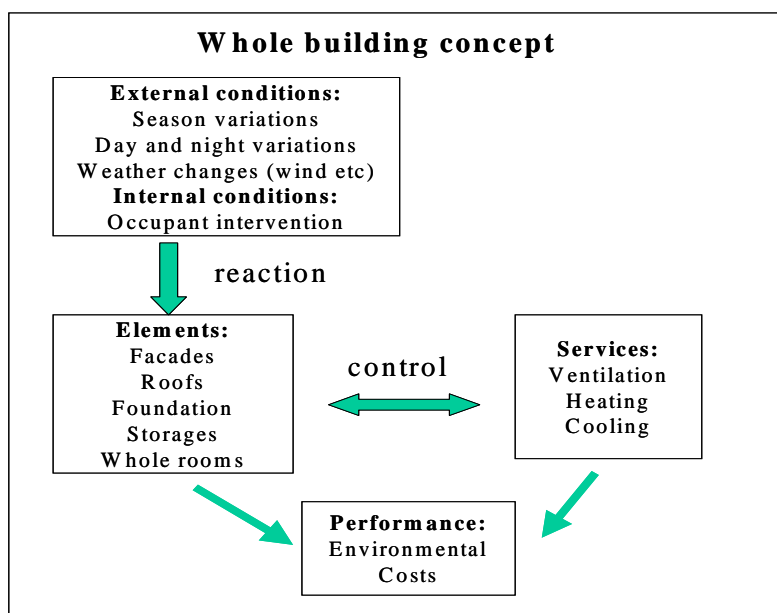
Chapter 4   Responsive Building Elements

Introduction

Research and technological innovation, over the last decade, have determined a significant improvement in the performance of specific building elements like the building envelope - including walls, roofs and fenestration components - and building equipment - such as heating, ventilation, cooling equipment and lighting. While most building elements still offer some opportunities for efficiency improvements, the greatest future potential seems to lie with technologies that promote the integration of "dynamic" building elements with building services.

In this perspective the term "dynamic" translates into the fact that functions, features and thermophysical behaviour of such building components may change over the time and adapt to different building/occupants requirements (heating/cooling, higher/lower ventilation, …) and to different boundary conditions (meteorological, internal heat/pollution loads, …).

Within Annex 44 such components have been defined as *Responsive Building Elements (RBE): an RBE is a building construction element that assists to maintain an appropriate balance between optimum interior conditions and environmental performance by reacting in a controlled and holistic manner to changes in external or internal conditions and to occupant intervention.*

This means that building components are now actively used for transfer and storage of heat, light, water and air and that construction elements (like floors, walls, roofs, foundation etc.) are logically and rationally combined and integrated with building service functions such as heating, cooling, ventilation and lighting.

The development, application and implementation of responsive building elements are considered to be a necessary step towards further energy efficiency improvements in the built environment.

Examples of RBE include, among the others: *façades systems* (ventilated facades, double skin facades, adaptable facades, dynamic insulation,…), *foundations* (earth coupling systems, embedded ducts, …), *energy storages* (active use of thermal mass, material - concrete, massive wood - core activation for cooling and heating, phase change materials, …), *roof systems* (green roof systems, …), *active/passive solar systems*, *daylighting technologies*.
In Annex 44 attention has been focused only on five specific responsive building elements, whose perspective of improvement and widespread implementation in the building sector seems to be much more promising. These are:

Advanced Integrated Façade (AIF)
An *Advanced Integrated Façade* (AIF) is a building envelope that exhibits adaptive characteristics that are in tune with both the physical/ climatic conditions of a particular location and the indoor environment requirements. An AIF provides the basic functions of shelter, security and privacy, while minimizing energy consumption. AIF are the actual development of what started with passive architecture principles and evolved, originally, into Double Skin Façades (DSF) and, recently, into the intelligent skins concepts. An intelligent skin may be defined as "*a composition of construction elements confined to the outer,*

weather-protecting zone of a building, which performs functions that can be individually or cumulatively adjusted to respond predictably to environment variations, to maintain comfort with the least use of energy". The concept of "intelligence" associated with DSF represents a change from a static envelope to one with a dynamic behaviour.

Thermal Mass Activation (TMA)

Thermal mass activation (TMA) is defined as the active use of the mass of the building that can be used to store thermal energy (for heating/cooling purposes). Components typically adopted when the TMA concept is applied include: the building envelope, the interior partition, the furnishing, or even the building structure. A well known example of use of TMA is the so called "night cooling", which minimizes or zeroes the need of mechanical cooling in buildings. There are two basic types of thermal mass according to its location: the external thermal mass (such as walls, roofs exposed to outdoor temperature) and the internal thermal mass (such as furniture and purpose-built internal concrete partitions exposed to indoor air temperature). A relatively new approach is represented by a combination of TMA and the radiant heating/cooling of the buildings. An air conditioning system utilizing TMA can smooth the cooling/heating loads without increasing the building initial costs.

Earth Coupling (EC)

The basic principle of the *Earth Coupling* (EC) is to ventilate air to the indoor environment through one or several buried ducts, in order to exploit the seasonal thermal storage ability of the soil. This enables a cooling effect of the hot summer air and a heating effect of the cold winter air. The ground's large thermal capacity is, therefore, used to preheat or pre-cool the ventilation air, resulting in energy savings for the building. Frequently, this technology is also addressed as "Earth to Air underground Heat Exchangers". In buildings with required indoor air temperatures between 20°C to 26°C, EC is primarily used for cooling purposes, since soil temperatures are usually below the indoor air temperature most of the time. However, EC can also be used for winter heating, when the outdoor air temperature is much lower than that of the soil, but additional heating systems are usually needed in this case.

Dynamic Insulation Systems (DIS)

The concept of *Dynamic Insulation Systems* (DIS) combines the conventional insulation and heat exchange characteristics of an outer envelope element, in order to effectively pre-heat the ventilation air. DIS are regarded as one possible method for reducing building envelope heat losses while achieving better indoor air quality. One of the most promising existing technologies is represented by the so-called "Breathing Wall" (BW). A BW is a suitably designed wall which let an air transfer through a permeable insulation layer. The system can act as a contra-flux mode heat exchanger and it usually consists of two main sub-layers: an external envelope (this could be a prefabricated reinforced concrete slab or a perforated metal sheet) - through which the ventilation air can be introduced from the bottom or top - and a dynamic insulation sub-layer (which may consist of layers of breathing, porous materials). The air flow through the wall is, usually, assured by means of mechanical ventilation, but "natural" systems have also shown encouraging performances.

Phase Change Material (PCM)

PCM are suitable materials characterized by the fact that, at atmospheric pressure, they undergo a phase change in a range of temperatures around the ambient temperature. The basic principle is to exploit their considerable capacity of accumulating heat at temperatures close to their melting point. In fact, as long as the phase change is under way, heat is stored and released without any sensible temperature variation of the medium. This property can be used

as a means of increasing the thermal inertia (thermal mass) of the building components and, therefore, to smooth the cooling/heating loads. The energy storage capacity of PCM per unit mass is much greater than that of usual building materials, like concrete or brickwork. For this reason, PCM are often used in lightweight constructions. The adoption of PCM in the building construction allows for a better control of thermal flows and also increases the potential of exploiting solar energy.

In the following paragraphs the state-of the-art for these five different types of RBE will be presented and discussed. Analysis of the working principles, design criteria and typical application fields will be developed, highlighting the "claimed" benefits and limitations.
Examples of application of RBE in existing buildings will be examined and barriers to their widespread application will also be discussed, focusing the attention on lack/availability of design tools and of experimental procedures to assess their performances.
The main aim of this investigation is to make the point on RBE use and to highlight open questions and future research needs.

Chapter 4.1 Advanced Integrated Facades

Component description and examples of existing applications

Introduction

The collective term Advanced Integrated Façades (AIF) refers to the outer, weather-protecting layer of a building that contributes to heating, cooling, ventilation and lighting requirements and promotes interior comfort through efficient, energy-saving measures. An AIF should make use of natural renewable sources (solar energy, airflows or ground heat) and should also result from an "intelligent design" rather than just an assembly of "intelligent components".

The concept of integrated design represents a change from a static envelope to one with a dynamic behaviour. The façade is then capable of adapting to changes in outdoor conditions in order to achieve indoor comfort requirements and reduce energy consumption. Therefore, the designer needs to have a good understanding of the performance that might be achieved. This information, which is application specific, may be obtained through simulations and tests.

From architectural and technical points of view, an AIF can be summarized as a responsive building element (RBE) that is in tune with both the physical and climatic conditions of a particular location. It is a building envelope that exhibits adaptive characteristics. The dynamic behaviour of an AIF provides the basic functions of shelter, security and privacy, while minimizing energy consumption. Being closely connected to the building energy and control systems, an AIF has to contribute to environmental sustainability and make the building a structure with climatic sensitivity.

Classification criteria

AIF classification is not a straightforward task due to the number of different and cumulative aspects to be considered. However double-skin façade (DSF) classification criteria can be used as a basis. Most common classifications consider the type of ventilation, the flow path and the system configuration as major items.

Type of ventilation

The driving force of the air flow within the cavity defines the type of ventilation. Types to be considered are: natural ventilation (NV), mechanical ventilation (MV), and hybrid ventilation (HV). Hybrid ventilation utilizes both natural and mechanical ventilation.

Flow path

The air flow path is a very important issue that is strongly associated with how the AIF is integrated into the building energy and control systems. Possible arrangements, shown in Fig. 1, are: exhaust air (EA), supply air (SA), reversible air flow (RAF), outdoor air curtain (OAC) and indoor air curtain (IAC).
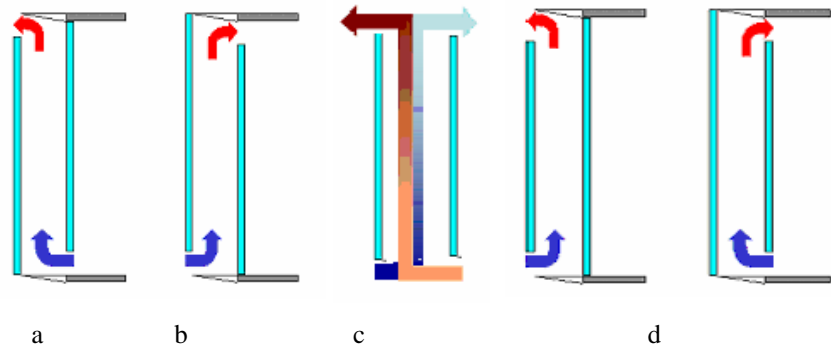
Figure 1. AIF flow path: EA-a); SA-b); RAF-c); OAC-d); IAC-e) [Annex 44 (2005)]

Façade configuration

Façade configuration is based on the Belgium Building Research Institute's (BBRI) classification for DSF, the most well-known and widely adopted in Europe. Modifications were made to this classification by merging some of the main characteristics with other classification systems. This proposed classification, represented schematically in Fig. 2, divides AIFs into transparent vertical façades (TVF) and other concepts including opaque vertical façades (OVF) and the Swindow (SW).
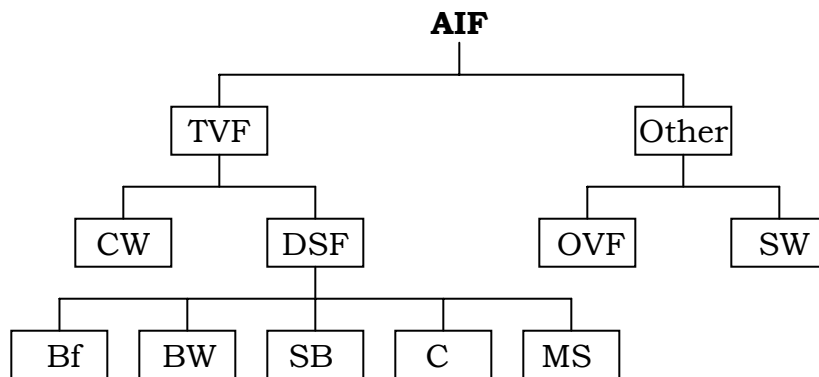
Figure 2. Proposed simplified classification of AIF, based on configuration

A brief review of the AIF configuration definitions is presented below.

- Climate wall (CW): merges the climate façade/climate window concepts, the difference between them being the existence or lack of a window division. A CW is characterized by an external double glazed pane, an internal single glazed pane or curtain, a MV connection to the building ventilation system, and a small gap (~10 mm) under the interior pane that allows air to flow into the cavity. This arrangement is similar to a box-window.
- Buffer (Bf): The still air within the cavity acts as a thermal buffer even if the cavity is connected to the outdoor air for pressure balance purposes.
- Box window (BW): The DSF is divided both vertically and horizontally, forming a box.
- Shaft box (SB): The SB has a similar configuration to the BW, except that the shaft box discharges exhaust air to a lateral building-height cavity.

19

- Corridor (C): This type of DSF is horizontally divided, forming a storey level corridor. Inlet and outlet openings are placed in such a way that the mixing of exhaust air and supply air to the above storey is avoided.
- Multi-storey (MS): A MS system is a DSF with no cavity partitions. Louvered façades are a particular case of MS, in which the external skin is composed of louvers that move from a closed to an open position. In the open position, they no longer act as a second skin.
- Swindow (SW): This is an opening developed for natural ventilation purposes with the capability of being integrated into the HVAC systems. The basic configuration consists of a horizontally pivoted window that is hinged just above mid-height. When opened, the weight of the window is balanced with a counterweight located at the top of the window. Different constructions with the same working principle are used for exhaust and supply modes.

Examples of applications
Within this state of the art review, a search was carried out in order to highlight how, where and how often different kinds of DSF/AIF are used in existing buildings. Over 200 buildings worldwide were found to be utilizing the DSF/AIF concept. It should be noted that it is not possible to assume that this search is exhaustive or to be certain that this figure is close to a final count, as can be inferred from the figures from Canada (1), Sweden (0), and the USA (5), for example.

Geographic distribution
The geographic distribution of the buildings that use DSF/AIF shows that a large fraction of buildings are located in Continental/Northern European countries (56.7%) and Japan (13.0%). In these countries the climate conditions are probably more suitable for the use of AIFs with cold winters and mild summers. However, as seen in a number of actual cases, habit and fashion may have a primary role in the choice of the building designer for the adoption of a DSF/AIF.

Typologies and period
At this moment it was not possible to obtain information concerning configuration, flow path or type of ventilation for some of the identified buildings. In some cases there is no information at all, while for others information for at least one of the typologies is missing. According to the proposed criteria, the most and least common solutions are:

- DSF/MS (47.0%) and Swindow configurations.
- Natural (58.1%) and hybrid ventilation.
- Outdoor air curtain (49.1%) and reversible air flow modes.

It is also interesting to note that in the period of major diffusion of DSF/AIF, the most common typologies were the multi-storey configuration, naturally ventilated systems, and the outdoor air curtain mode, Fig. 3. The first identified DSF building was built in 1967 at Cambridge University in the UK [Compagno, A (2002)]. The majority of DSF/AIF construction and retrofit occurred between 1995 and 2003 (80.1%).
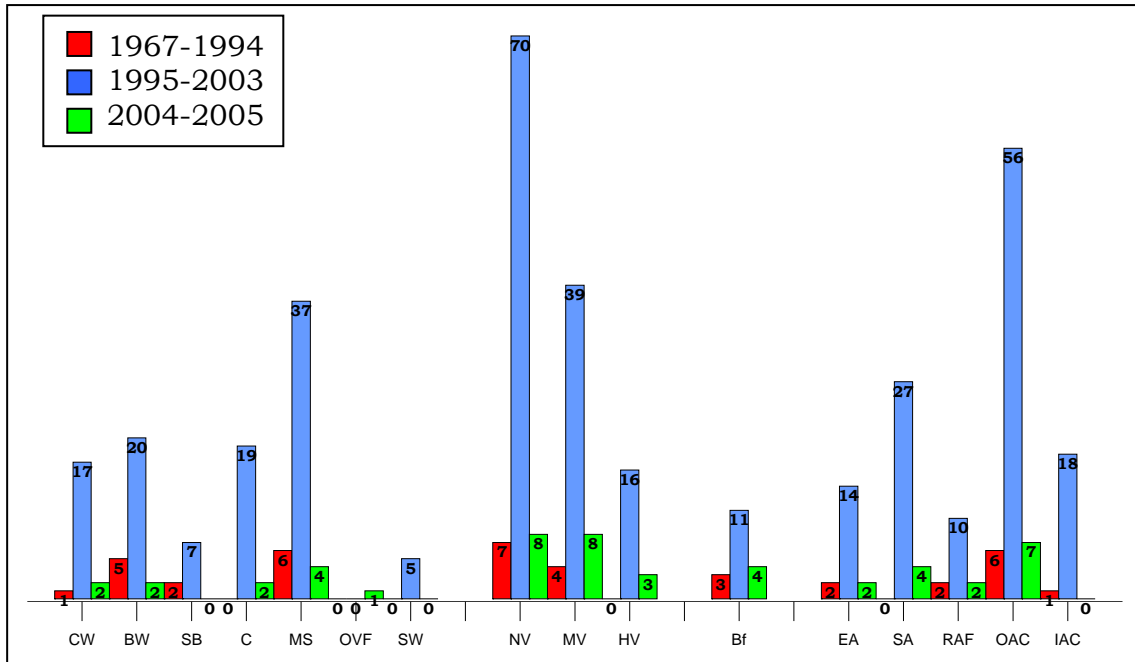
Figure 3. DSF/AIF typologies by period

Working Principles

Transparent ventilated façades

The working principle of a transparent ventilated façade is to use the air gap between the two glazed panes to reduce the thermal impact on the building environment. The air gap may use natural, mechanical or hybrid ventilation schemes, or simply act as a still air buffer. Figure 4 illustrates the window physics, showing the complexity and impact of solar radiation, conduction and convection on the airflow through the double-skin gap.
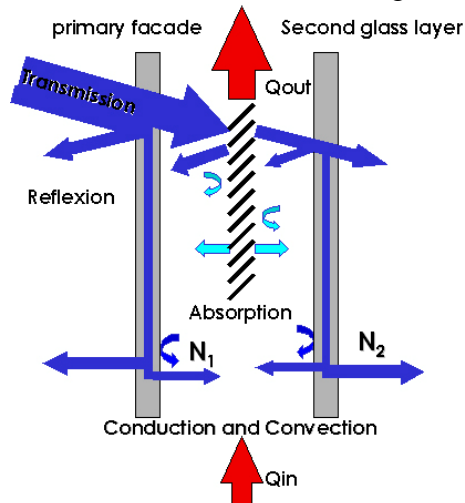
Figure 4. DSF/AIF working principles

The main functions of the DSF are:
- to recover heat during cold season and/or preheat ventilation air,

- to improve the thermal insulation of the glazed system during both hot and cold seasons,
- to reduce solar loads and enhance natural lighting control without the drawback of the overheating of a solar shading device located in the indoor environment, and
- to extend the use natural ventilation, particularly in the case of high rise buildings.

Swindow

There are two types of Swindows: air supply and exhaust. The Swindow is in the open position at $45°$ from vertical when the wind is calm. It then starts to move when the wind blows. The Swindow operates even in weak winds and provides unidirectional air flow in the supply or exhaust direction, while limiting surplus air flow.

Opaque ventilated facades

Opaque ventilated façades (OVF) are essentially Trombe walls that form a large solar collector when combined with an air space, insulated glazing and vents. Modern Trombe walls add vents to the top and bottom of the air gap between the glazing and the thermal mass. Heated air flows via convection into the building interior. The vents have one-way louvers that prevent convection at night, thereby making heat flow strongly directional. This kind of design is an isolated passive thermal collector. By moving the heat away from the collection surface, it greatly reduces thermal losses at night and improves overall heat gain. Generally, the vents to the interior are closed during summer months when heat gain is undesirable.

Design Criteria

An advanced integrated façade considers the combined use of several technical solutions in order to fulfil the design goals described above. A number of such technologies may be identified:

Solar control
- spectrally selective glazing
- simple and selective shading
- solar filters
- active and passive solar systems

Lighting
- sunlight and sky light redirection

Ventilated façades
- climate walls
- double-skin façades
- ventilated Trombe walls
- Swindows

This part of the state of the art report refers only to ventilated façades or, more specifically, to the ventilation and outdoor thermal load control aspects of an AIF.

Sound insulation

Undoubtedly an effective outcome of DSF is sound insulation. Acting as a protection wall, the external glazed pane reflects exterior sound. This significantly reduces interior noise

levels, even if the interior windows are open. Operable windows are possible with DSF when external noise levels are around 68-75 dB(A), conditions applicable to a wide range of inner city properties [Oesterle, et al (2001)]. However, noise produced indoors may be reflected back to the interior by the external pane (when interior windows are open), leading to the possible transmission of sound and information from room to room and floor to floor [Oesterle, et al (2001)].

Energy
When a designer wants to achieve energy savings, the use of DSF is one possible solution. However, figures from real buildings show very different values for yearly overall consumption. For instance, Lee (2002) reported the energy consumption for three German buildings with AIF/DSF. Values ranged from the excessive 433 kWh/m^2-yr to 59.8 kWh/m^2-yr when coupled with other innovative techniques. Energy savings may result from an increase in the use of daylighting in peripheral areas. Depending on the control scheme used, energy reductions between 38-52 Wh/m^2 may be achieved. Improved thermal behaviour can lead to a reduction in air conditioning use, while still achieving thermal comfort conditions. Comfort may also be improved, because the temperature of the inner glazing surfaces is closer to the indoor temperature. Although DSFs can save energy as compared with conventional solutions with full air conditioning, they may not be the best choice for every location.

