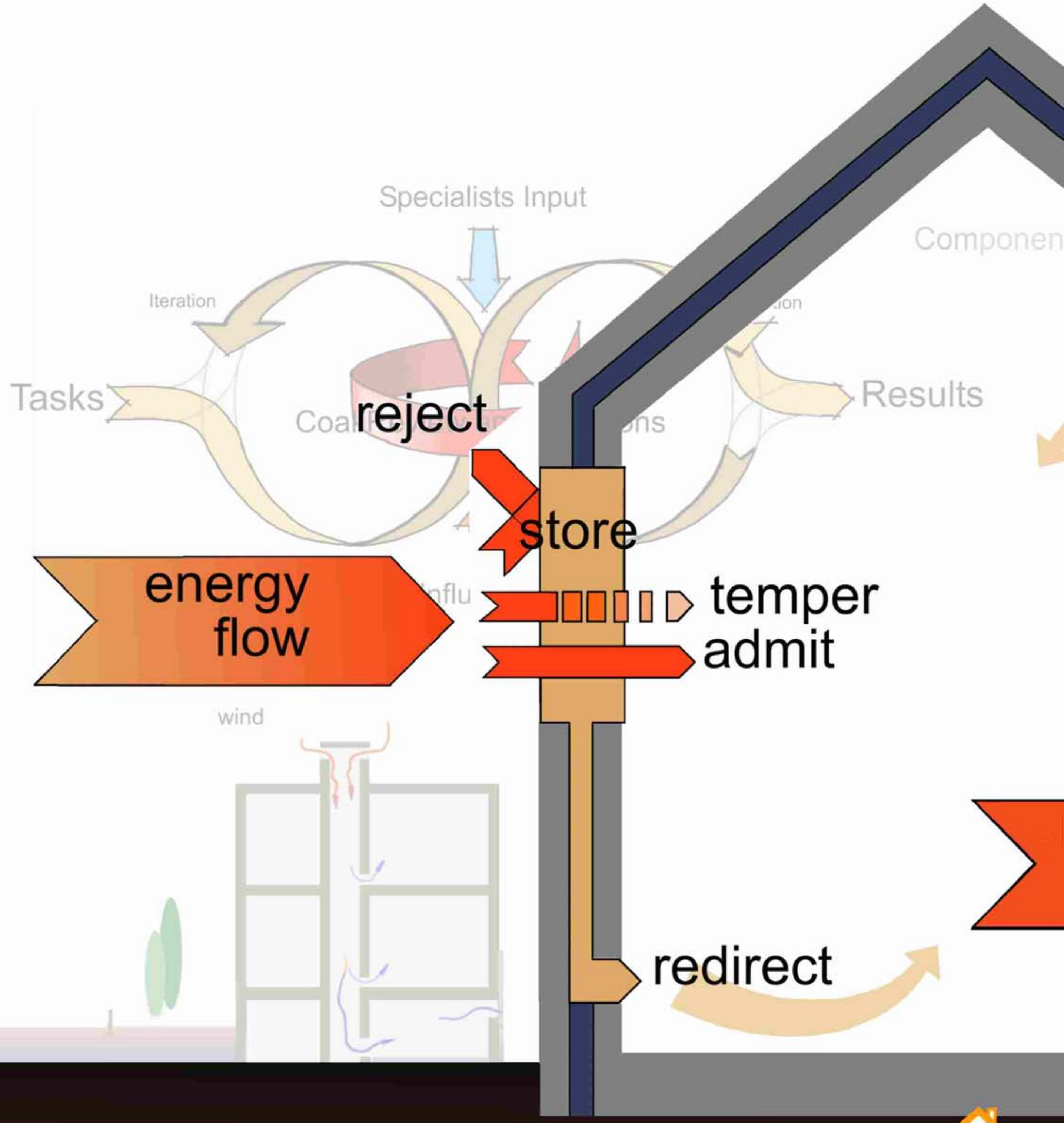
Designing with Responsive Building Elements



IEA-ECBCS Annex 44

Integrating Environmentally Responsive Elements in Buildings

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DESIGNING

WITH RESPONSIVE BUILDING COMPONENTS

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FOREWORD

An integrated building concept is a prerequisite for an energy efficient building with a good and healthy indoor air quality and indoor comfort. With the integration of responsive building elements, building services and renewable energy systems, building design completely changes from design of individual systems to integrated design of responsive building concepts. Within the framework of IEA-ECBCS Annex 44, research has been conducted on the design process for integrated building concepts with responsive building elements.
The objective of IEA ECBCS Annex 44 has been to collect information about the performance of buildings that utilize responsive building systems, and to improve and optimize such systems. Expert guide – Part I describes the principles of responsive building concepts, their benefits and limitations, impact on energy savings, comfort and building functionality and flexibility and gives guidance on the design of these concepts, including integration of responsive building elements and HVAC-systems as well as build examples. Expert Guide – Part II focuses on responsive building elements, in particular an overview of materials, components and systems, is given.

This booklet aims to address, highlight and illustrate the main ideas and principles of responsive building elements and integrated design for all those who are interested in this field.
In this booklet, therefore, the general information about responsive building elements, the responsive building concepts, their design considerations and the principles are described. For detailed information, reference is given to the design guides mentioned.

All Annex 44 publications can be downloaded from the website of the IEA ECBCS Implementing Agreement, www.ecbcs.org.

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The booklet is the result of an international, joint effort conducted in 12 countries. A list of all the participants can be found in the last pages of this booklet.

We are grateful to all those who have been contributing to the project.
On behalf of all the participants we also show our gratitude to the national founding bodies and the members of the Executive Committee of IEA Energy Conservation in Buildings and Community systems Implementing Agreement, especially Mr. Richard Karney, Senior Technical Advisor, US Department of Energy; Mr. Andreas Eckmanns, Leiter Forschungsbereich, Bundesamt für Energie BFE, Switzerland and Prof. Michael Donn, Victoria University of Wellington, New Zealand for reviewing the content.

CONTENT

CONTENT

1. INTRODUCTION

From classical to modern design

Before the advent of HVAC systems and artificial lighting, climate – not building style or appearance – was the major determinant of building form. Comfort was achieved through passive means and architectural features built into the design. Architects utilized a number of design features such as atriums, light shelves, or narrow building designs to bring natural lighting into