Wind action
The wind-building interaction determines the building envelope pressure distribution, which has a significant effect on ventilation flows. In particular, it affects the natural ventilation strategies selected. Turbulent fluctuations are "dampened" by the DSF due to the combined effect of openings in the inner and outer panes in conjunction with the cavity, which acts as a buffer. This is of particular importance in high-rise buildings where gust loads may induce high peak pressure values [Oesterle, et al (2001)]. A major factor that influences façade pressure distribution is the building shape. DSF configuration can dramatically change cavity pressures when compared to an "unsheltered" envelope. This change in pressure values should be accounted for in order to properly evaluate wind loads on the external pane and the type of ventilation strategy to be used. Potential difficulties in manoeuvring doors or windows to the cavity may also be affected by such pressure values.

Application field
Although the state review did not yield a complete overview of the application field in which DSF/AIF have been used, it was possible to determine that less than 10% or about 20 of the identified buildings are not of the office type.

Available Design Tools
The ability to accurately estimate the energy performance of a DSF/AIF during the design process is essential. This may be achieved through the use of simulation tools that are able to model the façade, compare different solutions, and properly evaluate its behaviour in order to make educated design decisions.

Two important types of categories for simulation tools can be identified: component for thermal, energetic and lighting behaviour, and building for thermal behaviour of the whole

building, including the façades [BBRI (2002)]. Note that although the building simulation tools can model façades, they are not tailored to model DSF/AIF configurations.

The ideal simulation tool would accurately model the outdoor climate (temperature, humidity, wind and radiation), the DSF/AIF (glazed panes, shading devices, ventilation strategy, thermal properties), the building (physics, occupancy schedule, air conditioning system), the control system, and the interaction of all these variables simultaneously. Such a tool does not yet exist in a form that is ready for designers to use.

Research groups have developed a number of models that are able to simulate DSF/AIF with different levels of sophistication. These models were usually developed using commercial CFD based software.

Available Experimental Procedures

It was found that that there are no standardized experimental procedures to test and evaluate DSF/AIF performance. Also, the availability and use of design tools is fragmented, and published results are limited to a number of examples of studies performed in different research centres with some field monitoring. Moreover, there is also a lack of knowledge about the type and definition of parameters to be used for the façade classification, like the U-value used for traditional glazed systems. The usual U-value, in fact, tends to be ineffective for ventilated façades and for some working conditions it looses its physical meaning.

Some experimental test rigs have been proposed and built for DSF/AIF testing. For instance, one example is that of PASLINK European Economic Interest Grouping (EEIG), a high quality network of outdoor test centres testing of advanced building components, supported by a data analysis and modelling group. Another case is presented by Shang-Shiou (2001) who proposed a protocol for DSF testing using a pair of twin test cells, one equipped with a NV-OAC window and the other equipped with a MV-IAC window.

Availability of Measured Performances

A complete, systematic set of experimental data is not available to researchers, designers and consultants. This is clearly a consequence of the fact that there are no standardised procedures for testing DSF/AIF, as mentioned in Section 6. Available measured performances are usually the result of "occasional" studies performed in the lab or results from field monitoring. Almost all the available data sets come from the research community.

A few measurement studies that were identified referred to both test facilities and real buildings. One example of a real building monitoring is the tests performed by the Plotitecnico di Torino on a climate window façade [Annex 44]. Results are usually reported over a typical time profile and highlight the heat fluxes through the façade component.

Availability of Simulated Performances

The situation concerning the availability of simulated performances is similar to that of the measured performances. There are no systematic and comprehensive data sets, and much of the data is collected for and used by researchers. The number of examples available in the literature is somewhat higher than that for the experimental studies, and a significant

number of tools were used that range from specially developed numeric schemes to commercially available tools. Performance simulations may be grouped into three categories: application examples of commercial tools, research simulations with no connection to any real building, and real building simulations.

Claimed Benefits and Possible Limitations

Major "claimed" benefits of DSF/AIF have already been described in previous sections. A detailed summary of the benefits and limitations is listed in Table 1.

Table 1 – List of possible benefits and limitations of DSF/AIF

	BENEFITS	LIMITATIONS
Acoustics	Offers better acoustical insulation against outdoor noise.	External pane openings may reduce noise insulation but usually not in a significant way. Room to room sound transmission ("telephone" effect) is possible.
Energy	May act as a static or dynamic thermal buffer, reducing heating/cooling energy needs. Cavity heated air may be used as input for A/C units.	High internal loads may require extra cooling energy, thus compensating the benefit of energy reduction. Sensitive to changes from design specification.
Ventilation	Improves the use of natural ventilation. Operable windows are allowed. Reduces cavity condensation.	Mechanical ventilation HVAC systems may be needed to ensure thermal comfort. Pollutant dissemination is possible.
Shading	Various types of solar shading device are possible due to the weather and pollution protection offered by the external pane.	--------------------------------------
Wind pressure	Protects the inner pane from gusting and reduces static pressure in high-rise buildings. Reduces the difficulty of operating windows/doors.	Cavity wind induced pressure depends on DSF/AIF configuration; certain zones of the façade may not be protective. Heavy wind loading is possible.
Lighting	Enables the installation of light redirecting elements. Improves the use of natural lighting with little thermal discomfort.	Reduces the amount of daylight entering the building in comparison with single glazed façades.
Fire safety	--------------------------------	The exterior glazing layer reduces the ability for smoke ventilation, and the air gap increases the risk of fire/smoke spreading among floors or rooms. Reduces the ability of fire fighters

		to reach the inner façade. Increases the risk of broken glass hitting the ground.
Cost	Lowers the operation costs of and may reduce overall costs, resulting in a more cost effective solution.	Higher investment costs and maintenance costs. May increase overall costs, resulting in a less cost effective solution.
Sustainability	May significantly reduce energy consumption. Higher lifecycle of weather protected elements, reducing waste. Improves adaptive comfort. Building refurbishment may be restricted to the façade.	Higher materials input. Environmental impact depends on used materials. Improper design may significantly increase energy consumption.

Future Perspectives

An inquiry to designers presented in [Lee, E. *et al* (2001)] shows that the main reason to adopt AIF solutions is not "fashion" but the improvement in energy management towards consumption reduction and indoor comfort.

To prepare for the future, the building sector has to be much less energy demanding. It also has to be fully adaptive to the local climate, environmentally sustainable and cost effective. Within this framework, as stated by Wigginton and Harris (2002), the façade will be one of the principal elements in the buildings of the future.

To fulfil such a challenge there is a need for team work from the onset of building design. Architects and engineers must educate investors and owners for decision making and occupants for use on the advantages of integrated solutions. For AIF solutions designers need guidelines in the form of simplified tools, standards and regulations, updated and more reliable tools for more advanced design stages, and specific benchmarks (as could possibly be the outcome of the EU BESTFACADE programme).

Barriers to Application

Barriers to DSF/AIF implementation mainly arise from several factors, the most significant being: costs, fire standards and regulations, construction regulations and laws, and lack of knowledge and lack of design tools

Open questions and future research work to be done

From Table 1 it is possible to see that there are several drawbacks to using AIF/DSF in a building. Furthermore, many of the available results obtained from field measurements point out that DSFs frequently performed worse than expected.

Rather than indicating that the technology is not beneficial, this may be a reflection of an incorrect design and/or integration with the building and the HVAC system. Such an

explanation has been substantiated by studies of the performance of existing ventilated facades.

It can be said that the technology is promising but that it is still quite young. Therefore such RBEs as DSF/AIFs need further development before their performances become satisfactory.

References

Annex 44 A1. Advanced Integrated Facades. Annex 44 State-of-the-Art Working Report Part A1. (www.civil.aau.dk/anex44).

Belgian Building Research Institute (BBRI) (2002). "Source book for a better understanding of conceptual and operational aspects of active facades." Department of Building Physics, Indoor Climate and Building Services, BBRI, Belgium. (http://www.bbri.be/activefacades/)

Belgian Building Research Institute (BBRI) (2004). "Ventilated double facades. List of buildings equipped with ventilated double facades." Department of Building Physics, Indoor Climate and Building Services, BBRI, Belgium. (http://www.bbri.be/activefacades/)

Compagno, A (2002). "Intelligente Glasfassaden: Material, Anwendung, Gestaltung = Intelligent glass facades: material, practice, design." *Intelligent glass facades*, Basel; Boston: 183.

Kopstad, S and O-J Engelstad (2001). "Double facades in Norway – use and future potential." Student project at the Norwegian University of Science and Technology, Department of Civil and Transport Engineering, Trondheim, Norway.

Lee, E, et al (2002). "High-performance commercial building façades." Lawrence Berkeley National Laboratory, Univ of California, Berkeley. LBNL-50502. (http://gaia.lbl.gov/hpbf/main.html)

Oesterle, E, et al (2001). Double-skin facades: integrated planning, building physics, construction, aerophysics, air-conditioning, economic viability. Prestel, Munich.

Wigginton, M and J Harris (2002). Intelligent Skins. Butterworth-Heinemann, Oxford.

Chapter 4.2 Thermal Mass Activation (TMA)

Component description and example of existing applications

Passive Utilization of the Thermal Mass

Thermal mass is defined as the mass of the building construction that has the ability to store thermal energy. Therefore, thermal mass offers the engineers or architects a powerful opportunity to manage energy flows in the building efficiently. Historically, there have been many successful passive thermal mass techniques used in buildings. These applications included passive cooling systems, such as night flush cooling and earth cooling, thermal storage heating system or passive solar heating system, for example, Chinese Kang in northern China or Ondol – traditional Korean under floor heating system.

Description of the component types:

According to its location, there are two basic types of thermal mass (Li and Xu, 2006), i.e. external and internal. The external thermal mass (walls, roofs, etc.) is directly exposed to ambient temperature variation. The internal thermal mass (furniture and purpose-built internal concrete partitions) is exposed to indoor air temperature. The thermal mass can be passively used both in residential and commercial (office) buildings. Technical solutions are commercially available.

Thermo Active Building Systems (TABS)

Active building components are thermally heavy parts of the building construction (walls, ceilings, floors), which are equipped with ducts for circulation of air or embedded pipes for circulation of water (Meierhans, 1993 and 1996). Circulation of the heat transfer media activates the thermal mass of the slab, which has not only a direct heating or cooling effect, but also reduces the peak load and transfers it outside the period of occupancy (loads can be removed with lower expenses – night electricity tariff, etc.). Because temperature of heat transfer media is kept close to room temperature, the efficiency of heat pumps, ground heat exchangers and other systems using renewable energy sources is increased when coupled with TABS.

Description of the component types:

Airborne systems: The cavities are used to circulate air through the concrete slabs (Figure 1a). The circulated air can be also used as supply air to the premises. Water based systems: Pipes are commonly installed in the centre of concrete slab between the reinforcements (Figure 1b). Usual diameter of the pipes varies between 17 and 20 mm. The distance between pipes is within the range 150 - 200 mm. Both air and water based components are commercially available and particularly suitable for multi storey buildings.

Working principles

Passive Utilization of the Thermal Mass

Two important thermal properties of the building construction/materials should be considered when thermal mass is to be passively utilized. It is the heat capacity by volume and the heat-absorption rate. The first determines the ability of the materials to store thermal energy, and

the second determines the ability of the element/part of the building construction to adsorb the thermal energy. The combined convective and radiant heat transfer coefficient and the surface area of the thermal mass determine the rate of heat transfer between the thermal mass element and the air. The time delay between maximum/minimum external and internal temperature is called the time lag. The surface area of the thermal mass is a crucial design parameter. The heat penetration through the thermal mass body is by the heat conduction, and the penetration depth is limited by the diffusivity of the material during one cycle (Li and Xu, 2006). There are generally two systems (CIBSE, 2001): Direct interaction system – the thermal mass directly exposed to the indoor air. Both convection and radiation play roles in heat transfer (Figure 2a). Indirect interaction system – the ambient air passes through floor voids, cores and air paths. Convective heat transfer is the main heat transfer mode (Figure 2b).
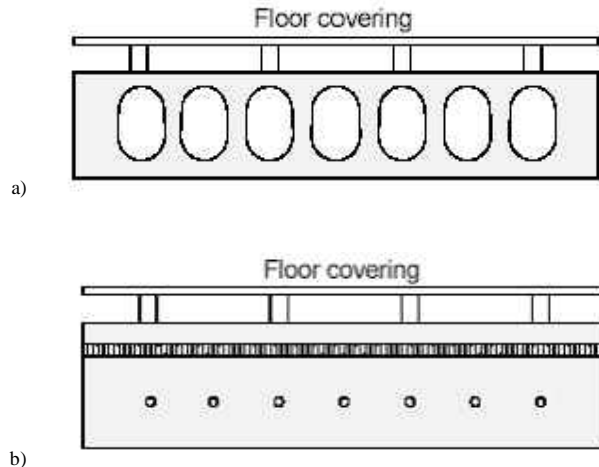
Figure 1 – Basic types of currently used thermo active building components (Wietzmann, 2002): a) hollow deck with cavities for air circulation; b) on-site constructed floor (with insulation)
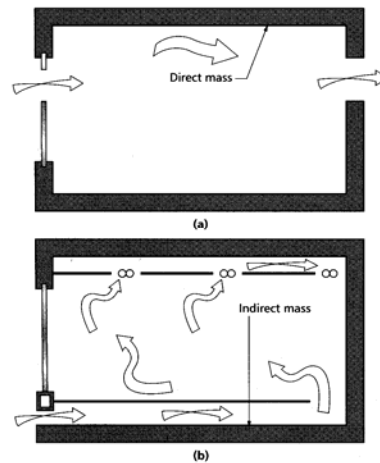
Figure 2 – Direct a) and indirect b) interaction of the room air and building thermal mass (CIBSE, 2001)

Thermo Active Building Systems
Technologically, the design of thermo active components is based on the characteristics of other radiant systems: distance, diameter of pipes, thickness of the concrete layer, position of the pipes inside the concrete, supply water temperature and water mass flow rate. Besides the direct cooling and/or heating capacity, the TABS have also the thermal storage effect - the peak load during the day will be stored and removed by cooling during the night. Thermo active components have a large radiant part in the heat transfer between heated/cooled surface and room (Olesen et. al., 2000). Influence of both convection and radiation can be expressed by means of combined heat transfer coefficient. The response time of the system is rather long due to its high thermal mass. Therefore, an individual room control is not reasonable, but a zone control (south – north) is often suitable solution. Small difference between heated/cooled surfaces (supply water) and the ambient temperature results in a significant degree of self-control effect, because a small change in this temperature difference will influence the heat transfer between the cooled/heated surface and the space significantly. In order to avoid condensation, the water temperature or the surface temperature and the absolute humidity should be controlled (surface temperature should be maintained above the dew-point of the ambient air for all operational conditions).

Application field

Passive Utilization of the Thermal Mass
In general the application has been found to be particularly suitable for climates with big diurnal temperature variation. Cooling by night-time ventilation, one of the most efficient applications of thermal mass, can be used if night temperatures are low enough to release heat from the building's thermal mass.

Thermo Active Building Systems
Most of the component applications can be observed in moderate climatic zones. Installations in cold climatic zones are limited mainly by heating capacity of the system. Using the systems in hot and humid climate is limited by need to avoid condensation. Utilization of the thermally activated components effectively reduces the size of the ventilation system. It is not designed to extract cooling loads or heat the building but only supply fresh air for the occupants.

Available design tools

Passive Utilization of the Thermal Mass
A large number of previous studies and computational methods on thermal mass were reviewed (Balaras, 1996). Li and Yam (2004) proposed a new concept of virtual sphere method for effective thermal mass design. The idea is to lump up the mass elements into a virtual solid sphere with the radius determined from some significant dimensions of the mass (e.g. volume and surface area). Utilization of more complex tools (simulation codes) often requires a great amount of input information, but provide highly accurate results. Some of them are well-known software packages available on the market, for example ESP and TRNSYS.

Thermo Active Building Systems
Commercially available building simulation programs can be used to determine behaviour of the system when installed in a particular building. Available capacity of the system, distributions of indoor temperatures and thermal comfort indices can be also evaluated. For dynamic simulation of the entire system with embedded pipes acting together with the building construction, a validated model for a floor heating system and concrete core conditioning provided as a module of simulation program TRNSYS can be used (Schmidt et al., 2000).

Available experimental procedure to assess element performances

No available experimental procedure was identified for passively used thermal mass. Moreover, an experimental testing is not practically done and necessary also in case of TABS. For testing and predicting of the operational behaviour of TABS, it is more efficient to use mathematical models (simulations) based on FEM/FDM to evaluate performance of the planned system.

A new methodology called dynamic thermal networks is being developed by Claesson (2003). It deals with the factors that influence a dynamic heat loss/gain calculation, such as choice of materials and whole building design strategy. The theory is based on step-response functions. The relations between boundary heat fluxes and boundary temperatures for any time-dependent heat conduction process in a solid material are represented as an ordinary thermal

network. However a new absorptive component had been introduced at each node or surface. This way the building thermal memory effect is accounted for by the use of certain averages of preceding boundary temperatures.

Availability of measured performances (labs. and field measurements)

Passive Utilization of the Thermal Mass
Givoni (1998) tested the effectiveness of thermal mass and night ventilation in lowering the indoor air temperature during daytime. It was found that, for building with light construction, night ventilation had only a very small effect on reducing indoor maximum temperatures. However, it was very effective to lower indoor maximum temperatures for the building with high thermal mass (heavy construction).

Thermo Active Building Systems
De Carli and Olesen (2001) measured thermal environment parameters in four buildings heated or cooled by hydronic radiant systems. Buildings with the following systems were examined: (a) wall-floor-ceiling heating-cooling system (light structure building), (b) floor heating-cooling system, and, (c) active thermal slab system with pipes embedded in the deck. Results of the measurements showed that operative temperature was most of the time within the range 22 – 24 ℃ and observed temperature ramps did not exceed 0.5 K/h during the occupation period.

Availability of simulated performances

Passive Utilization of the Thermal Mass
Goodwin and Catani (1979) investigated the effect of thermal mass on cooling load and on insulation requirements in different climates. Three types of buildings were selected to study the relationship between mass and cooling load. The results showed that adding insulation to walls can increase the cooling load while the mass is effective in reducing cooling load. By using the ESP program, the simulations on the role of thermal mass effects in Greek buildings were carried out (Argirious, 1992). The annual cooling load per square meter of floor area was shown to be a function of the effective thermal mass. And the reduction of cooling load is significant up to thermal mass approaching a particular value.

Thermo Active Building Systems
In the study by Meierhans (1993), a system with embedded pipes for heating and cooling was introduced in the slab constructions of office buildings. Results in the form of simulations (compare to the measurements) were presented for an office building in Horgen, Switzerland. The results indicated that the indoor temperature was kept at an acceptable range even during very hot outdoor conditions. Computer simulations of heating/cooling system with pipes embedded in the concrete slabs between the floors in a multi-storey building were conducted by Hauser et al. (2000). The results showed a significant improvement of thermal comfort by reducing the annual maximum operative temperature by 10 K (39°C - 29°C) compared to no cooling.

Claimed benefits

- Due to the utilization of the thermal mass, cooling and heating loads can be reduced and shifted to off-peak hours.

- The temperature of the cooling/heating water can be close to desired room temperature. This means high potential for using renewable energy sources (heat pumps, ground heat exchangers etc.), which can operate with high efficiency.
- The cooling system does not have to be designed to cover the maximum heat load. This leads to reduction of the refrigeration equipment or even to its omission.
- Peak loads from the daytime can be removed during the nighttime when the prices of electricity are lower. This leads to lower operation costs.
- Night-time ventilation can be used to cover or reduce cooling loads.
- As the ventilation systems only have to be sized for the ventilation rate needed for acceptable indoor air quality, ducts can be much smaller and a suspended ceiling is not needed.
- The avoidance of suspended ceilings has the big advantage of reducing the total building height, resulting in significant savings on construction costs and materials used.
- Using surface heating/cooling creates safe and comfortable indoor environment (more space in the rooms, no danger of burns, less dust in the indoor air).

Future perspectives

The technology of the thermal mass utilization, both passive and active is very well developed today. Systems are commercially available. Future development will focus on simplification of the system on-site construction. This requires higher level of prefabrication. There are several studies showing the use of TABS together with Phase Change Materials (PCM) integrated in building constructions (walls). This approach can be mainly applied for lightweight structure buildings and retrofits. Additional PCM layer of approx. 50 mm has the same thermal capacity as 300mm thick concrete wall (Koschenz and Lehmann 2000).

Barriers to application

- The effect of passive utilization of the thermal mass is dependent on the climate context.
- The thermal properties of the passively used thermal mass elements and surrounding environment should be considered to exert its storage ability. The surface area of the element needs to be sufficiently large to ensure sufficient heat transfer rate.
- TABS are suitable for buildings with low heat/cooling loads ($40 - 50$ W/m^2). High thermal insulation of the building envelope and proper solar shading is necessary.
- There should be a balance between heating losses and cooling loads, so that the system can work optimally (the same heat exchange surface is used for both cooling and heating).
- Without suspended ceiling, the acoustical requirements must be solved in other ways.
- Buildings with thermo active components cannot be expected to keep a fixed temperature. Further research is needed to evaluate occupant responses to the temperature drifts and the influence of these drifts on the performance of office work.
- Individual control of the indoor thermal parameters is possible only when additional air-conditioning/heating system is used.
- High standard of building construction management is needed.
- Optimization of the system, based on the experience, measurements and simulations, is needed in the beginning of the operation.

Limitations

- Heating/cooling capacity of the system is approximately $40 - 50$ W/m^2. In buildings with higher need additional systems are necessary.
- Individual control is not possible. Building can be divided into zones.
- Non-steady indoor environment – operative temperature drifts can be expected.
- Suspended ceilings should not be used, acoustic problems and lighting installations need careful design.
- During the heating period, there is a risk of cold downdraft at windows, which may be solved by the design of windows with glazing U-factors less than 1.2 W/(m^2 K), or with additional heating in the perimeter area.
- Regarding the cooling period, the control of humidity may limit the cooling capacity of the radiant system.

Open questions and future research work to be done

- Improved modelling algorithms in building energy simulation codes are required to be able to sufficiently predict convective heat transfer between passive thermal mass components and room air.
- Combination of the TABS with other responsible building elements (PCM) should be studied.
- The relationship between drifting operative temperature and human thermal sensation, prevalence of SBS symptoms and performance should be properly defined.
- Optimization algorithms based on measurements and simulations should be further studied.
- TABS should be tested using different renewable energy sources (solar and geothermal energy, waste heat from industrial processes etc.).
- Comparison of different system combinations should not focus only on energy issues. The construction and running costs of building and system, comfort and productivity of the occupants and the environmental impact must also be considered. Also first costs (including installation) and running costs (including maintenance) during the lifetime of the building should be taken into acoount.

References

Annex 44 A2. Thermal Mass Activation. Annex 44 State-of-the-Art Working Report Part A2 (**www.civil.aau.dk/Annex44**).

Argirious, A. 1992. A study of thermal mass in Hellenic buildings. Institute for technological applications, Hellenic productivity centre, Athens, Greece

Balaras, C. A. 1996. The role of thermal mass on the cooling load of buildings. An overview of computational methods. Energy and Buildings 24(1):1-10

CIBSE. 2001. CIBSE Guide B2 – Ventilation and Air Conditioning. Chartered Institute of Building Services Engineers (CIBSE), London, UK

Claesson J. 2003. Dynamic thermal networks: a methodology to account for time-dependent heat conduction, Proceedings of the 2nd International Conference on Research in Building Physics, Leuven, Belgium, p. 407-415. ISBN 90 5809 565 7

De Carli, M., Olesen, B. W. 2001. Field measurements of thermal comfort conditions in buildings with radiant surface cooling systems. Clima 2000, 15th – 18th 2001, Naples, Italy

Givoni, B. 1998. Effectiveness of mass and night ventilation in lowering the indoor daytime temperatures. Part I: 1993 experimental periods. Energy and Buildings 28(1):25-32

Goodwin, S. and M. Catani. 1979. The effect of mass on heating and cooling loads and on insulation requirements of buildings in different climates. ASHRAE Transactions, 85(1): 869-884

Hauser, G., Kempkes, Ch., Olesen, B.W. 2000. Computer simulation of the performance of a hydronic heating and cooling system with pipes embedded into the concrete slab between each floor. ASHRAE Transactions. Vol. 106, Part 1.

Koschenz, M., Lehmann, B. 2000. Thermoaktive Bauteilsysteme TABS. EMPA Duebendorf, Schwizerland, ISBN 3-905594-19-6

Li, Y. and P. Xu. 2006. In press. Thermal mass design in buildings – heavy or light? International Journal of Ventilation, Special Edition 5 (1):143 - 150

Li, Y. and Y. Yam. 2004. Designing thermal mass in naturally ventilated buildings. International Journal of Ventilation. 2(4): 313-324

Meierhans, R. A. 1996. Room air conditionning by means of overnight cooling of the concrete ceiling, ASHRAE Transactions Vol. 102, Pt. 2

Meierhans, R. A.1993. Slab cooling and earth coupling, ASHRAE Transactions Symposia, Vol. 99 (2)

Olesen, B.W. (2000) Cooling and heating of buildings by activating the thermal mass with embedded hydronic pipe systems, ASHRAE-CIBSE Dublin 2000

Schmidt, D., Weber, T., Jóhannesson G. 2000. Concrete core cooling and heating – a case study. Proceedings of Healthy Buildings 2000, Helsinki, Vol. 2.

Weitzmann, P. 2002. Modeling Building Integrated heating and coolind systems, Ph.D. thesis at Department of Civil Engineering, Technical University of Denmark, Lyngby, Denmark, ISBN 87-7877-152-2

Chapter 4.3   Dynamic Insulation Systems

Component description and example of existing application

The concept of dynamic insulation (DI) is to effectively use the combination of conventional insulation and heat exchange characteristics of a wall to pre-heat outdoor air for ventilation. It is regarded as one possible method for reducing building envelope heat losses while achieving better indoor air quality. The existing technology of dynamic insulation can be divided into two categories: the design using cavities to circulate the fluid (mostly air) in the wall, and the design of the breathing wall, which let the air transfer through the permeable insulation. Currently the research and application of dynamic insulation system focus on the latter. In this kind of structure, the interaction of air and solid phase acts as a contra-flux mode heat exchanger.

The dynamic insulated wall component usually consists of the external envelope sub-layer, the dynamic insulation sub-layer, and an air gap to separate these two sub-layers. The external envelope sub-layer could be a prefabricated reinforced concrete slab, or a profiled metal sheet. The ventilation air can be introduced from the bottom or top of the external envelope sub-layer. The dynamic insulation sub-layer may consist of layers of breathing materials, such as compressed straw board, mineral wool and thin paperboard, or cellulose fiber insulation. These breathing materials let the air enter the room due to a pressure difference between indoor and outdoor environment.

For the internal surface of the dynamic insulated wall, problems might exist with the use of a permeable wall liner. Air impermeable materials, such as plasterboard, have therefore been used. The air is drawn through the dynamic insulation sub-layer into a cavity behind the plasterboard. From there it is distributed into the room through vents.

Specific technologies have also applied to assure the uniform airflow and hence one-dimensional heat transfer through the wall. For example, for the construction that air comes into the wall from the bottom of the external layer, the lower part of the wall is constructed of having a higher air resistance. The indoor-outdoor pressure difference which assures the inward air flow through the dynamic insulation can be normally achieved by means of a fan.

Solar energy or heat recovery devices such as heat pump or heat pipe unit can be considered in the design to increase the performance of dynamic insulation component.

Working principles

In dynamic insulation, as air is intensively drawn through the building envelope to reduce the conduction heat loss, the airflow has a significant effect on the overall thermal performance of the building envelope. Assuming a uniform air flow, heat transfer in the dynamic insulation can be described using the 1-D steady-state model as follows:

$$k\frac{d^2T(x)}{dx^2} - u\rho_a C_p \frac{dT(x)}{dx} = 0 \tag{1}$$

Where,

k - The thermal conductivity of the wall material (W/m K)

T - The temperature (K)

ρ_a - The density of air (kg/m^3)

u - The air velocity (m/s)

C_p - The heat capacity of air (J/kg K)

Assuming a constant temperature boundary condition for the indoor and outdoor environment, the following dynamic U-value can be de derived to represent the overall heat loss (conductive and infiltration):

$$U_{dyn} = \frac{u\rho_a C_p}{e^{\frac{u\rho_a C_p L}{k}} - 1} \tag{2}$$

Where L is the insulation thickness (m). It is clear that the dynamic U-value is a function of the air velocity, or, more exactly, the Pe number

$$Pe = \frac{u\rho_a C_p L}{k}, \tag{3}$$

and the heat exchange efficiency of the dynamic insulation can be represented as

$$\eta = \frac{U_{static} - U_{dyn}}{\rho u C_p}. \tag{4}$$

Where U_{static} is the U-value at the static condition (W/m^{2}K).

Therefore the dynamic U-value can be regarded as a characteristic of the heat exchange performance of dynamic insulation. Figure 1 illustrates the dynamic U-value as a function of the airflow rate, for cellulose insulation with a thickness of 0.1m and 0.2m, respectively. It can be seen that U_{dyn} decreases with the airflow rate. It also can be noticed that the difference of U_{dyn} under the two thickness conditions decreases with the airflow rate, though the 0.2m insulation has a lower dynamic U-value.

The dynamic U-value only accounts for the conductive heat loss at the exterior surface. For the overall thermal performance of the dynamic insulation, the conductive and ventilation heat loss need to be considered. With the increase of airflow rate, the dynamic U-value tends to approach zero; however, the ventilation loss increases and becomes the dominating factor of the energy consumption.

Numerical investigations have been carried out on the thermal performance of the dynamic insulation. The results show that heat exchange in the dynamic insulation is first determined by the airflow rate, with the secondary influence of airflow path length and configuration. However, the influence of porosity, indoor and outdoor temperature difference, and convective heat transfer coefficient of the boundary condition, is not significant.

Thus, the key principle of dynamic insulation is to determine the insulation thickness and assure the range of airflow rate. On the one hand, to supply adequate outdoor air, promote the heat exchange between air and insulation, and to decrease the risk of condensation; the airflow rate should not be too slow. On the other hand, if the incoming air is not pre-heated before it enters the dynamic insulation, and its temperature is equal to the outdoor temperature, then the energy consumption of the building increases with airflow rate.
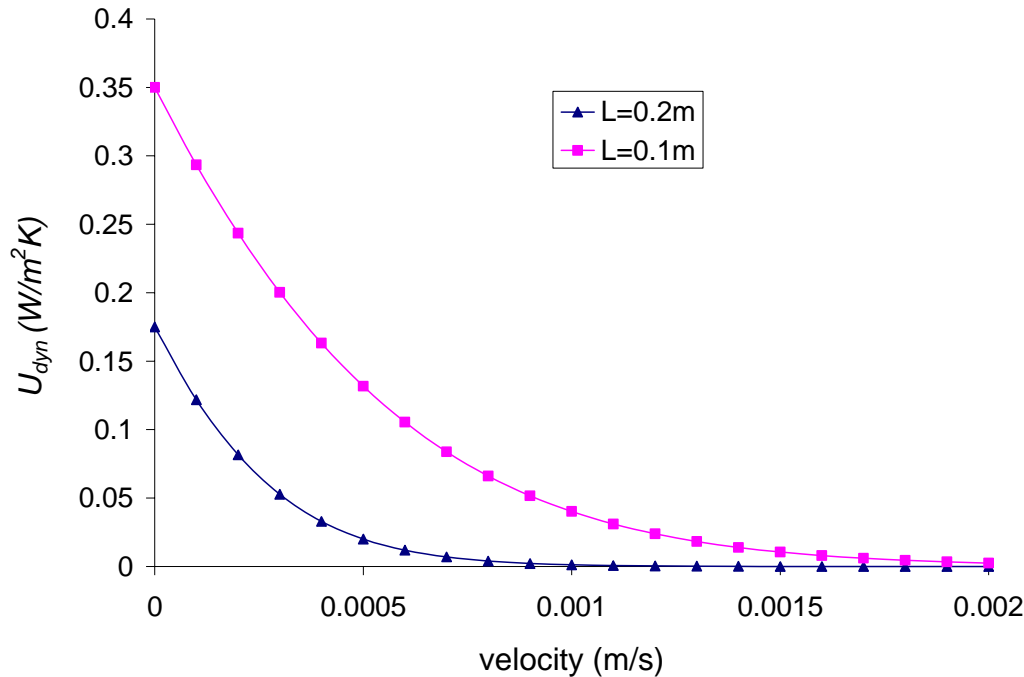
Fig 1 Variation of dynamic U-value

Application field

The dynamic insulation has the potential to be implemented in most climate conditions. The ideal type of building for implementation of dynamic insulation is the place that more fresh air is preferred, for example, swimming pools and hospitals. Concerning the energy consumption, it can be used in both business and residential buildings, though it may be more appropriate for small detached buildings.

Available design tools

Until now, no special design tools for the design of dynamic insulated wall have been reported. However, concerning the thermal performance, some commonly used building energy analysis tools, such as TRNSYS, can be modified to incorporate dynamic insulation elements. This can be carried out based on the steady-state analytical model, and applying the dynamic-U value to calculate the conductive heat loss.

Available experimental procedure to assess element performances

To measure the thermal performance of a dynamic insulation element, a special test cell needs to be designed and constructed. Investigations have been conducted using full scale test cells under outdoor climate conditions. The impact of ventilation rate and solar radiation, etc on the performance of a dynamic wall has been discussed, and the hourly variation of internal-external surface temperature difference and conductive heat flux at the internal surface has been reported.

Claimed benefits

"Claimed" benefits of applying the dynamic insulation in the building include: (1) Less energy is required to maintain an indoor air temperature, thus the operating costs for space heating and cooling are reduced; (2) The construction cost can be reduced as low heat loss can be achieved by using a thin dynamic insulated wall; (3) Cost of supplying and installing ventilation ducts can also be saved as the dynamic insulated wall becomes the air supplying ventilator; (4) Meanwhile, working as an air filter, dynamic insulation can remove airborne particulate pollution from the ventilation air.

Future perspectives

Future aspects of the dynamic insulation focus on the further development of the simulation model. Research is needed to evaluate the thermal performance of the dynamic insulation by using a coupled heat and moisture transfer model, and to find out the appropriate method to avoid the occurrence of condensation. Besides, radiation needs to be included in the numerical simulation.

Barriers to application

Barriers of the dynamic insulation mainly come from: (1) The guideline for dynamic insulated wall design is not well developed; (2) The impacts of dynamic insulation on the requirements of building regulations and standards have not been investigated; (3) The property of materials concerning the air permeability and water vapor permeability is not accessible to some designers; (4) Building designers are still unfamiliar with the concept of dynamic insulation, and it may take a long time for them to recognize the advantage of this technique and implementing it in their designs.

Limitations

Limitations exist concerning performances of the dynamic insulation. From point of view of the thermal performance, the simulation results shows that the overall energy saving is generally about 10%. This is not very attractive if considering the additional electrical energy consumption by the fan.

Open questions and future research work to be done

Other concerns are also related with the application of dynamic insulation. First, investigation on thermal comfort in the room needs to be further studied. Second, efforts should be made to combine the dynamic insulation with natural ventilation, or mixed ventilation, taking the advantage of pressure gradient by wind and stack effect. Finally, the implementation of the technology might be more promising if new design protocols can be developed to make the system work more effectively.

References

Annex 44 A3. Dynamic Insulation Systems. Annex 44 State-of-the-Art Working Report Part A3, (www.civil.aau.dk/Annex44).

Chapter 4.4 Phase Change Materials (PCM)

Component Description and Example of Existing Applications

The use of PCM (Phase Change Materials) in the construction field is aimed at being a solution for monitoring of thermal fluxes and exploitation of solar energy by using its enormous capacity for accumulating latent heat around temperatures close to its melting point. In fact, by exploiting their latent heat of fusion, and to a lower extent, their specific heat, these materials act as heat accumulators by absorbing and discharging heat while keeping their temperature unaltered and thus avoiding the overheating of the elements they are contained in.

Classification of PCM
A large number of PCMs are known to melt with a heat of fusion in the required range. PCMs are categorized as Organic, Inorganic and Eutectic materials.
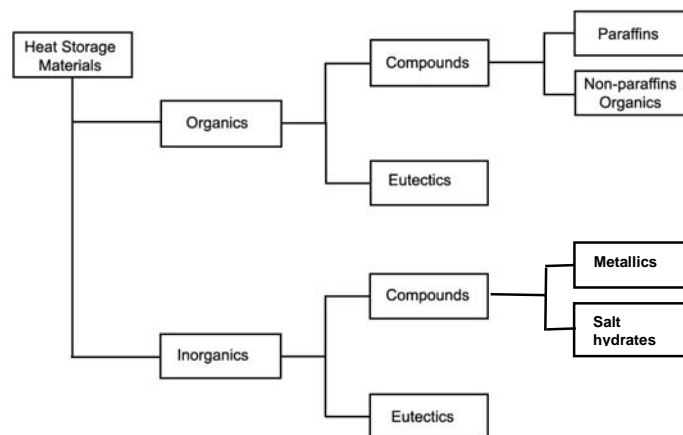
fig. 1: Typologies of phase change heat storage materials.

Organic materials are further described as paraffin and non-paraffins. Organic materials include congruent melting, self-nucleation and usually non-corrosiveness to the container material. Commonly used organic PCMs for heating and cooling in buildings falling in the range of 20–32 °C with their melting point and latent heat of fusion are listed in Table 1.

Table 1: Organic and inorganic substances potentially utilizable as PCM

Organic compound	Melting point [°C]	Heat of fusion [kJ/kg]	Inorganic compound	Melting point [°C]	Heat of fusion [kJ/kg]
Butyl stearate	19	140	KF· 4H2O	18.5	231
Paraffin C16–C18	20-22	152	Mn(NO3)2 ·6H2O	25.8	125.9
1-Dodecanol	26	200	CaCl2 · 6H2O	29	190.8
Paraffin C18 (45–55%)	28	244	LiNO3 ·3H2O	30	296
Vinyl stearate	27-29	122	Na2SO4 ·10H2O	32	251
Capric acid	32	152.7			

Inorganic materials are further classified as salt hydrate and metallics. Inorganic compounds have a high latent heat per unit mass and volumes have low cost if compared to organic compounds and are fireproof. However they suffer from decomposition and super-cooling which further can affect their phase change properties. The commonly used inorganic PCMs in the range of 20–32°C are listed in Table 1.

An eutectic is a minimum-melting composition of two or more components, each of which melts and freeze congruently forming a mixture of the component crystals during crystallization.

Properties of PCMs
PCM to be used in the design of thermal storage systems should own desirable thermo-physical, kinetic and chemical properties, which are recommended as follows.

Thermophysical properties
- Melting temperature in the desired operating temperature range.
- High latent heat of fusion per unit volume so that a smaller volume for the container to store a given amount of energy is required.
- High specific heat to provide additional significant sensible heat storage.
- High thermal conductivity of both solid and liquid phases to assist the charging and discharging energy of the storage system.
- Small volume increment on phase transformation and small vapour pressure at operating temperature to reduce the containment problem.
- Congruent melting of the phase change material for a constant storage capacity of the material with each freezing/melting cycle.

Kinetic properties
- High nucleation rate to avoid super cooling of the liquid phase.
- High rate of crystal growth, so that the system can meet the demand of heat recovery from the storage system.

Chemical properties
- Complete reversible freezing/melting cycle.
- No degradation after a large number of freezing/melting cycles.
- No corrosiveness to the construction materials.
- Non-toxic, fireproof and non-explosive material for safety.

Building applications
Particularly in warm climates, houses are frequently built using lightweight construction materials, which do not provide sufficient thermal mass for storage of heat. These houses are therefore overheated during daytime, but rapidly cool down at night. In order to compensate these fluctuations in temperature, the air conditioning is used during the day and a heating system in the evening.

The Integration of Phase Change Materials into building fabrics is considered to be one of the potential and effective ways of minimising energy-consumption and CO_2-emissions in the building sector.

Wall applications

A PCM layer can be placed within wall constructions to increase the thermal mass of houses. This will ensure that the thermal energy created by solar radiation is stored in the walls during daytime and then released to the room, when the ambient temperature has dropped or released outside the building. As a result, the room temperature will, in general, be more comfortable and less switched, and energy consumption for both air conditioning and heating will decrease.

In the market there are many solutions for walls with the use of one PCM layer, which are described in the following. In this technological solution, a layer of salt crystals stores the heat of the incoming sunlight and transfers this to the interior if required. A prismatic glass that is also included lets the incoming sunlight pass through it only if it is at a shallow irradiation angle (i.e. in winter), thus protecting the interior from overheating. In this way, a component is created that not only uses and stores the power from the sun, but simultaneously provides protection against it. Or, to put it in a nutshell: a component that stores, heats and cools. In the same place, at the right time.
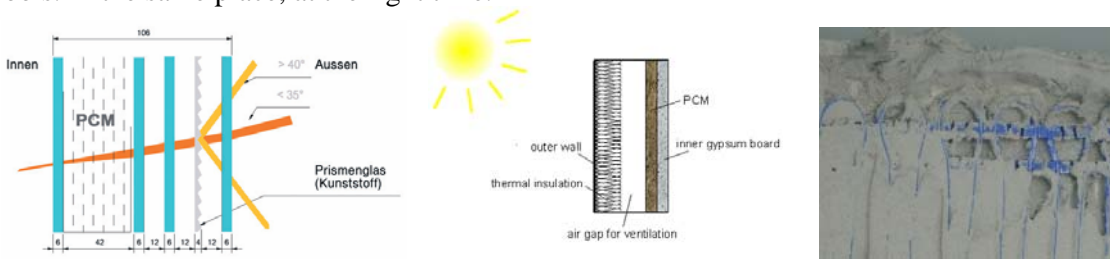
fig. 2: Wall application (GlassX , Rubitherm, BASF)

Thin-layered latent heat fibre boards or a bulk material, such as latent heat granulate, can be placed within wall constructions to increase the thermal mass of the house. This will ensure that the thermal energy created by solar radiation is stored in the walls during daytime and then released to the room in the evening, when the ambient temperature has dropped. As a result, the room temperature will, in general, be more comfortable and less swithced, and energy consumption for both air conditioning and heating will decrease.

The PCM plaster is applied like conventional plaster. The thinness of the coating and its low weight combined with a high thermal storage capacity are particularly advantageous in renovation projects. The capillary tube mats, which are visible on the ceiling, can be connected to any type of cooling source, such as an evaporative cooling tower or underground water.

The closely spaced capillary tubes, through which water is pumped, provide very good thermal coupling to the surrounding plaster. Thus, the ceiling can be cooled quickly, even if the temperature differences are only small. This feature, and the thinness of the plaster coating enable the system to react quickly compared to e.g. conventional cooling ceilings, despite the high thermal storage capacity of PCM

Underfloor applications

The internal surfaces when are directly irradiated, incline, in particular if built with lightweight technologies, to be overheated. The application of PCM in floor stratifications or in underfloor heating and cooling systems can avoid or reduce this problem, stabilize the surface temperature in a range close to the melting temperature. Also if the air temperature is higher then the temperature of the surface and the PCM, they absorb heat form the internal environment, lowering the internal temperature of air. The energy that is stored in the day can

be easily removed, if necessary, by a hydraulic system, or for used for heating the building in the night. In the winter the PCM avoid or reduce the temperature oscillation due to switch of the heating system and if directly irradiated by sunlight, exploit the solar energy for heating. Another application of PCM in building components is in a electric floor-heating system. In this case the floor-heating system stores heat at night, when electricity rates are low, and discharges it during the day.
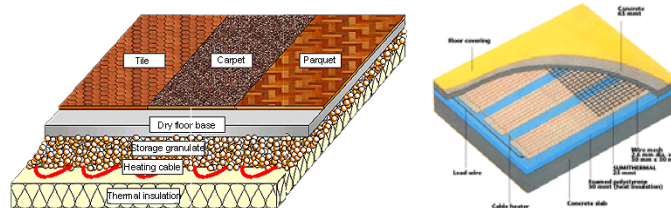
fig.3: Underfloor heating and cooling system (Rubitherm GmbH, SUMIKA).

Working Principles

PCM are ''latent'' heat storage materials. They use chemical bonds to store and release heat. The thermal energy absorption and release occur when a material changes from solid to liquid, or liquid to solid. This is called a change in state or phase. PCM, having melting temperature between 20 and 36 °C, were used/recommended for thermal storage in conjunction with both passive storage and active solar storage for heating and cooling in buildings.

When a solid PCM is heated up and reaches its melting point, it goes through a phase change, from solid to liquid. During this process the material absorbs a certain amount of heat, known as melting enthalpy. Despite the heat input, the temperature of the material holds at a relatively constant temperature, even though phase change is taking place. Thus we speak of latent (concealed) heat having been taken up by the material. Equally, when the phase change process is reversed, that is from liquid to solid, the stored latent heat is released, again at a nearly constant temperature. Unlike sensible storage materials, such as water, masonry or rocks, PCM stores much more heat per unit volume and another key advantage with the use of a PCM is that heat storage and its recovery occurs isothermally, which makes them ideal for space heating/cooling applications. A smaller amount of the heat storage capacity (depending on the temperature difference) consists of sensible heat.

Behaviour of a PCM inserting in a dry wall façade
The aim of application of a PCM layer in a external wall is the control of the heat flux, the temperature of the components and internal environment, and the utilization of solar energy for heating buildings. The control of the heat flux is made by changing the thermal inertia and storage capacity of these components, without an important change of the thermal resistance of the wall. The elevate thermal inertia in a range of temperature close to the point of fusion of the PCM reduce the temperature oscillation of the components, avoiding the overheating, the temperature and flux peak, typical in the day and night in the summer seasons. Also the effect of the application of the PCM layer is a shifting of the flux peak, in the cool hours of the day.

In the winter it is possible to use PCM as a solar heating storage system to capture solar energy and release heat in the internal environment of the building, reducing the use of heating systems and not renewable energy.

Behaviour of a PCM inserting in underfloor heating and cooling system

One of the possible uses that was figured out for the PCM blanket is an underfloor application, integrated to a radiant heating or cooling system. In this sense, the blanket would replace the thermal mass traditionally obtained through concrete elements, giving the added benefit of being able to design both the operating temperature of the system and its thermal capacity according to the specific situation.

The technical solution is made up of two layers formed by the PCM blanket with water pipes embedded between them in order to enhance heat exchange between the surface of the pipes and the PCM contained in the pouches. The upper surface is then made smooth trough a thin self-levelling screed, where the floor material can be laid.

The basic idea was to maintain the floor at an about fixed constant temperature: that of the melting point of PCM contained in the blanket. In summer, the floor heats up, because of the radiation from the sun entering the windows, but when it reaches the melting temperature the phase change process begins. Then, the energy gained from the sun is used in latent form, while the temperature of the PCM layer remains constant. If the melting temperature is accurately chosen, during the phase change process the floor works as a radiant surface at a comfortable temperature for the users of the building. Most of the energy coming from the sun is thus used for PCM melting instead of increasing the air temperature inside the building. When PCM's are completely melted, or night has fallen, cool water circulating in the floor is used to activate the inverse process of solidification (discharging of the PCM layer by taking latent heat away). In this way, the PCM element is ready for another storage cycle, be it the same day or the next morning. If the melting temperature is well chosen, a similar strategy can be used also in winter, with hot water used to warm up PCM's, which then release heat to the internal environment.

Behaviour of an air exchanger with PCM

In modern buildings greater use of it is increasing the risk of overheating in the summer. The application of a air exchanger having a latent thermal mass provides a low cost passive environmental solution to avoid the need to resort to air conditioning. This application uses the thermal mass of a building to store cooling introduced at night by circulating relatively cool ambient air through the building - "night cooling". This stored cooling is then released by circulating air the next day to offset heat gains and limit internal temperature rises.

fig. 4: Air conditioning system based on thermal energy storage in building structure, night and day behaviour.

Application Fields

The development of an energy storage system may be one of the solutions to the problem when electricity supply and demand are out of phase. A building integrated with distributed thermal storage materials could shift most of the load coming from residential air conditioners from peak to off peak time periods. As a result, capital investment in peak power generation equipment could be greatly reduced for power utilities and then could be reflected in less expensive service to customers. Where power utilities are offering time of day rates,

building integrated thermal storage would enable customers to take advantage of lower utility rates during off peak hours. There are some studies that have examined the shifting of heating and cooling loads to off peak times of the electrical utility but did not reach general conclusions regarding optimal PCM properties. Their analysis looked at potential applications of PCM wallboard as a load management device for passive solar applications and found out that it saved energy with reasonable pay back time periods.

Available Design Tools

Nowadays, there are different commercial programs for the thermal simulation of buildings: EnergyPlus,TRNSYS15,ESP-r,RADCOOL,DOE-2,IDA-ICE3,HVACSim,CLIM2000, and many others. Although all the possibilities of these programs, none of them have modules that allow direct simulation of the effect of adding a PCM in a wall or window. While analytical models of several PCM building elements are available, very few authors have worked on the simulation of the effect of PCM in buildings using whole thermal building simulation programs.

Available Experimental Procedure to Assess Element Performances

A procedure to validate a finite element algorithm for the simulation of a two dimensional problems of heat transfer with Phase Change, comparing the numerical results with the experimental ones deriving from tests carried out on two different kinds of PCM containing panels is described.

In this tests four prototypes of ready-made PCM containing panels were tested (two of them used to validate the numerical finite element method for design purposes) in a climatic chamber, capable of simulating several kinds of outdoor and indoor environmental conditions, aimed at evaluating their energetic performances, which make them suitable for use in different climatic contexts or in different elements of buildings.

The numerical model was used for the simulation of prototypes. A finite element algorithm was used to describe the two-dimensional thermal conduction phenomenon which occurs within the PCM containing panels. For the aims of the work, the procedure was integrated in the COSMOS/M software.

Claimed Benefit

Energy storage in the walls, ceiling and floor of buildings may be enhanced by utilising Phase Change Materials. PCM can absorb solar energy at daytime while PCM changes from solid to liquid, and releases the energy and freezes back to solid when the room temperature falls down at evening. Therefore, the human comfort level can be increased by using PCM to lower indoor air temperature fluctuation and maintain the indoor air temperature to the desired range for a longer period. The use of PCM (Phase Change Materials) in the construction field aims to be a solution for the control of thermal flows and the exploiting solar energy by using its enormous capacity for accumulating heat around temperatures close to its melting point.

Future Perspectives, Barriers, Open Questions

The possibility to use PCM in the building industry can be realistic if its performance in time can be stabilized in order to control them and keep them unchanged.
The main problems encountered have to do with the determination of the characteristics of the PCM layer (thickness and melting point).

The choice of the stratification and functional model, considering the climate contest, type of building and the orientation of the wall surface is very important for having a desiderated performances of the PCM.

Furthermore the application of the phase change materials are subject to two fundamental restrictions: firstly, the heat transfer between the air and the wall limits the maximum storage power within a day/night cycle; secondly, the application is fully dependent on the outdoor temperature of the night air as a heat sink. In some building types or under certain climatic conditions, these restrictions appreciably limit the applicability of such materials.

An important limitation of the use of some kind of PCM, for example the inorganic hydrates salt is the durability of these substances. The principle problem attributed to these salts, but on the other hand to hydrate salts as well, lies in performance loss with repeated thermal cycles, which entails a substantial lowering of their storage and discharge capacity during phase change. In order to do so we must first and foremost observe and evaluates all the phenomenon which determine their loss of storage capacity and deterioration in time.

References

Annex 44 A4. Phase Change Materials. Annex 44 State-of-the-Art Working Report Part A4, (www.civil.aau.dk/Annex44).

Abhat A. (1983) Low temperature latent heat thermal energy storage: Heat storage materials *Solar Energy, Volume 30, Issue 4, 1983, Pages 313-332*

Carbonari A., M. De Grassi, C. Di Perna and P. Principi (2006),Numerical and experimental analyses of PCM containing sandwich panels for prefabricated walls, *Energy and Buildings, Volume 38, Issue 5, May 2006, Pages 472-483*

Feldman D, Banu D (1996). DSC analysis for the evacuation of an energy storing wallboard. Thermochimica ACTA, Volume 272,pp 243-251.

Hawes D.W, Feldman D, Banu D (1993) Latent heat storage in buildings materials. Energy and buildings, Volume 20, no. 1, pp77-86

Hed G., Bellander, R (2006), Mathematical modelling of PCM air heat exchanger, *Energy and Buildings, Volume 38, issue 2, pp 82, 89*

Lemma M., Fioretti R., Imperadori M.(2005), Development of a technology for inserting a PCM layer in building envelopes, Atti del XXXIII IAHS World Congress "Housing, Process & Product", Pretoria 2005;

Marks S. (1980). An investigation of Gluber´s salt with respect of thermal cycling. Solar Energy 25,pp 255-258 .

Chapter 4.5   Earth-to-Air Heat Exchangers

Component Description

An Earth-to-Air Heat Exchanger (ETAHE) ventilates air to the indoor environment through one or several horizontally buried ducts. In this way, the ground's large thermal capacity and relatively stable temperatures are used to preheat or pre-cool the air, resulting in energy savings for the building. Most existing ETAHE systems are installed in mechanically ventilated buildings, in which electrical fans provide the airflow driving force and the buried ducts are of small diameter. Recently, to reduce the airflow resistance in an ETAHE as well as the related fan energy consumption, some hybrid ventilated buildings have adopted very large cross-sectional ducts. The integration of ETAHE and hybrid ventilation is regarded as a new approach to improve building energy efficiency.

Working Principles

The earth is a steady and practically infinite heat source, sink, and storage medium due to the high thermal inertia of soil. As far as soil temperatures are concerned, an ETAHE should be installed as deep as possible since the temperature fluctuations are dampened deeper in the ground. However, the excavation cost for laying an ETAHE very deep may not be economical. When outdoor air is drawn into an ETAHE duct, the temperature difference between the air and the duct causes convective heat transfer, which changes the duct temperatures. The resultant temperature gradients from the duct surface to its surrounding soil will further cause new temperature distributions in the soil. Moisture diffusion takes place as a simultaneous process, which affects the heat transfer to some extent. The temperature change of air from the inlet to outlet represents a sensible heat variation. When the duct material is moisture-permeable or the duct surface temperature reaches the dew point temperature, latent heat changes may take place through condensation, evaporation, or moisture infiltration. In most systems, a certain mount of energy has to be spent to circulate the air. Therefore, an optimal design is considered as a trade-off between maximizing energy savings in conditioning the air and minimizing energy consumption in circulating the air.

Design Criteria

- Airflow rates through an ETAHE need to satisfy the building's airflow requirement assuming the ETAHE is the only air entrance for the building.
- It is desirable to maximize the heat transfer rate between air and duct wall while also minimizing the airflow resistance.
- Condensation and moisture infiltration on the ETAHE wall should be avoided.
- The buried ducts should be anticorrosive and structurally stable.
- Safety, insect entrance, and noise transmission in ETAHE should be considered.
- Long term operation of an ETAHE may exhaust its capacity. The system should be sustainable.

Application Field

ETAHE's application is not restricted to particular building types. A large number of ETAHE systems have been implemented in greenhouses and livestock houses, as well as in residential and commercial buildings. When an ETAHE is used for heating in winters, additional air conditioning devices are usually necessary, for example, an ETAHE is usually coupled with a heat recovery unit to help prevent icing (see Figure 1).
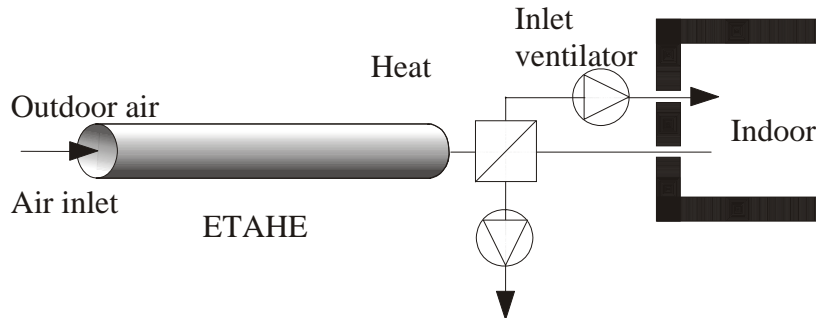
Figure 1. An ETAHE system with heat recovery for winter operation

An ETAHE is suitable for independent cooling of indoor air as well as for supplementation for other cooling systems. Figure 2 is an ETAHE system for cooling.
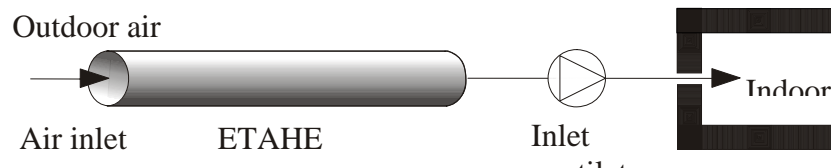
Figure 2. An ETAHE system for summer operation

Available Design Tools

- Calculation charts by Santamouris and Asimakopoulos (1996)
- Computer program, WKM (http://www.igjzh.com/huber/wkm/wkm.htm)
- Analytical method by De Paepe and Janssens (2003)
- Computer program, GAEA, by The Division of Building Physics and Solar Energy, University of Siegen, Germany (http://nesa1.uni-siegen.de/index.htm?/softlab/gaea.htm)
- TRNSYS compatible moist air hypocaust model by Hollmuller and Lachal (1998)
- Early design guidance for different weather conditions and locations with a few design charts and tables by Zimmermann and Remund (2001) under the framework of the IEA-ECBCS Annex 28

Although many ETAHE systems have been built in the past decades, the design tools are still under development. Especially, there has not been a method to predict the performance of the large cross-sectional ducts due to the complex airflow and heat transfer processes involved in the systems.

"Claimed" Benefits

- ETAHEs can save energy for winter heating and summer cooling when conditioning the indoor environment.
- ETAHEs can reduce CO_2 emissions and improve indoor thermal comfort.
- Appropriate exploitation of moisture transfer between air and soil may realize moisture control for the supply air.
- ETAHE' ducts have a filtration effect (concentration reduction of airborne particle, spores and bacteria after passing ETAHE).
- ETAHEs' construction is cheaper than active cooling systems.
- ETAHEs have a very long lifespan.
- ETAHEs are compatible with other ventilation system components
- General availability of pipe materials makes ETAHE systems easy to be replicated anywhere.

Future Perspectives

ETAHE technology has been used in many buildings with good success. It has been proven applicable for wide range of climates and various types of buildings, such as livestock houses, greenhouses, residential and commercial buildings. For buildings with moderate cooling load, properly sized ETAHE systems may become alternatives to many mechanical heating and cooling systems. Buildings with the following favourable factors may become the potential users of ETAHEs:

- moderate cooling loads
- low ground temperature
- large daily outdoor air temperature swings
- relatively low requirements for indoor environment
- displacement ventilation system

Hybrid ventilation has very good potential for future ETAHE applications. When an ETAHE needs to be integrated into a hybrid ventilated building, large cross-sectional area ducts are favourable for the integration.

Barriers to Application

- ETAHEs provide a path for outdoor noise transmitting to indoor. Plus, many systems are equipped with electrical fans in their ducts. There are concerns that some systems may contravene current noise regulations.
- ETAHEs techniques do not appear completely safe for the environment in terms of contamination of soil, underground water, and microbial growth in the airway.
- There is a general lack of easy-to-use design methods. Existing modeling methods are not accessible for designers. Training programs need to be promoted.
- Design of ETAHE's control strategies vary significantly between countries and regions because of climate differences. Such variations impact technology transfer and adoption of best practice.
- Many building owners and equipment installers lack confidence in new energy technologies. Frequent conservative reflexes when it comes to investment will often lead to more conventional choices.

- The system costs are very dependent on the actual project. In some cases, the initial investment for installing an ETAHE might be more expensive than the regular air conditioning system. This may cause less attraction for building owners. However, it should be noted that an ETAHE has very long lifespan. The energy saving potential should be considered as a competitive alternative.
- The installation of the heat exchangers should be carried out with high precision in regards to the hygienic regulations, declined mounting and leak tightness. Construction supervision from designers or HVAC experts is therefore often necessary at the site. These extraordinary installation demands could be a reason why the heat exchangers have presently not established a growing market demand.

Open Questions and Future Research Work to be Done

Although many simulation studies have been done to investigate ETAHEs and many applications have achieved successful performances, there are still some issues that need to be studied in the future, such as

- the complex airflow and heat transfer in large cross-sectional ETAHE ducts
- integrated system design under the whole building concept (taking into account the interaction between ETAHE and building energy system) to achieve system optimization
- development of design tools
- optimization of system design and control strategy
- diurnal and seasonal balance between heating and cooling
- long-term monitoring for soil temperature development to access if the capacity of the system is sustainable
- interrelated constraints among minimizing initial investment, enhancing heat transfer, and reducing operation cost

References

Annex 44 A5. Earth-to-Air Heat Exchangers. Annex 44 State-of-the-Art Working Report Part A5, (www.civil.aau.dk/Annex44).

Santamouris, M. and Asimakopoulos, D.N. (1996). *Passive Cooling of Buildings*, James & James, London, ###-###

De Paepe, M., and Janssens, A. (2003). *Thermo-Hydraulic Design of Earth-Air Heat Exchangers*. Energy and Buildings, 35(4), 389-397.

Hollmuller, P. and Lachal, B. (1998). *TRNSYS Compatible Moist Air Hypocaust Model - Final Report. No. 19507*, Centre universitaire d'étude des problèmes de l'énergie, University de Geneve.

Zimmermann, M., and Remund, S. (2001). *IEA-ECBCS Annex 28 Subtask 2 Report 2, Chapter F Ground Coupled Air Systems*. Low Energy Cooling - Technology Selection and Early Design Guidance, N. Barnard and D. Jaunzens, eds., Construction Research Communications Ltd, 95-109.

Chapter 5   Integrated Building Concepts

Introduction

The purpose of this chapter is to give examples of integrated building concepts, the related available performance data and information about design processes and tools that are being used. The chapter does not aspire to give a complete overview of all possible integrated building concepts and processes. The buildings have been selected according to the knowledge of the participants in the project, as characteristic examples of the concepts and the challenges they represent.

Chapter 5.1 describes process methods and tools used in the design of integrated building concepts. This includes a description of the use of the methods and tools, any experiences from their implementation, barriers, and research needs.

Chapter 5.2 describes the integrated building concepts including the following information, if available:

- General building data (name, location, owner, start of operation, area, number of floors, construction type, building use, operation time, etc)
- Climate and context
- Heating, cooling, ventilation, and control systems
- Responsive building elements applied and their integration
- Construction costs, LCC
- Energy use for operation
- Indoor environment
- Operation and maintenance related issues
- Architectural issues
- Adaptability issues
- Design and construction process issues (co-operation, contract, strategies, methods and tools, special challenges related to the integrated building concept)
- Barriers to implementation
- Open questions and needs for future research

Chapter 5.1 Methods and Tools for Designing Integrated Building Concepts

Introduction

This chapter contains a description of 11 different methods and tools that the members of the IEA Annex 44 have contributed. In addition, the report contains a short overview of computer simulation tools that may be used to predict the performance of integrated building concepts and responsive building elements. At last, the report gives a description of uncertainty modelling in building performance assessment. A more comprehensive description of the methods and tools may be found in (Andresen et al 2006).

The descriptions of the design methods and tools include an explanation of how the methods may be applied, any experiences gained by using the methods, barriers for further use, and research needs.

Overview of the methods

Name	Origin	Year
The Integrated Design Process, Task 23	IEA SHCP Task 23 (International)	2003
The Integrated Design Process, Knudstrup	M-A.Knudstrup, Aalborg University, Denmark	2004
Integrated Building Design System, IBDS	K.Steemers, Cambridge University, UK	2005
The Eco-Factor Method	Erik Bjørn, Åsa Wahlström (Swedish National Testing and Research Institute, Henrik Brohus (Aalborg University)	2004
Trias Energetica	Ad van der Aa, Ir. Nick van der Valk, Cauberg-Huygen Consulting Engineers, The Netherlands	2005
Energy Triangle	Haase, M. and A. Amato, Hong Kong University	2005
The Kyoto Pyramid	T.H. Dokka, SINTEF, Norway	2004
E-Quartet	A. Satake, Maeda Corporation, Japan	
Eco-Facade	M. Kolokotroni (et al), Brunel University, UK	2004
LEHVE	T. Sawachi, NILIM, Japan	2005
VentSim	S. Nishizawa, Building Research Institute, Japan	

Although the methods contain many similar aspects, they may be organised into 5 main categories:

1) Design Process Methods/Tools
The first three methods can be described as process focused methods. They describe how to work during the design, what issues to focus on in what stages of design, how the issues may be organised, how they interact, etc. The Integrated Design Process Task 23 method can be characterised as a design process method with tools. The Integrated Design Process Knudstrup method is focused around a trans-disciplinary process approach to designing low energy buildings. Both of these methods use the architect's design process approach as the point of departure. The IBDS is more focused on design issues, and offers the possibility for a strategic

interaction between the various parameters in the process. In this respect, the IBDS may also be described as a Design Strategy Method (see below).

2) Design Evaluation Methods/Tools
The design evaluation tools are typically used later in the design process to check the performance of a given design concept or to evaluate a specific design scheme and compare it to a benchmark or to another alternative scheme. The Eco-Factor Method and the VentSim tool fall into this category.

3) Design Strategy Methods/Tools
The Trias Energita, The Kyoto Pyramid and the Energy Triangle are methods that present a way to structure the technological design issues. They all stem from the Trias Energetica approach devised by Lysen (1996). They are based on the philosophy that the order of measures should be similar the "reduce-reuse-recycle" –principle, i.e. passive measures first, then renewable technologies, and at last efficient use of non-renewable resources.

4) Design support Methods/Tools
The design support tools are typically used in the early stages of the design to get an idea of what approaches and design schemes are the most promising for the given project. The E-Quartet, the Eco-Façade, and the LEHVE tools fall into this group.

5) Simulation Tools
Computer simulation tools are used to predict the performance of a specific design solution.

There are no sharp borders between the different types of tools. The design support tools may in some case also be used as design evaluation tools, and vice versa. The available computer simulation tools for predicting energy use and indoor climate are typically used as design evaluation tools, but may also be used as design support tools. In fact, in order to succeed in creating effective integrated building concept, it is very useful to apply advanced computer simulation tools in the early design stages.

References
Andresen et al (2006), "State-of-the-Art Review of Designing Integrated Building Concepts. Working Report", IEA Annex 44, (www.civil.aau.dk/Annex44).

The Integrated Design Process by IEA Task 23

Description of method

A method called the Integrated Design Process was developed within the framework of IEA Task 23: Optimization of Solar Energy Use in Large Buildings. The approach is based on the well-proven observation that changes and improvements in the design process are relatively easy to make at the beginning of the process, but become increasingly difficult and disruptive as the process unfolds.

Based on experience in Europe and North America, the overall characteristic of an Integrated Design Process is the fact that it consists of a series of design loops per stage of the design process, separated by transitions with decisions about milestones. In each of the design loops the design team members relevant for that stage participate in the process. The design process itself emphasizes the following sequence:

1) First establish performance targets for a broad range of parameters, and develop preliminary strategies to achieve these targets,

2) Then minimize heating and cooling loads and maximize daylighting potential through orientation, building configuration, an efficient building envelope, and careful consideration of amount, type, and location of fenestration;

3) Meet these loads through the maximum use of solar and other renewable technologies and the use of efficient HVAC systems, while maintaining performance targets for indoor air quality, thermal comfort, illumination levels and quality, and noise control; 4) Iterate the process to produce at least two, and preferably three, concept design alternatives, using energy simulations as a test of progress, and then select the most promising of these for further development.

Application of method

The IDP approach was applied to a number of building projects in Europe and Canada. In all the cases, the approach proved to be very successful. The case studies showed energy saving in the order of 50% compared to conventional buildings.

Benefits

Task 23 has shown that there are significant advantages in using Integrated Design Processes. Integration on the level of the process results in synergies at both the systems level and the whole-building level.

Barriers

- Extra time and resources are needed in the early design stage.
- The different members of the design team needs to have an understanding and of the integration aspects. This requires that they have some knowledge of the whole range of professional fields.

Need for further research

- Developments of design tools that facilitate and Integrated Design Process

References

Larsson, N. and B. Poel (2003) "Solar Low Energy Buildings and the Integrated Design Process – An Introduction", http://www.iea-shc.org/task23/.

Architecture and the Integrated Design Process (IDP)

Description of method
The idea behind the development of the Integrated Design Process IDP methodology by Knudstrup [Knudstrup 2004] was to focus upon the ability to integrate knowledge from engineering and architecture in order to solve the often very complicated problems connected to the environmental design of buildings. The method copes with technical and aesthetical problems, and focuses on the creative element, in order to identify new opportunities and make innovative solutions in a new building design. The process is conducted as an integrated process by using the method, the Integrated Design Process IDP, in which the professional knowledge of architecture and parameters from engineering are integrated and optimised. The method was developed for the specialisation in Architecture at Aalborg University's Engineer Education in Architecture & Design, Aalborg University.

The method presents the following project phases applied in the order of presentation: Problem formulation phase, Analysis phase, Sketching phase, Synthesis phase and presentation phase. The process is iterative and the iterations happen in loops

Application of method
IDP is based on group work, but it can also be done by traditionally educated architects and engineers as well. When the method is used in practice it would be easier to overcome the many aspects in a team consisting of people with different competencies, especially if it is a larger project and if they are not educated in the Integrated Design Process IDP, because of the many parameters and the trans-disciplinary approach.

Benefits
Student projects indicate the following benefits of the application of the IDP:
- Avoidance of problems of poor integration between technical solutions and the architectural expression.
- Low operating costs due to well functioning environmental building

Need for future research
- The IDP can be used for environmental or sustainable projects. But there is still a need more specific methods, e.g. related to a particular function in a specified climate.
- There is a huge challenge to develop programmes which can be used for co-optimising a wide number of parameters at the sketch level - both architectural and engineering parameters.
- How can we implement this method to mainstream architects or designers?

References
Knudstrup Mary-Ann (2004), "Integrated Design Process in PBL", article in The Aalborg PBL model red. Anette Kolmoes, Flemming K Fink and Lone Krogh. Aalborg University Press 2004, Denmark.

Integrated Building Design System (IBDS)

Description of method

A method called Integrated Building Design System (IBDS) has been developed at Cambridge Architectural Research Limited and The Martin Centre for Architectural and Urban Studies. Department of Architecture, University of Cambridge by Koen Steemers.

The approach to the integrated building design system, the IBDS methodology provides a flexible system for assessing the interrelationships and levels of integration of design parameters for low energy design in an urban context. The method is flexible in that additional and alternative parameters can be included in the analysis

This is the methodology for an integrated building design system (IBDS) in an urban context. It sets out to provide a framework of working which demonstrates and reminds the design team of the range of issues and interactions through the design process. It should not be considered as a rigid process but rather as a way of raising awareness of the integration implications of a range of environmental and design parameters. The aim of IBDS methodology is to demonstrate how the various factors interact and – more importantly – how they can be integrated successfully and holistically to achieve low energy urban building design.

Application of method

Clearly, design is an iterative process and the strategy outlined here should not be considered as a simplistic linear process. The main purpose is to increase an awareness and understanding of interrelationships that exist in the design process. It can be used as a framework for design team discussions at the various key design stages, as well as a design tool at any given stage (be it outline design or construction detailing).

One strategic aim of the integrated approach is to avoid conflicts between the architecture and technology. This requires a close collaboration between architect and engineer from the beginning of the design process.

Benefits

The method shows how one can combine the design variables with both the passive and active energy strategies, and then it becomes possible to rank the strength of interrelationships. The method lists the various parameters and here one can see whether the parameters are design related or energy related, according to the frequency of interrelationships between each category. This methodology can be applied to any key set of parameters as set by the design team.

References

Koen Steemers at Cambridge Architectural Research Limited and the Martin Centre for Architectural and Urban Studies. Department of Architecture, University of Cambridge. 2005.

Eco-Factor Method

Description of method
A guideline tool for an integrated design approach has been developed within an EU-project called IDEEB (Intelligently Designed Energy Efficient Buildings) during 2002-2004. The concept is thoroughly described in Bjørn et al. (2004) and Brohus et al. (2004), and summarized in Wahlström and Brohus (2005). The project's "motto" was that the whole energy system, regarding both the building and the technical installations, must be considered in order to achieve energy efficient buildings with good indoor comfort and low environmental impact. This requires an integrated design approach of all building elements with involvement of all disciplines. The assessment concept is using the Eco-factor method for assessment of different building designs and thereby avoid unforeseen dangers of compromising indoor climate in order to improve the energy performance, or vice versa. However, the concept can be extended with other assessments, for example of the buildings function at integration of building elements.

Application
The concept works on two levels. The first and most "simple" level, the *concept design level*, is applied to get a fast overview and intelligent suggestions of alternative building designs. The second and "advanced" level, the *detailed design level*, is aimed for the consultants to do detailed designs of a few chosen cases. Each level consists of two phases, a *design phase* and an *assessment phase*.

Benefits
The assessment concept is intended to be an integral part of new design guidelines where architects and engineers should be able to obtain a quick overview of the effect of changing key parameters and the potential for improvements in energy-related emissions and indoor climate. The assessment concept should be possible to use with different contracts/organizations but require a close cooperation between different parties in different stages of the process (Nordström, 2004).

Need for further research
The guideline is developed by primarily considering design of European office buildings and should cover warm, moderate and cold European climates. With small adjustments it should be possible to use it at design of any kind of building. The assessment concept is using an integrated approach with involvement of all disciplines. This makes the guideline very suitable for integration of responsive building elements, and it is now ready to be tested in practice.

References
All referenced reports are freely available on www.ideeb.org

Trias Energetica

Description of method

Trias Energetica is a three step approach that gives the priorities for realising an optimal sustainable energy solution. The approach was introduced in 1996 by Novem in the Netherlands (Lysen 1996) and has been further worked out by the Technical University of Delft. The Trias Energetica method contains the following steps:

- Reduce the energy demand, by applying energy reducing measures (thermal insulation, air tightness, heat recovery)
- Use as much sustainable energy sources as possible for the generation of energy (solar, wind and biomass);
- Apply fossil fuels as efficient as possible (high efficient gas boilers, high efficient lighting)
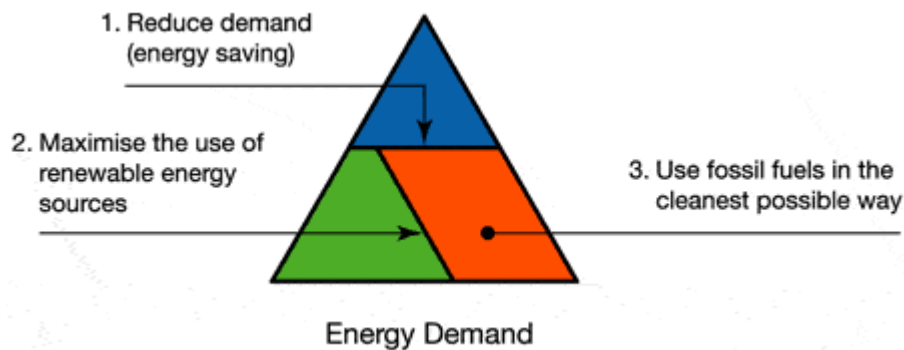
Application of method

The method is being implemented in an Excel-based toolkit by Cauberg-Huygen, Rotterdam, the Netherlands. The toolkit evaluates the energy use, the extreme conditions and the cost frames through a three step calculation:

- Energy needed and load/duration curves calculated for heating, cooling and lighting
- Calculation of floor tempertures
- Features of the control system

References

Lysen, E. H. (1996), "The trias energetica: Solar energy strategies for Developing Countries" *Eurosun Conference*, Freiburg, Germany.

Energy Triangle

Description of method

The Energy Triangle is a method described by Haase and Amato (2005). The method involves a three steps approach that is related to the work of Lysen (1996). The triangle is divided into three layers:

1. Energy conservation: The building should be planned by making use of all energy conservation strategies.

2. Increasing efficiency: all necessary energy consuming units in the building should be optimised by using the latest energy efficient devices and components.

3. Utilization of renewable energy resources: for the remaining amount of necessary energy all renewable energy resources should be exploited and implemented.

Application of method

Haase and Amato (2005a, 2005b) have applied the method to the development of an innovative ventilation system that integrates climate responsive building elements with an innovative building envelope for an office building located in Hong Kong, which has a hot and humid climate. First, the impact of building location and climate, size and orientation was analyzed with respect to thermal comfort and energy conservation. Then, six passive strategies for improving thermal comfort were investigated: 1) thermal mass effect, 2) exposed mass + night purge ventilation, 3) passive solar heating, 4) natural ventilation, 5) direct evaporative cooling, and 6) indirect evaporative cooling. The effect of the six strategies was illustrated using a psychometric chart. This resulted in the following conclusions:

1) In subtropical climates with up to 7 months with HDD the maximum heating requirement in office buildings can be delivered by a passive solar heating strategy.

2) Night purge ventilation needs a significant temperature difference during the night time. 3) Natural ventilation has a high potential especially in April and October. 4) Evaporative cooling strategies can only be applied to dry climates were it is possible to humidify the air.

Further analysis indicated that natural ventilation was the most promising strategy, however the problem of highly dynamic wind pressures had to be solved. A double-skin facade combined with a solar chimney was then suggested as a solution to this problem. For increasing the energy efficiency of the facade, optimum solar shading and ventilation strategies were suggested. For utilization of renewable energy, BIPV, solar assisted cooling and wind power were suggested in combination with the solar chimney.

References

Haase, M. and A. Amato (2005a), "Development of a double skin facade system that combines airflow windows with solar chimneys", Paper at the World Sustainable Building Conference, September 27-29, 2005. Tokyo.

Haase, M. and Amato, A. (2005b), "Fundamentals for climate responsive envelopes", Paper at Glass in Buildings 2, CWCT, 2005, Bath, UK.

The Kyoto Pyramid

Description of method
The Kyoto Pyramid is a strategy that has been developed for the design of low energy buildings in Norway. It is based on the Trias Energetica method described by Lysen (1996). The Kyoto Pyramid has been developed by SINTEF Building and Infrastructure and the Norwegian State Housing Bank. The method consists of 5 steps, and there is one version for residential houses and one version for commercial buildings. For the design of low energy dwellings, the Kyoto Pyramid steps are:

1. *Reduce heat loss*
   Super insulated and air tight envelope. Efficient heat recovery of ventilation air during heating season.
2. *Reduce electricity consumption*
   Exploitation of daylight. Energy efficient electric lighting and equipment. Low pressure drops in ventilation air paths.
3. *Exploit solar energy*
   Optimum window orientation. Atria/sunspaces. Proper use of thermal mass. Solar collectors. Solar cells.
4. *Control and display energy consumption*
   Smart house technologies, i.e. demand control of heating, ventilation, lighting and equipment. User feedback on consumption.
5. *Select energy sources and carrier.*
   E.g. heat pumps, biomass, district heating, electricity, natural gas.

Application of method
The method has been applied in the design stage of several low energy dwelling projects in Norway.

Benefits
The main benefit of the method is that it stresses the importance of reducing the energy load before adding systems for energy supply. This promotes robust solutions with the lowest possible environmental loadings.

Barriers
The cost-effectiveness of the energy supply systems may be reduced, due to the fact that the energy load is smaller. Thus the strategy may be opposed by equipment suppliers.

Need for further research
Implementation of the strategy into design tools and design processes.

References
www.lavenergiboliger.no

E-quartet

The "E-quartet" is an easy-to-use proposal tool that helps create an energy-saving building design and ensure an optimal equipment system from the points of view of economy, energy-saving and environmental problem. Highlights of the tool include:

- Input conditions of a building and equipment from dialogue boxes.
- Calculate initial costs, running costs, LCC, and LCCo2 at the same time.
- Take energy-saving techniques of building design into consideration, such as changing the direction of a building, the position of a core, the position and size of a window or eaves, and the degree of heat insulation.
- Propose an optical combination of energy-saving equipments such as cogeneration system, photovoltaics, wind power generator, natural ventilation, etc.

References
SATAKE Akira, at MAEDA Corporation, Japan.

Eco-Facade Tool

The Eco-Facade Tool is a concept design tool for evaluating internal environmental conditions, energy use and environmental impact of façade designs. The results are presented in a user-friendly interface requiring a minimum number of inputs. The following parameters can be assessed very quickly describing the performance of a specific façade type throughout a whole year:

- Heating Energy Demand (normalised per m^2 floor area).
- Cooling Energy Demand (normalised per m^2 floor area).
- Maximum comfort temperature (average of surface weighted radiant and room air temperature).
- Numbers of hours that maximum temperature exceeds 25^oC and 28^oC.
- Minimum comfort temperature.
- Daylight Levels.
- Embodied Energy in the facade

Need for further research
Through discussions with designers the following topics were raised which merit further development:

- Financial implications of the façade options in particular the impact of the selection on the whole life cost in particular for the high quality facades which have a higher initial outlay but may result in lower whole life costs.
- Internal shading has not been considered in this study, as this requires user-behaviour scheduling of its use. However, such shading devices under user control would have a significant impact on energy consumption.
- Consideration of more complex variations of façade and building type; for example the retail sector.

References

Kolokotroni M, Robinson-Gayle S, Tanno S, and Cripps A, (2004*). Environmental impact analysis for typical office facades*, Building Research and Information, Vol 32, No 1, pp2-16.

LEHVE Tool

The Design Guideline of LEHVE is a design tool utilizing the energy conservation technique to achieve the 50% reduction in energy consumption, running cost reductions, and a method for provisionally calculating the effect of CO_2 emission reduction. The energy conservation technique are divided into 13 fields, and for each technique, the effect is concretely verified by experimental proof and simulations. Of the 13 different elemental technologies are five that correspond to "natural energy utilization techniques", two that correspond to "thermal insulation techniques of building facades", and six kinds that correspond to "techniques of energy conservation equipment".

References

Takao Sawachi, National Institute for Land and Infrastructure Management, Japan.

VentSim – Ventilation Network Analysis Tool

VentSim is a tool to calculate the airflow rate among multi zones based on the ventilation network analysis. The pre-processor "VentPre" is attached to "VentSim", and all data for "VentSim" is able to be input easily by using "VentPre". "VentSim" is used to the ventilation design by evaluating the ventilation performance (airflow rate, Supply Rate Fulfilment Index (SRF), contaminant concentration, and so on).

References

Nishizawa Shigeki, at Building Research Institute, Japan.

Summary of Computer Simulation Tools

A comprehensive overview of building energy performance simulation programs may be found at www.energytoolsdirectory.gov. At this web-page, one may also find a report by Crawley et al (2005) contrasting the capabilities of 20 building energy performance simulation programs: BLAST, BSim, DeST, DOE-2.1E, ECOTECT, Ener-Win, Energy Express, Energy-10, energyPlus, eQUEST, ESP-r, IDA ICE, IES <VE>, HAP, HEED, PowerDomus, SUNREL, Tas, TRACE and TRNSYS. The comparison includes the following categories:

- Zone loads
- Building envelope
- Daylighting and solar heat gain
- Infiltration
- Ventilation and multizone airflow
- Renewable energy systems
- Electrical systems and equipment
- HVAC systems
- HVAC equipment
- Environmental emissions
- Economic evaluation
- Climate data availability
- Results reporting
- Validation
- User interface
- Links to other programs
- Availability

Another useful overview of building energy performance simulation tools has been presented by Wachenfeldt (2003), see the table below.

Overview of simulation tools by Wachenfeldt (2003).

TOOLS:	ESP-r	TRNSYS	EnergyPlus	APACHE	Energy-10	IBLAST	DOE-2	BSIM 2002	SCIAC Pro	IDA	Microflo	Fluent Airpac	CFX	FLOVENT	COMIS	COMTAM	Radiance	ADELINE	Window 5
	Energy and system performance										Computational fluid dynamics				Airflow network		Solar radiation and daylighting		
Air flow and IAQ-related:																			
Airflow network with ext. pressure	Y3	YL	Y3	Y	N	N	N	N	Y	Y	YL	N	N	N	Y3	Y2	N	N	N
General contaminant/CO2 transport	N	YL		YL	N	N	N	N	Y	Y	Y3	Y3	Y3	Y3	Y	Y	N	N	N
Moisture transport	Y	N	Y	N	N	Y	N	Y	Y	Y	N	N	N	N	N	N	N	N	N
Contaminant source/sink effects	N	N	N	YL	N	Y	N	N	N	N	Y	N	N	N	N	Y	N	N	N
Air cleaning	N	N	N	YL	N	N	N	N	N	N	Y	N	N	N	N	Y	N	N	N
Contaminant gradients	Y2	N	N	N	N	N	N	N	N	N	Y3	Y3	Y3	Y3	N	N	N	N	N
Computational fluid dynamics	Y2	N	N	YL	N	N	N	N	N	N	Y2	Y3	Y3	Y3	N	N	N	N	N
Energy flow and HVAC																			
Heat Balance	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y3	Y3	Y3	N	N	N	N	N
Advanced interior surface convection	Y3	Y1	Y2	N	N	Y2	Y1	N	N	N	Y	Y3	Y3	N	N	N	N	N	N
Electric power flow	Y3	Y3	Y3	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Renewable energy conversion Syst.	Y3	Y3	Y3	Y	N	N	N	Y	N	Y	N	N	N	N	N	N	N	N	N
Fluid loops	Y	Y	Y	Y	N	N	N	N	Y	Y	N	N	N	N	Y	Y	N	N	N
Air loops	Y	Y	Y	Y	N	N	Y3	Y	Y	Y	N	N	N	N	Y	Y	N	N	N
User configurable HVAC-systems	Y1	Y3	Y2	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
High temp. radiant heat trans.	Y2	Y3	Y3	Y	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N
Low temp. radiant heat trans.	Y2	Y2	Y3	Y	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N
Solar and lighting:																			
Anisotropic sky model for diff. rad.	Y	Y	Y	Y	Y	N	Y	Y	N	Y	N	N	N	N	N	N	Y3	Y	N
Daylight control/shading	Y2	N	Y3	Y	Y3	N	Y	Y	Y1	Y3	N	N	N	N	N	N	Y3	Y	N
Advanced daylight illumination	YL	N	Y2	Y	Y1	N	Y	Y1/YL	N	Y1	N	N	N	N	N	N	Y3	Y	N
Advanced fenestration calculations	Y2	N	Y3	Y	Y	N	Y	Y2	Y2	Y2	N	N	N	N	N	N	Y3	Y	N
Advanced window calculations	Y2	Y2	Y3	Y	N	N	Y	N	Y1	Y1	N	N	N	N	N	N	N	N	Y3
Various other capabilities:																			
Integrated simultaneous solution	Y3	Y3	Y3	Y	Y1	Y	N	Y	Y2	Y3	YL	Y	Y	Y	N	N	YL	N	N
Multiple timestep	Y3	Y3	Y3	Y	N	N	N	N	Y2	Y3	Y	Y	Y	Y	N	N	YL	N	N
Advanced control algorithms	Y3	Y3	Y3	Y	N	N	N	N	Y1	Y3	YL	Y	Y	Y	N	N	YL	N	N
Multiple zone capabilities	Y3	Y3	Y3	Y	Y1	Y	Y	Y3	Y2	Y3	YL	N	N	N	Y	Y	N	N	N
Input functions	N	Y3	Y	N	N						N	Y	Y	Y	YL	Y	N	N	N
Graphical user interface/CAD facility	Y2	YL	N	Y	Y3	Y	Y	Y3	Y2	Y3	Y	Y3	Y3	Y3	YL	Y3	N	Y	N
Graphical user report mechanism	Y2	YL	N	Y	Y3	Y	Y	Y3	Y2	Y3	Y	Y3	Y3	Y3	YL	Y2	N	Y	N
Particular building design facilities	Y3	YL	Y	Y	Y3	Y	Y	Y3	N	Y3	Y	Y3	N	Y3	N	N	Y	Y	N
Thermal comfort	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y3	Y3	Y3	N	N	N	N	N
Atmospheric pollution	N	N	N	Y1	N	Y	Y	N	Y1	N	N	N	N	N	N	N	N	N	N
Life cycle assessment	Y2	N	N	N	N	N	N	N	N	Y1	N	N	N	N	N	N	N	N	N
Acoustics	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Import from CAD-tools	Y2	YL	Y	Y	N	N	N	Y3	Y1	Y3	Y	Y	N	Y	N	N	N	Y1	N
Link to TRNSYS	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	Y	N	N	Y1	N
Link to Radiance	Y3	N	Y	N	N	N	Y1	N	N	N	N	N	N	N	N	N	N	N	N
Link to ESP-r	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y3	N	N
Link to APACHE	N	N	N	N	N	N	N	N	N	N	Y3	N	N	N	N	N	N	N	N
Link to Microflo	N	N	N	Y3	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
General public licence	Y	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
FREE version exists	Y	N	Y	N	N	N	Y	N	N	N	N	N	N	N	Y1	Y2	N	N	N
Runs under windows	Y1	Y	Y3	Y	Y	Y	Y3	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N
Runs under Linux/Unix	Y3	N	Y	Y	N	N	N	N	N	N	N	Y	Y	Y	Y	Y	N	N	N
Programming language	F77/C	F77	F90	VB,C++,F77	Visual C++	F77	F77	Visual C++	Visual C++		C++,Tcl	F90			F77	C	F77	F77	F77, C ,Div

Signification:
Y= a general Yes.
Y1= Yes, but only with limited features, models and/or capabilities.
Y2= Yes, with "standard" features, models and/or capabilities.
Y3= Yes, with "state of the art" features, models and/or capabilities.
YL= Yes, but only through integrated coupling with another tool.
N= No.

Definitions:

Air flow and IAQ-related:	
Airflow network with ext. pressure nodes	Network with air nodes, connecting ambient nodes, zones, fans, coils, mixing boxes etc. The pressure at the ambient nodes serves as boundary conditions, taking wind and thermal buoyancy into account when solving the network.
General contaminant/CO2 transport	Allowing for the transport of general contaminants such as CO_2 with the inter-zone airflow.
Moisture transport	Moisture transport as well as transport within the building fabric for detection of condensation.
Contaminant source/sink effects	Algorithms and models for pollutant source and sink-effects.
Air cleaning	Models for air cleaners as filters and dispersion.
Contaminant gradients	Models for contaminant -gradients within zones (i.e. not the full-mixing assumption).
Computational fluid dynamics	Solving the mass, energy and momentum equations through computational fluid dynamics (CFD), including turbulence models, models for thermal buoyancy etc.
Energy flow and HVAC	
Heat Balance	Simultaneous calculation of radiation and convection processes each time step.
Advanced interior surface convection	Dependent on temperature and air flow and thermal mass.
Electric power flow	Solving a nodal voltage network for modelling of e.g. PV-panels.
Renewable energy conversion Syst.	Model capabilities for renewable energy conversion systems as ducted wind turbines, phase change materials, PV-panels etc.
Fluid loops	Solving a liquid plant network.
Air loops	Solving a network of air nodes for the plant.
User configurable HVAC-systems	Containing a variety of pre-defined plant components with adjustable parameters.
High temp. radiant heat trans.	Models for gas/electric heaters and wall panels.
Low temp. radiant heat trans.	Models for heated floors/ceiling and cooled ceilings.
Solar and lighting	
Anisotropic sky model for diff. rad.	Models for the effect of solar position on the diffuse radiation.
Daylight control/shading	Models for shading blocks, blinds, curtains etc. and related control algorithms.
Advanced daylight illumination	Models for prediction of lux-levels and daylight factors within the room.
Advanced fenestration calculations	Models for electromagnetic glazings, double facades, particular coatings, solar incident angle-dependent properties etc.
Advanced window calculations	Models for layer-by-layer input for custom glazing, including low e-coatings etc.
Various other capabilities	
Integrated simultaneous solution	Solving the whole system simultaneously, requiring iterations within each time step.
Multiple timestep	Possibilities for variable timesteps, and different timestep for the solution of e.g. the thermal model and the HVAC system.
Advanced control algorithms	Advanced control-options for airflow openings, plant, electrical system etc. (e.g. PID-controllers and fuzzy-logic controllers)
Multiple zone capabilities	Solving complex buildings with many zones.
Input functions	Possibilities and flexibility with respect to input-functions to solve particular problems without having to recompile source-code.
Graphical user interface/CAD facility	Ease of use, capabilities, integrated cad tool.
Graphical user report mechanism	Fast and easy presentation of multiple results.
Particular building design facilities	Particular features adapted for the design process, e.g. integrated performance view, algorithms for parametric studies etc.
Thermal comfort	Models for thermal comfort prediction, e.g. the predicted percentage of dissatisfied (PPD) and predicted mean vote (PMV).
Atmospheric pollution	Models for prediction of emissions to the environment
Life cycle assessment	Methods for life cycle assessment of costs/energy/environmental impact.
Acoustics	Models for prediction of acoustical performance.
Import from CAD-tools	Ability to import various CAD-formats.
Link to TRNSYS	Coupling with TRNSYS, allowing for integrated evaluation of several parameters.
Link to Radiance	Coupling with Radiance, allowing for integrated prediction of solar radiation-effects within the building.
Link to ESP-r	Coupling with ESP-r, allowing for integrated evaluation of several parameters
Link to APACHE	Coupling with APACHE, allowing for integrated evaluation of several parameters
Link to Microflo	Coupling with Microflo, allowing for integrated evaluation of airflow.
General public licence	Source code available under General Public License (GPL).
FREE version exists	Free version exists.
Programming language	Programming language of "simulation-engine" and eventually also the interface.

References

Crawley et al (2005), "Contrasting the Capabilities of Building Energy Performance Simulation Programs", United States Department of Energy, University of Strathclyde, University of Wisconsin.

Wachenfeldt, B. J. (2003), "Trial lecture for PhD defense at the Norwegian University of Science and Technology, Trondheim, Norway.

Uncertainty in Building Performance Assessment

Introduction

In the design of integrated building concepts it is crucial to be able to predict the building performance with a satisfactory accuracy, especially, when selection between alternative design solutions is needed or if the aim is to perform an optimization of the building performance. It is essential that the simulation result reflects the characteristics of the building and its technical systems and is able to simulate the building performance with a satisfactory accuracy - that the results are reliable and comparable. Traditionally, building performance simulation is based on a deterministic approach, which implies that the spread of input parameters is zero. However, to be able to compare different design alternatives against each other it is necessary also to estimate how reliable a design is, i.e. to quantify the uncertainty that is affiliated to the simulated result of each design alternative. This can contribute to more rational design decisions. At the same time it may lead to a more robust design due to the fact that the influence of variation in important design parameters has been considered.

Description of method

First of all it must be decided if the uncertainty in model predictions is considerable. This is most often based on subjective judgment in the first case. Next step is a screening analysis (based on a simplified sensitivity analysis) that limits the number of investigated parameters to a manageable amount and, finally, an uncertainty analysis determines if the uncertainty is considerable. Uncertainty and sensitivity analyses can in principle be used for all kinds of projects, however, the more spread found in the various input parameters and the higher the sensitivity to those parameters, the more benefit will be gained from the analyses. The analyses will usually focus on the building energy consumption (e.g. kWh/(m^2 year)) and the indoor environmental quality (e.g. average/cumulated PPD, number of hours exceeding a certain predefined temperature etc.). The building costs may be linked to the UA/SA analyses and form an integrated part of the entire decision process.

Benefits

The uncertainty analysis makes it possible to identify the most important parameters for building performance assessment and to focus the building design and optimization on these fewer parameters. The results give a much better background for evaluation of the design than a single value (uncertainty quantified), which often is based on cautious selection of input parameters and therefore tends to underpredict the potential of passive technologies.

Barriers

The main barrier for application of uncertainty analysis in building performance assessment is the increase in calculation time and complexity. Monte Carlo simulation is attractive for the uncertainty analysis, as the only requirement is that it is possible to describe the probability density function of the important input parameters. The disadvantage of the method is the high number of simulations. Even if an appropriate sampling procedure is selected the number of simulations to investigate the uncertainty is 2 – 5 times the number of parameters investigated with a total number of realizations not lower than 80 - 100.

Need for further research

Uncertainty analysis is far from being a central issue in consultancy. Explicit appraisal of uncertainty is the exception rather than the rule and most decisions are based on single valued estimates for performance indicators. At the moment experiences from practical design cases are almost nonexistent. These are needed to demonstrate the benefits and transform the methods to practice, i.e. include uncertainty analysis in commercially available building simulation tools. Uncertainty analyses have a potential to be used to assess the robustness of different solutions to changes in boundary conditions and different user scenarios to avoid the design of very sensitive solutions. Methods and procedures for this purpose have to be developed. The knowledge of typical variations of many input parameters is very limited. Material properties and characteristic parameter values of building components can only be estimated from tabular data and theoretical calculations. It is necessary to establish knowledge about the natural variability in properties of building components and materials as constructed in the built environment to improve the quality of the uncertainty analysis.

References

Brohus, H. (2005). Uncertainty of IAQ Performance Assessment of a Naturally Ventilated Building, Proceedings of the 10th International Conference on Indoor Air Quality and Climate Indoor Air 2005, pp. 2854 – 2859, Beijing, China, September 4 – 9.

Chapter 5.2 Integrated Building Concepts

Introduction

The Annex 44 participants have submitted descriptions of 23 case study buildings with integrated building concepts. The buildings include office buildings, residential buildings, school buildings, and other public buildings, located in different climates in 9 different countries. This review provides descriptions of the buildings and their contexts, a description of the integrated energy systems, and the overall performance of the building with respect to energy, indoor environment and costs, where available. Also, barriers towards implementation and lessons learnt from the projects are summarized.

The table below shows an overview of the case study buildings that have been described within Annex 44. The table gives the name and location of the building, the building type, and type of climate. The table also gives an indication of which of the main types of responsive buildings elements that the building employ. It may be noted that many of the buildings include a range of integrated building elements that are not indicated in the table. Due to space restrictions, only 7 of these buildings are described in this chapter. The buildings are selected to represent different types, different climates, and different technologies. A full description of all the buildings may be found in (Andresen et al, 2006).

Name of building, country	Type of use	Climate	Responsive building elements				
			AIF	TMA	EC	PCM	DIS
BedZED, UK	Residential/office	Temperate		x			
Commerzbank, Germany		Temperate	x				
Gleisdorf City Hall, Austria	City Hall	Temperate		x	x		
Itoman City Hall, Japan	City hall	Subtropical	x			x	
Kansai Electric Power, Japan	Office	Temperate/hot	x	x		x	
Kvadraturen School, Norway	School	Temperate/cold		x	x		
Kvernhuset School, Norway	School	Temperate/cold		x	x		
Longley Park, UK	Office	Temperate		x			
The Lowry, UK	Theatre	Temperate		x	x		
Mabuchi Motor, Japan	Office	Moist and mild	x	x		x	
Marzahn, Germany	Residential	Temperate		x			
Menara Mesiniaga, Malaysia	Office	Hot and humid		x			
MIVA, Austria	Office	Temperate		x	x		
M+W Zander,Germany	Office	Temperate		x			
Nikken Sekkei, Japan	Office	Mild					
Passive Hauptschule, Austria	School	Temperate		x	x		
Photo-Catalytic Building Japan	Experimental	Mild and humid					
Pourous building, Vietnam	Residential	Hot and humid		x			
RWS Terneuzen, Netherlands	Office	Temperate		x			
Sakai Gas Building, Japan	Office	Mild		(x)			
Solar XII Building, Portugal	Office + lab	Hot and dry	x	x	x		
W.E.I.Z, Austria	Office	Temperate		x	x		
ZUB, Kassel, Germany	Office	Temperate		x	x		

AIF: Active Integrated Facades, TMA: Thermal Mass Activation, EC: Earth Coupling, PCM: Phase Change Materials, DIS: Dynamic Insulation Systems

References
Andresen et al (2006), "State of the art review of Integrated Building Concepts. Working Report", IEA Annex 44, (www.civil.aau.dk/Annex44).
.

BedZed

Name of building: BedZED (Beddington Zero Energy Development)
Type of building: Residential / commercial
Location: Hackbridge, Sutton, U.K.
Owner: the Peabody Trust and the Bioregional Development Group
Start of operation: June 2001
Architect: Bill Dunster Architects
Engineering: Ove Arup and Partners
Net conditioned area: 83 dwellings and 3000 m^2 for offices and services
Total energy use: 80% less than standard practice

Climate, site and context

The climate is mild and temperate, typical for the London area. The building complex is built on a brown field in a London suburban area, which means that the degree of exposure to wind and sun is quite high. The quality of the local environment is very good, as the complex is situated in a suburban area on a brown field with an ecological park as the adjacent site.

Description of integrated building concept

Heating system
The heating system is designed with 19°C as a minimum target temperature and the system relies on the following sources of energy: passive solar heating, heat from occupants, heat from lighting and appliances, heat from cooking and domestic hot water, super-insulation, very high air-tightness, heat-exchange in the ventilation, high thermal inertia, bio-fuelled combined heat and power unit (CHP).

Cooling system
There is no cooling system per say, however, the complex uses thermal mass as well as the heat-exchange system in the wind cowls to keep the temperature steady during hot summer.

Ventilation system
The ventilation principle is a natural system with a passive heat-exchange system (wind cowls). The effective opening area equals at least 5 percent of the floor area in the habitable rooms and they are designed for night time cooling by using secure locking. The inlets are placed in the low polluting rooms, such as the living room and bedrooms, and the outlets are placed in the kitchen, the bathroom.

Electric systems
The complex is designed to use natural daylight instead of electric lighting, in order to save energy for electricity and reduce the cooling load in summer. The daylight in the offices has been of the highest priority, as these primarily are used during the day. This, and the internal heat gain in the offices, has affected the orientation of the offices in the complex, which

means that these have been placed with a north orientation in order to ensure diffuse daylight levels and a minimum degree of solar heat gain.

The complex also relies on PV-cells which are used for reloading the electric cars which are used for car pooling. Energy meters are placed in a way, which increases the user's awareness of the energy consumption and all appliances are low-energy appliances.

Control system
The ventilation is controlled by the users supported by the wind cowls which secure a minimum level of ventilation in the units. The heating system is designed to maintain a background temperature in the dwellings during longer periods of un-occupancy. This is achieved by using a thermostatically controlled vent from the domestic hot water cylinder cupboard.

Architectural issues
The architectural expression and the terrace-houses were inspired by the architectural expression of traditional British housing and the project has a holistic approach to sustainability, as it considers both urban design and architectural design elements in the solution. The architectural expression has also been under great influence of the technical solutions, e.g. in case of the wind cowls, the double high rooms, the green terraced roofs, the choice of material and the orientation of the different units.

The aesthetic expression of the technical solutions, such as the wind cowls and the PV-panels, helps underline the identity of the complex. The shape of the building as well as the different expressions of the facades provide an architectural quality, as it provides different types of spaces depending on which side of the building is experienced and at which level.

East facing façade with winter gardens and PV panels in the façade and on the glazed roofs of the winter gardens.

Performance
The first period of monitoring has already shown that compared with current UK benchmarks:
- Hot water heating is about 45% less.

- Electricity for lighting, cooking, and all appliances is 55% less.
- Water consumption is about 60% less.

Summary of barriers

Extra costs related to innovations, design research and quality control, and implementation of new working methods.

Open questions and needs for future research

The effect of the wind cowls and further development aesthetically and technically.

References

Dean Hawkes and Wayne Forster (2002), "Architecture, Engineering and Environment", Laurence King Publishing, London, England

http://www.unige.ch/cuepe/idea/_buildings/b_123/frm_obj.htm, date: January 2005

http://arup.uk, date July 7th 2005

http://www.theweathernetwork.com/weather/stats/pages/C00625.htm?UKXX0085, date: July 7th 2005

http://www.zedfactory.com/bedzed/bedzed.html, date: July 7th 2005

Kansai Electric Power Building (KANDEN)

Name of building: Kansai Electric Power building (KANDEN)
Type of building: Office building
Location: Osaka, Japan
Owner: The Kanden Industries, Inc.
Start of operation: January 2005
Architect: Nikken Sekkei Ltd
Engineering: Takenaka etc., Kinden etc., Sanki etc., Sanko etc
Net conditioned area: 60 000 m^2
**Total energy use:** 30% less than standard (estimated)

Climate, site and context
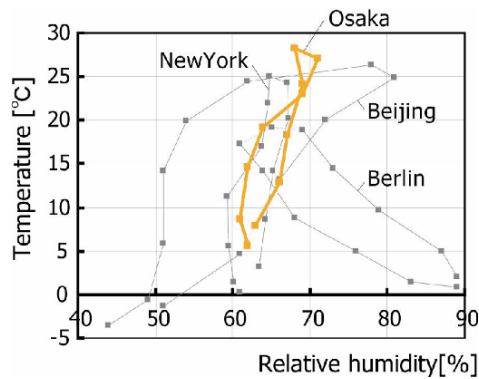
The KANDEN

Illustration showing temperature and relative humidity in Osaka and some other cities (left). Aerial view of Osaka City (right).

The climate of Osaka is temperate – a relatively hot and humid area in Japan. It has about 550 heating degree days and about 280 cooling degree days.

The building stands on the sandbank of the river crossing the city of Osaka from East to West.

**Description of the building and the integrated building concept**
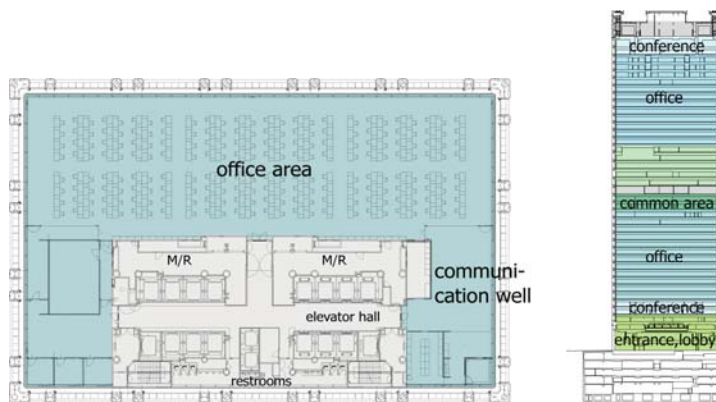
Plan (left) and section (right) of the Kansai Electric Power office building.

This building is the new head office building of KANSAI Electric Power Co., Inc. (KEPCO), supplying electricity in the Kansai area. It was planned and designed with a concept, 'A model building of environmental symbiosis', to suggest a vision of new office buildings in the future. Specific plans are as follows; 1) Adoption of the 'Eaves' utilizing columns and beams to block direct solar radiation, 2) Adoption of a natural ventilation system to lead a river wind inside the building, 3) Adoption of district heating and cooling system utilizing the river water. In addition, a new air conditioning and lighting system, which enable personal control to meet individual demands, were adopted to realize coexistence of energy saving and personal comfort compared to the 'uniform light and thermal environment' adopted in a conventional office.

Task and ambient air conditioning system
This system enables separate control of the personal environment of the office workers and the overall environment of the entire room. Indoor environment levels will be reduced within the ambient area while securing the comfort of the task zone with task floor A/C outlets and ambient ceiling A/C outlets. Task A/C outlets enable changes in the 'directionality and diffusion' of air and the air volume. By adopting this system, the energy consumption is reduced.
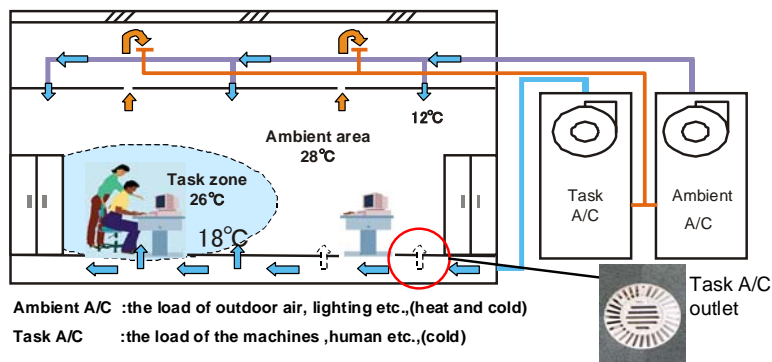
District Heating and cooling plant utilizing river water

The district heating and cooling system is adopted in the basement of the KANDEN Building. It has two characteristics. First, it utilizes the river water as thermal source, taking geographical advantage of standing in a sandbank of the river. The River water has a smaller temperature change through the year compared to the air. Therefore, the efficiency of a heat pump system increases. The cold and warm water is produced by less energy consumption (reduced approx.14%). Second, the system uses a large-scale ice thermal storage tank. Foundation pits of the building are used as the thermal storage tank of approx. 800m^3. Electricity at night is used to make ice used for daytime air conditioning, so that electricity use at daytime is restrained. This leads to electricity load levelling to raise the generating efficiency at the power station and emission of CO_2 being restrained.

Façade design

The "Eco-Frame", columns and beams jutted out by 1.8m outside from the window surface, shows effects of eaves to block the direct solar radiation during 10AM to 2PM, the peak period of the cooling load in the summer time. And Low-e glass, which has high performance in direct solar radiation blocking and insulation, is adopted in a window to reduce theinflow of heat from exterior. By adopting these technologies, the cooling load in perimeter zone is greatly reduced (2/3 of a perimeter annual load to standard used in Japan), so that an air conditioning system for perimeter zone such as a fan-coil unit becomes unnecessarily.
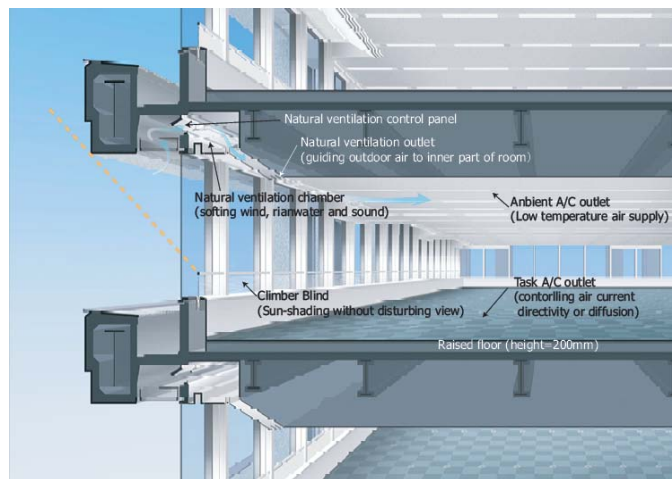
Ventilation system

The ventilation inlet is designed to be less affected by strong wind or rain, by utilizing theshape of the "Eco-Frame". Ventilation is done by wind pressure, by leading the river wind inside from the ventilation inlet under the eaves. The design of ventilation inlet is chosen by a numerical simulation and an inspection of a full-sized experiment to maximize the volume and time of ventilated air in any circumstances. In addition, opening and closing of the ventilator is automatically controlled by the conditions gained from the simulation to meet target performance (reducing 24% of cooling load). The design of ventilation outlet in the room is also chosen by the experiment to make an air current along the ceiling to send the ventilation air into the room as deep as possible.

Natural lighting

By taking in skylight as much as possible while blocking the direct solar radiation effectively, the energy of illumination is reduced. First, the ceiling near the window is bent up to maximize window height up to the lower part of the 'Eco-Frame'. Second, window shades that climb up from the bottom are adopted, and these techniques are automatically controlled according to an annual schedule based on sun position and presence of the direct solar radiation measured by lighting sensors.

Building thermal storage system

In summer, by keeping the climate control system operating at night, coolth is stored in the flooring slabs, furniture and interior materials. Then this cold is released during the day-time, and we can reduce energy consumption during the peak electricity usage period by approximately 20%.

Ice thermal storage system

The usage of the 'double-slab' space as ice tanks saves a huge indoor space and the substantial tank cost of the thermal storage system. This figure shows the section of the machine room.
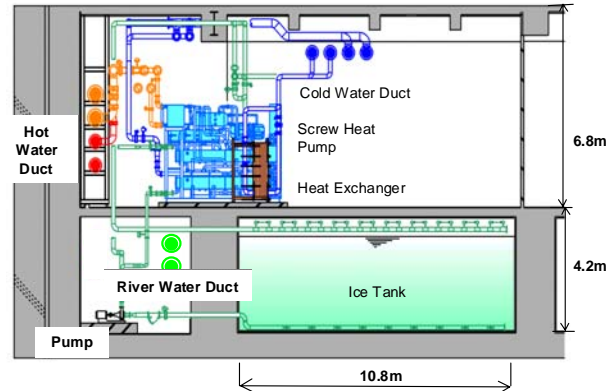
Performance

The figure shows the prediction of energy consumption of this building. The energy consumption is estimated to be reduced by 30% compared to a conventional office building.

The building construction was completed in January 2005, so the energy consumption is currently being measured.
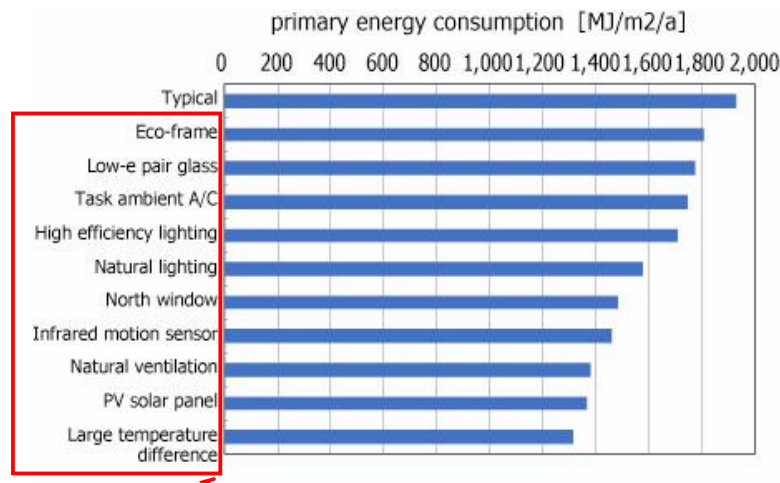
Energy saving methods

Summary of barriers

In Japan which is frequently attacked by typhoons with strong wind, there was no case of adopting natural ventilation system widely at the full scale for a high-rise building. Major concern was a possibility that malfunction of natural ventilation system could cause inability of closing inlet openings in the wall and storm water could invade into office area. A mock-up test was conducted to confirm that storm water would not invade.

References

Masashi YAMAGIWA (2005), "The Environmental Symbiosis Technologies of the KANDEN BUILDING", SB05 TOKYO, Japan.

The Lowry

Name of building: The Lowry
Type of building: Office
Location: Salford, UK.
Owner: The Lowry Centre Trust
Start of operation: April 2000
Architect: Jim Stirling and Michael Wilford
Engineering: Buro Happold Consulting Engineers
Net conditioned area: 23 930m^2
Total energy use: Concrete earth tube and plenum provides 4°C cooling
Cost: Within budget

Photo: Mandy Reynolds, Buro Happold

Climate, site and context

The climate is temperate, with 2276 heating degree days and 1395 sunshine hours per year. The Lowry is located adjacent to the Manchester ship canal at the heart of the redeveloped Salford Quays. The building therefore has a high level of exposure, however as development continues at the Salford Quays the building will become more sheltered.

A 25m high concrete wall encloses the whole theatre. The ground floor is a concrete structure, supporting pre-cast reinforced concrete floor units. Beneath the floor units a plenum is created by the structure. The floor units are a minimum of 175mm thick and are supported by sleeper walls constructed of blockwork that are 200mm thick, the floor of the plenum is 450mm thick concrete.
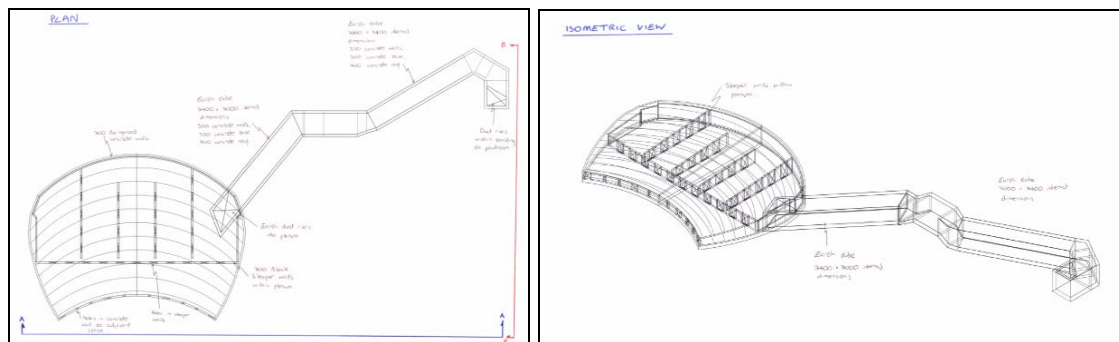
Plan of Ground Floor Plenum and Earth Duct (left). Isometric View of Ground Floor Plenum and Earth Duct (right).

The supply air for the theatre stalls is supplied into the plenum via an earth duct constructed from 300mm concrete base and walls and a 200mm concrete roof.

The two internal upper seating tiers are steel structures supporting pre-cast reinforced concrete floor units through which ventilation air flows from the air plenum within the steel cantilever frames. The internal steel frame and cantilever floor tier supports work compositely with the concrete wall.

Description of the building and the integrated building concept

Heating and cooling systems

Heating is provided through the ventilation system. Air Handling Units (AHU) 1, 2 and 3 all have pre-heater batteries and heater batteries. Cooling is provided through the ventilation system. AHU's 1, 2 and 3 all have cooling coils.

The air supply plenum beneath the stalls is constructed of concrete. The conditioned air supplied from AHU 1 is passed through a concrete earth duct into the plenum and is then supplied into the theatre space via the pedestal diffusers.

When the theatre was first opened it was found that the temperature in the stalls was cool. The temperature of the supply air coming off of the AHU was checked, and was found to be as the design setpoint. Checking the temperature of the air as it passed through the pedestal diffusers it was found that a fall off $4^{o}C$ had occurred between the air coming off of the AHU and leaving the pedestal diffusers. This cooling effect is therefore provided either by the earth tube or the concrete plenum, or a combination of both. This feature is a net benefit to the energy costs of the Lowry. It is therefore of interest to look at the cooling that is provided by the thermal mass of the earth duct and plenum and to consider other active control strategies that could be used to improve the energy storage potential of the earth duct and plenum.

Ventilation system

The theatres are served by low velocity displacement ventilation – 2-2.5 m/s for supply, 3-3.5 m/s for extract. The supply air is passed into the plenum and then the air is injected into the space though diffusers beneath the seats. For the stalls the air passes through an earth duct before it enters the plenum, whereas the 1st and 2nd tier plenum is supplied via conventional ductwork.

The stalls are supplied by AHU 1, the 1st tier is supplied by AHU 2 and the 2nd tier is supplied by AHU 3. This was done to allow flexibility in the ventilation strategy to meet the needs of the theatre e.g. when a matinee performance is on in the theatre and the 2nd tier is not used AHU 3 can then be turned off. Air is extracted at high level above each of the stalls, 1st tier and the 2nd tier. This air is then extracted to the main foyer, providing heating to this space in the winter, and ventilation in the summer. Heat recovery is provided from the extract air to AHU's 2 and 3 via a run around coil.

Control system

Each AHU is controlled independently according to the readings provided by the temperature and carbon dioxide sensors in each space.
Heating: Pre heater battery provides frost protection to the air handling unit – 5°C off coil
Heater battery provides heat to control the space temperature – 22°C space temperature
Cooling: Cooling coil provides cooling to control the space temperature – 22°C space temperature. The Lowry has a Building Management System (BMS) that allows readings to be monitored remotely via a head end computer located in the Facilities Managers office (Buro Happold also have a remote connection).

The BMS monitors:
- Temperature and CO2 content of each space
- The supply air temperature off of each AHU

The BMS also allows the set points to be changed easily and allows the facilities management team to turn the systems on and off as required to suit the times of the performances in the Theatre.

Architectural issues
The Architecture was influence by requirements made by Theatre Project Consultants and the need to accommodate seating arrangements and sight lines.

Performance

The performance will be tested by measuring the temperature of the air at various points throughout the earth tube and plenum. This will be done for both for a period in summer and a period in winter (at least a month for each). It is also intended to measure the temperatures of the slab at various locations and, if possible, depths. This data will then be used to validate a computer model of the earth tube and plenum constructed using IES Virtual Environment and simulated using the dynamic thermal modeling element of the software.

Summary of barriers

Cost could potentially have been a barrier. The project was within budget, but due to the use of the space as a theatre the budget was larger than that for other more standard projects.

Open questions and needs for future research

To determine the cooling provided by the thermal mass of the earth duct and the concrete plenum beneath the theatre. This will be done by monitoring the conditions within the earth duct and the plenum.

Control strategies that can be adopted to improve the cooling potential of the thermal mass of the earth duct and concrete plenum beneath the theatre. This will be done through computer modelling of the earth duct and plenum using IES software.

References

POWELL, K., (2000) "Affairs of the art" *The Architect's Journal,* 06/07/2000, pp. 29-41.
BUILDING SERVICES REPORTS, 2000. Picture this, *Building Services Journal, May 2000.*

http://www.thelowry.com

Mabuchi Motor Corporation Headquarters

Name of building: MABUCHI Motor headquarters office building
Type of building: Office
Location: Chiba, Japan
Owner: Mabuchi Motor Corporation
Start of operation: October 2004
Architect: Nihon Sekkei Ltd
Engineering: Nihon Sekkei Ltd
Gross area: 4782 m^2
Total energy use: 25% reduction in CO2-emissions (design)
Cost: £ 15.7 mill

Climate, site and context

The climate is moist and mild, the highest ambient temperature is 33.4°C (design assumption value), while the lowest ambient temperature is 0.0°C (design assumption value). The building is located in the suburbs of the city area. The site is comparatively large, and has active forestration and pond work for the regeneration of the natural environment.

Description of the building and the integrated concepts

The energy consumption of the air conditioning system shows a big ratio of that of the whole building. So it is very important to reduce the air conditioning load with the building design from the angle of the passive method as well as making the active mechanical systems more efficient.

The typical floor plan of the project is a space without columns with flexible spans of 33.6m (one wing has an area of 1500m2). Four floors are piled up towards the East-West wing and the central atrium is arranged in order to have an effective vertical floor communication, natural lighting and natural ventilation.

Double glass skin on the outer walls

The double glass skin has many functions which are necessary for an outer wall in Japanese climate, like heat insulation in winter, exhaust of heated air in summer, natural ventilation in spring and autumn. These functions are realized by automatic controlling ventilation dumpers at double glass skin (dampers installed at top, bottom and each floor).
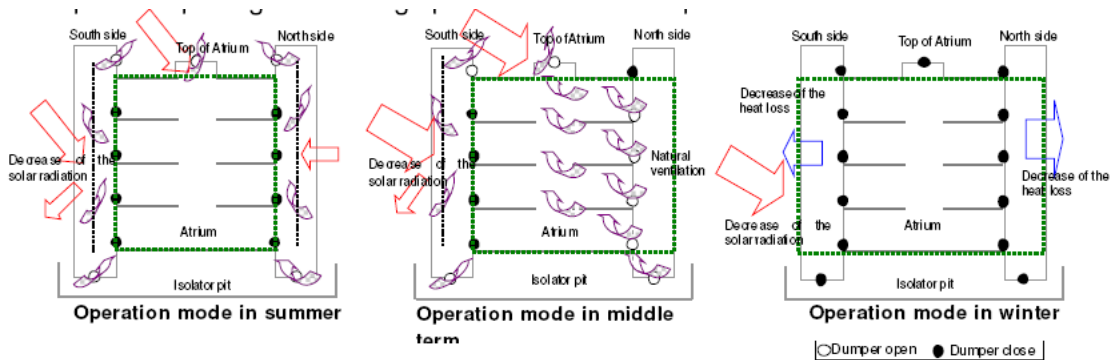
Partition panel air conditioning system.
The task and ambient air conditioning system which has supply openings for under floor air supply on the frequently-used partition panels was adopted to create an efficient air-conditioning system in the large scale and high ceiling office.
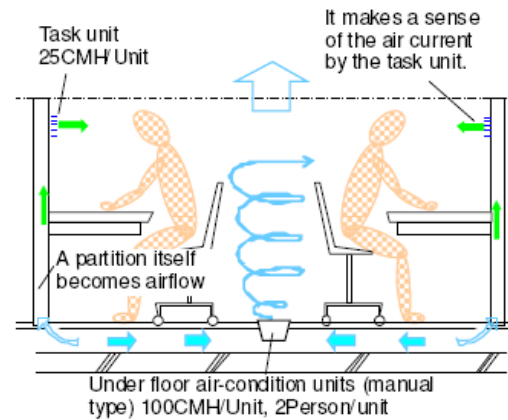
Thermal storage in the building frame with the void slab
Air flow switching system: In this system, the void slab which becomes the structure of the building is used as an air conditioning duct. At the usual air conditioning time (at the daytime), cooled air is supplied by the under-floor air conditioning system, and warmed return air passes through this void slab from the ceiling side. And the other way around, the void slab is used for air supply route at night. The void slab is cooled with supply air from the AHU at night, and this thermal storage is recovered with warmed return air from the room at the daytime. In summer, the peak load of electric power can be shifted by using both this thermal storage and the ice storage system installed as a coolth source of this building. Furthermore, in middle term, the cooling air conditioning load in the daytime can be decreased with this thermal storage system using outdoor air cooling at night instead of using chilled water from the coolth source.
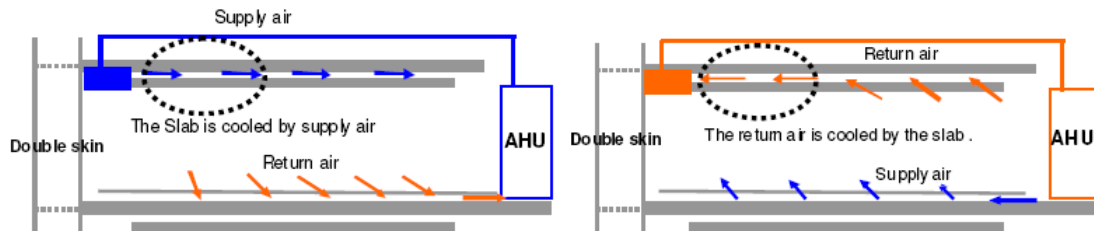
Performance
Double glass skin on the outer walls
It is very difficult to figure out the effect of the passive-design techniques like this double skin quantitatively with the existing heat load calculation. Because it depends on many parameters such as the weather condition, the buildings form, air conditioning systems and these operations. And there are few study cases about the relativity between the heat transfer model and the air ventilation model and about state change in the airflow and dumpers by temperature and pressure condition for whole buildings. In consideration of this background, it is possible to figure out the effect with the thermal and air flow network model.

PMV distribution
The PMV distribution in the perimeter zone was predicted by simulation (using the data of room and surface temperatures). In summer during air conditioning time, the inside glass surface temperature is 30.2 degrees on the 1st floor, and 31.4 degrees on the 4th floor. The differences of the temperature and that of PMV are small. A similar tendency is shown even at the middle term. In winter air conditioning time, the PMV of the middle floor is 0 and it becomes a little low on the 1st floor and 4th floor which faces the outdoor air.

Thermal load distribution
In summer, the thermal load distribution of every floor with double glass skin shows lower tendency than the low-E glass and reflective glass. But on the north skin with low solar radiation, it shows lower effect than the south skin though it is expected to show a big effect with cooling in the seismic isolation pit. In the middle term, the heat load of low-E glass and reflective glass is twice as large as the double glass skin on the south side.

The examination of saving energy
The usual air conditioning system was planned at 26 degree room temperature, 16 degree supply air and the return air the same as the room temperature on the assumption that the indoor air is diffused equally. But the task and under floor air conditioning system was planned as 18-20 degree supply air, 28-30 degree return air on the assumption that it is possible to raise the temperature level. The effect of energy saving with the task air conditioning shows the highest value with the improvement the conditioning of the outside air cooling. It shows 2.4% saving from the whole building energy consumption at 27 degree room temperature, and 3.3% saving at 28 degree room temperature.

Thermal storage on the building frame with the void slab - a result of thermal performance prediction.
The energy consumption of the thermal storage system using the thermal and airflow network simulation model in summer and the middle term could be reduced about 5% from the primary air conditioning energy consumption in both summer and a middle term. Simulations showed the following tendencies:
1) In summer, supply air volume should be set to minimum in a short time period. (4 hours storage is the best in this simulation)
2) In the middle term, supply air volume should be set to minimum in a long time period. (8 hours storage is the best in this simulation)

CO_2
It is the result that about 25% of CO_2 can be reduced by introducing both the techniques and the high efficiency equipment systems by the energy simulation of the design stage.

Summary of Barriers
- The construction of Void slab which reaches 40m.
- A functional assignment in the task air conditioner with the equipment and the furniture.
- A uniformity-ization of the air flow distribution in the raised-floor of the under-floor air conditioning system.

Open Questions and Needs for Future Research
We will reflect to facilities operation with confirm of the occupied person's evaluation by POE. Moreover, development schedule in double-skin, task air-conditioning, and building frame thermal storage to operation improvement like control judgment setting value etc. based on result of detailed verification every each season.

References
Yanai, T. (2005). "The Simulation Study of the Thermal Performance on the Building with Double-Skin-Façade". Technical Papers of Annual Meeting of IBPSA-Japan (2005).

Sasaki, M. (2004), "Study on Task-Air-Conditioning-System using Low-Partition Unit." SHASEJ Conference Thesis 2004.

MIVA Office Building

Name of building: MIVA Office Building, "Christophorus" House
Type of building: Office
Location: Stadl-Paura, Austria
Owner: MIVA
Start of operation: 2003
Architect: Bill Dunster Architects
Engineering: AEE INTEC, Gleisdorf
Net conditioned area: 1215 m^2
Total energy use: 20 kWh/m^2/yr heating, 6.4 kWh/m²/yr cooling
Cost: 1205 EUR/m²

Climate, site and context
The climate is temperate, typical for Upper Austria, with 3923 heating degree days. The building is located in a rural area.

Description of the building and the integrated concepts
This project describes the new built office building of the Catholic Church association "MIVA". The association is active in development cooperation and mission work. One of their activities is to prepare all kinds of vehicles for developing countries. During the last 10 years the MIVA association has also worked with providing mobility through ecological means, in energy and water supply. With this background, it was a natural step to build their new office building from an ecological point of view.

The office building with 1,215 m² is a work place for 40 persons. The remaining building area is used for parking of the company's cars (325 m²) and basement (550 m²). The building has a basement, a ground floor and two upper floors.

Energy concept
The goal of the planning team for the construction were:
- Multi functional application of the building (offices, events, mini shop, exhibition facilities and logistic central).
- Wooden construction
- Heating load < 15 kWh/m²a
- Pressure test air change $n_{50} < 0,6$ h^{-1}
- Primary energy consumption < 80 kWh/m²a (including electricity for the domestic use)
- No compressor cooling machine
- Covering the remaining energy demand with renewable energy sources to a maximal extent
- Highest possible comfort for the employees with lowest possible running costs
- Building certified as "passive house quality" by the passive house institution in Darmstadt, Germany

These high ambitions were a challenge for the planning team and could be reached due to an integral planning process.

Load reduction measures / Optimisation process
The reduction of the energy demand for heating and cooling was a requirement to build a sustainable and also a cost efficient energy supply system. An optimisation process was carried out by the planners and the first calculations resulted in very hot indoor climate during the summer (approx. 50°C in exposed areas) but rather low heating demand for the winter (approx. 30 kWh/m²a). With this as base, further calculations were carried out for two reference years, one with an extreme hot summer and one with an extreme cold winter. This was optimised with the dynamically simulation program TRNSYS. A thermal mass of 100 tons was integrated into the house, as results from the simulations, which showed a need for additional storage mass.

Implemented energy concept
Since there is a significant cooling demand in the building, the solution for a sustainable cooling concept played an important role. The energy supply should be both based on renewable energy sources and be cost effective. A monovalent system for both heat and cooling supply was planned to achieve these guidelines.

Responsive building elements
The main cooling concept for this passive office building is the application of deep sonds. The temperature of the water, which is lead to the water-circulated earth heat exchanger is evened out and is relatively stable in comparison to the fluctuations in outside temperature.
Deep sonds are used both for the heating and cooling period. They serve as both heat source (heating period) and cooling source (cooling period). The sonds are used as heat source for a heat pump during the heating period. Heat is extracted from the ground and a beneficial temperature profile is thereby established for the summer cooling period. The energy supply during the winter is coupled with a highly efficient ventilation system with heat recovery. The deep sonds are used as so-called "direct cooling". This direct cooling is realised through panels, which are flushed through with cold water and integrated in the building components. It is thereby possible to have a cooling without the application of a compressor cooling machine. The cooling capacity of this concept is approximately 25 W/m². The same panels are also applied for the heating system during the heating season.

This cooling concept is supported by a natural air flow through the atrium during the night. The stream of air is the result of the difference in density of the warm inside air and the cold air outside as well as from the cross section area of the inlet and outlet openings. The ventilation of the office building is carried out with the means of two separated ventilation systems with heat recovery systems (78% recovery rate and 2,800 m³/h nominal air flow) through a rotation heat exchanger. The ventilation of the seminar premises has a 86% heat recovery and a nominal air flow of 1,000 m³/h.

The storage mass of the building is the stabilising element of the room temperature. The cooling period at night should be at least 5 hours to reach enough capacity to remove the gained heat. The pre-requisite for an effective thermal day-night balance is suitable material with a high thermal conductivity and good heat storage capacity (concrete, heavy-weight walls etc.) of the construction parts foreseen for thermal storage. The upper 10 cm in the room are decisive for this effect. 100 tons of storage mass was included in the MIVA building.

The office building was constructed following the passive house standards, with the goal to reach 15 kWh/m²a. The heating is carried out through the ventilation system and the active components (applied for cooling in during summer) are also used distribute the heat during

winter. This brings the advantage of a sense of a higher comfort level. Furthermore, a floor heating system is installed in the atrium area for winter operation.

The project included alternative ways for the generation of the electricity demand of the pumps and ventilators. The photovoltaic system has a peak load of 9.8 kW. Further, the building has a solar thermal system with a collector area of 5 m², which supply the building with domestic hot water.

Performance
Thermal comfort and humidity
The monitoring results show that the comfort parameters indoor temperature and humidity show extraordinary good and constant values. Also the supply during the transition time function well and almost without any auxiliary primary energy supply (heat pump). This means that the heat recovery from the ventilation system and the "direct cooling" concept with the deep sonds are enough to keep the room climate at a comfortable level.

Energy consumption
The heating demand was measured to 20 kWh/m²a and the maximal heat load was 13 W/m² for the winter operation. During the cooling period, the measured cooling demand was 6.4 kWh/m²a and the maximal cooling load was 11 W/m².

Maintenance and operation of the systems
The operation of the building is of high satisfaction and the occupants are very pleased. The shading devices and the lighting is operated through sensors at the work area, which results in an optimal daylight utilisation. The conference rooms are equipped with CO_2 sensors via which the ventilation is regulated and is activated when the CO_2 level is higher than a set value (1000 ppm).

Costs
The establishing costs for the entire building complex were 1,205 EUR/m², without royalties. The running costs for the heat pump (7,5 kWh/m²a) and for the HVAC equipment operation (42 kWh/m²a) can be calculated in total with an electricity price of 0,14 €/kWh (+20% sales tax) and a total yearly electricity consumption of 108,742 kWh. This results in running electricity cost of 15,224 €(+20% sales tax).

Lessons learned
This project is of best practice character because of the very early integrated planning process with the planning team (architectures, energy engineers, civil engineers). With this expertise working team could lower running costs be achieved and the CO_2 emissions are 80% lower than those for a conventional office building. The energy systems and the application of the building have worked in an optimal way ever since it was taken into operation in 2003.

AEE INTEC coordinated the entire planning process and carried out the energetic calculations and optimisations. It was shown that such coordination with one partner acting as "energy party in charge" was of great importance of such innovative construction project. This coordinator not only dealt with the conventional energy processes, but also kept the overview of the energy relevant areas and acted as the link between the project partners.

References
Ernst Blümel, AEE Intec, Gleisdorf, Austria.

Passiv Hauptschule Klaus-Weiler-Fraxern

Name of building: Hauptschule Klaus – Weiler – Fraxern
Type of building: School
Location: Klaus, Austria
Owner: Gemeinde Klaus Immobilienverwaltungs GmbH & Co
Start of operation: 2003
Architect: Dietrich Untertrifaller Architekten
Net conditioned area: 4522 m^2
Total energy use: Less than 15 kWh/m^2/yr for heating and less that 120 kWh/m^2/yr total primary energy
Cost: 8.3 million Euros

Climate, site and context
The climate is temperate, typical for Austria (Zürich area). The area around the building is open and green. The passive house school building was built as an extension to an existing school from the 1970s. The building is situated in a small town in a mountain area.

Description of the building and the integrated concepts
This school building in Austria is a good example of a passive approach to architecture, which lives up to the low energy consumption demanded by the passive house standard.
Besides being a passive school building, the building also provides architectural quality as well as comfortable indoor conditions for its users. The school is a good example of how for instance shading devices and acoustic solutions can be integrated into the overall architectural expression of the building. The building has a very comfortable atmosphere and indoor climate for a building living up to the passive house standard.

Heating and cooling system via mechanical or hybrid ventilation system, with an inlet air temperature of 18°C, this system supplemented by earth coupling in the basement. The heating strategy is furthermore supplemented by a biomass (wood chips) heating unit.

Ventilation system. Mechanical or hybrid ventilation system with heat recovery supplemented with earth coupling which preheats or cools the inlet air. Air-change in the classrooms: 100m^3/h pr. person. The inlet and extract openings are placed in the ceiling in the 12 classrooms. The rooms which needs a high air change are placed in the basement, close to the aggregate.

Responsive building elements applied and their integration
- Hybrid ventilation (natural ventilation supplemented with mechanical ventilation when necessary, the mechanical ventilation system uses heat-recovery)
- Earth ducts
- Automated shading (different types; external blinds in classrooms, internal screens in atrium, external cobber screen in library and assembly room)
- Materials (wooden construction, thermal mass in floors and partitions)

- The energy consumption and the savings in CO_2-emmisions are visible to the users (children and teachers) in the cloak area adjacent to the atrium.
- Use of daylight (every room, except the bathrooms are daylit), it does however seem that the daylight design is not sufficient, as the electric lights were on when we visited the building on a sunny day around noon in September 2005.

The external shading is automated, but the automation can be overruled by the users. Inlet openings are placed in the bottom in order to allow shading and ventilation simultaneously. The classrooms are also mechanically ventilated through inlet and outlet openings in the ceiling.

The picture shows the ducts through which the air is let into the basement area where the air is preheated or pre-cooled.

Performance

Energy

The school buildings performance lives up to the passive house standard, which means that the total energy consumed for heating must not exceed 15 kWh pr. m^2 pr year and the combined consumption of primary energy must not exceed 120 kWh pr. m^2 pr year for heat, hot water and household electricity. Furthermore the passive house standard demands an evaluation of the energy consumption in the building after completion, to ensure that the finished building lives up to the standard.

The architectural vision in relation to the technical solutions

There is great accordance between the vision for the project and the technical solutions, as the technical solutions in the building are well integrated into the architectural expression, which makes for a very harmonious building without large visual technical installations.

Elements in the building providing architectural quality

Every room is daylit (except the bathrooms); even the staircases have great visual qualities caused by a symbiosis between the daylight levels, the concrete material, the shading and the décor in the stairway. The ceiling in the classrooms and the cloak area is painted black in order to hide the installations and make the acoustic ceiling (in wood) stand out as the ceiling.

This however reduces the daylight level in the room, which can be considered a problem for the perception of the light in the room.

Summary of barriers
Overall this is a really good example of passive architecture. The quality of the indoor climate is good and the architectural expression is complete and focused on the functionality of the building.

Problems encountered in the project are related to the daylight perception in the classrooms. There seems to be sufficient daylight in the classrooms, but in spite of this the electric lights were turned on, on a sunny day, this is, however, difficult to be sure of, as the building was not visited on an overcast day. The ceilings in the classrooms play a large role in this problem, because of the colour of the ceiling, the installation and the acoustic panels. It would be interesting to see a simulation of the daylight conditions in the building compared to the actual daylight conditions.

Open questions and needs for future research
In relation to this project there seems to be a need for research in the area of the relationship between the daylight solution and the energy consumption in the building, but in fields of research relating to the perception of the light in the rooms compared to the daylight levels.

References
http://www.nextroom.at/building_article.php?building_id=3843&article_id=7263

http://www.theweathernetwork.com/weather/stats/pages/C01592.htm?SZXX0033   date October 27th 2005

http://www.vobs.at/hs-klaus//Texte/Klassen-Überblick.htm date: November 10th 2006

http://www.nextroom.at/building_image.php?building_id=3843&article_id=&kind_id=2&index=0 , date: October 26th 2005

http://www.nextroom.at/building_image.php?building_id=3843&article_id=&kind_id=2&index=0 , date: October 26th 2005

http://www.dietrich.untertrifaller.com/projects_d.html date: October 26th 2005

http://www.passivhaus-institut.de November 9th 2005

ZUB Kassel

Name of building: The Centre for Sustainable Building (ZUB)
Type of building: Office
Location: Kassel, Germany
Owner: Zentrum für Umweltbewusstes Bauen e.V.,
Start of operation: Spring 2001
Architect: Arbeitsgemeinschaft Jourdan & Müller – PAS, Seddig Architekten
Engineering: Ingenieurbüro Prof. Hauser
Net conditioned area: 1347 m^2
Total energy use: 32 kWh/m^2/yr (measured), 20% of standard
Cost: 1766 EUR/m^2

Climate, site and context

The climate is temperate (middle Europe) with 3317 heating degree days and the mean annual horizontal radiation is 1027 kWh/m². The building is situated in an urban area, surrounded by buildings of approximately same height.

Description of the building and the integrated concepts

The new building of the ZUB closes a gap between an ensemble of old houses. An atrium, used as a light gap, which contains the entrance zone and the staircases, joins the old brick building to the modern concrete construction. The ZUB office building consists mainly of three different parts: one part for exhibitions and events, one part for offices and an experimental part for different kinds of research.

Heating / Cooling system

All office rooms and the lecture hall of the building are equipped with a surface heating and cooling system, with thermally activated building constructions. On all floor slabs, conventional floor heating has been installed in addition to activated ceilings. This has been done for research purposes. Each office is equipped with separately regulated heating/cooling circuit in the ceiling and in the floor slab. Demand controlled heating and cooling is done via a regulation of the mass flow of the heat carrier (water).

Ventilation system

A combination of natural and mechanical ventilation is used. In summer conditions, the offices are ventilated by natural means. During wintertime, windows the balanced mechanical ventilation with heat recovery is used for low outdoor temperatures. For mechanical ventilation, one central air handling unit with heat recovery (two cross flow heat exchangers) is used. Maximum design airflow is 4000 m^3/h. In the normal operation mode, fresh air is supplied directly to the office rooms and exhaust air is extracted from the atrium, and then transferred to the heat recovery unit. For research purposes, the fresh air can be supplied to the central atrium and extracted from the offices. When the lecture hall is fully occupied, the mechanical ventilation system is employed only for the air-change of this room, while for the offices natural means are used. To allow natural ventilation in offices, fresh air is supplied through the open windows and the exhaust air leaves the rooms through particular air outlets,

which are set in the clay wall near the doors. In this way the exhaust air is sent into the atrium and leaves the building through openings at its top, thus avoiding the installation of fan systems. The ventilation system works from 6 a.m. to 8 p.m., and at night and during the weekend it is turned off.
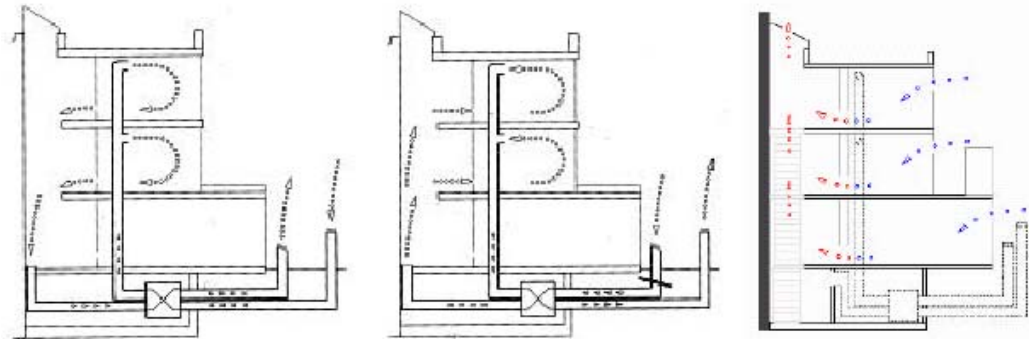
Operation modes of the ventilation system (Hausladen 2000)

Control system
Heating: The indoor temperature is set at the lower value of 19°C and the upper value of 21°C for the offices and approximately at 18° C in the experimental room. To achieve these conditions the inlet temperature of the radiant systems depends on the outside temperature, thus avoiding the heating system working continuously at the highest temperature. Then, after 8 p.m., the indoor air temperature is set at 19°C.

Cooling: The temperature of the rooms is set at an upper value of 26°C and the water mass flow rate is cooled by the ground heat exchanger. In this way, the inlet temperature of the water depends on the ground temperature. Furthermore, the building structure can be cooled during the night by a flow of external air.

Ventilation: The ventilation system is regulated by the actual demand and air quality. Sensors measuring the content of volatile organic compounds (VOC) in the air are installed in the offices. Increasing levels of VOCs mean increasing speed of the air supply fans (increased airflow). The office with the worst air quality guides the ventilation system. A CO_2 sensor is installed in the lecture hall. In case of CO_2 concentration above 600 ppm the lecture room is ventilated in parallel to the offices. If the concentration rises above 1000 ppm the system ventilates the lecture hall only and the offices have to be ventilated by windows.

*Responsive building elements applied and their integration*
In the ZUB building, radiant systems for heating and cooling have been installed. They include both activated thermal slabs and conventional floor heating. The pipes are embedded in the upper concrete layer on the floor and in the centre of the slab. The distribution has a coil shape and an individual circuit for each room; in this way, each room has its own control system.

(Hauser 2002)

Each circuit of the floor radiant system and the active thermal slab system is supplied by about 600 kg/h water mass flow rate, thus allowing to keep the difference between supply and return temperature lower than 4-5 °C. In the heating mode,

the radiant system is connected with the district heating supply system. It is divided in two different circuits to supply the traditional floor system and the system of activated thermal slabs.
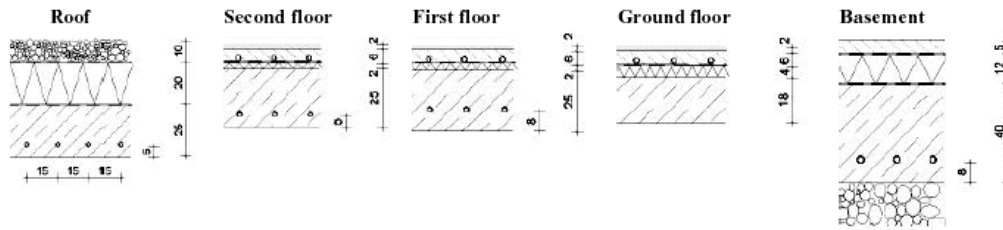

Position of the different pipe layers in the concrete slabs of the ZUB building (De Carli 2003)

As for the cooling system, the hydronic pipe circuits employed are the same as the heating system, but, for investigating the possible use of renewable energy sources, an additional circuit of pipes in the slab construction of the basement has been installed to exploit ground coolness to cool the water. Thus, the ground heat exchanger replaces the installation of a mechanical cooling machine. Measurements have shown that the ground heat exchanger works with a COP of 23, in comparison to a normal mechanical cold production with COP of about 3.5.

Performance

Energy

Measured annual energy consumption of the ZUB building is depicted in the figure below. Calculated energy demand according to the EnEV (the new energy code) is 21.3 kWh/m^{2}a. Implementing the demand controlled ventilation strategy decreased electrical power consumption for the ventilation by about 50%. The use of natural lighting strategies in combination with demand controlled artificial lighting ensures very low electricity consumption of the ZUB building. The annual energy consumption for lighting in the ZUB building is 60 % lower than the Swiss guideline SIA 380.
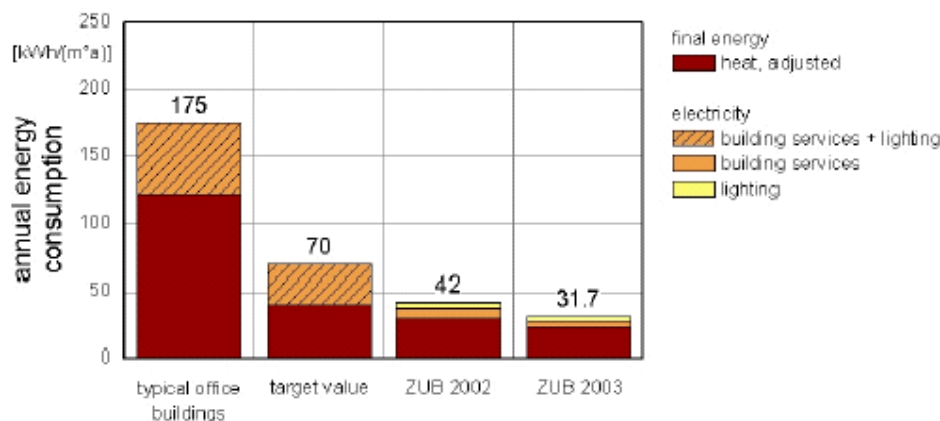
Specific annual energy consumption for heating, building services and lighting (Hauser 2005)

Economics

Construction costs were 1260 EUR/m2, service and equipment were 497 EUR/m2, which give a total building cost of 1766 EUR/m2 (net floor area) (Hauser 2005).

Indoor environment and thermal comfort
The integrated building concept of the building provides comfortable thermal environment for its occupants during the whole year. Indoor climate measurements were conducted in 2002 and 2003. In the heating mode, indoor temperatures below 21°C appear only in the case when the heat supply is switched off. In the cooling mode, during a very hot summer in 2003, the operative temperature exceeded 26°C during 125 hours, which means 4% of the work time.

Summary of barriers/lessons learned
The cooling power of the ground heat exchanger depends strongly on the temperature and water flows (moisture) of the ground. For very dry ground, the cooling potential could be worn out after a few weeks as the ground temperature rises and only a very limited cooling power can be used. In case of flowing ground water, it is possible to use greater cooling power and rooms can be cooled more intensively.

Simulations showed that a constant cooling power of about 8 W/m^2 is reasonable for the ZUB. Maximum measured cooling power was 40 W/m^2 and the maximum heating power 80 W/m^2. The overheating hours, hours with room temperature above 26°C, could be diminished by using this system up to only 125 h or 4 % of the occupancy time in a representative office room during the very hot summer in 2003.

Since almost all room surfaces are built in a heavy construction, the effect of the clay wall has been found to be of minor importance.

The lighting level observed by the occupants is also dependent on the color and surface of the internal room surfaces. Dark surfaces absorb more light than bright ones. The light floor covering and the white stone walls in the ZUB reflect the light, whereas the darker concrete ceilings are not as good as a reflector.

References

Dietrich Schmidt, Fraunhofer-Institute for Building Physics, Kassel, Germany

De Carli, M., Hauser, G., Schmidt, D., Zecchin, P., Zecchin, R. 2003, An Innovative Building Based On Active Thermal Slab Systems, *58th ATI National Conference, San Martino di Castrozza, Italy*

Hauser, G. Kaiser, J., Schmidt, D. 2005 Energy Optimised in Theory and Practice – The Centre for Sustainable Building, *Submitted and accepted: Proceedings to the Sustainable Building Conference 2005, September 27-29, 2005, Tokyo, Japan*

Hausladen, G. 2000, Innovative Gebäude, Technik und Energiekonzepte, *Oldenburg Industrieverlag, Munich*

Kolarik, J., DTU, Lyngby, Denmark

Meyer, C. 2001, Photos of ZUB, *Meyer Architekturphotographie, Cologne*

Seddig, I. 2000, Architectural drawings and planning of ZUB, *Jourdan & Müller PAS, Seddig Architekten, Kassel, Germany*

Schmidt, D. 2002, The Centre of Sustainable Building (ZUB)- A Case Study, *In: Proceedings of the 3rd International Sustainable Building Conference, September 23-25 2002, Oslo, Norway*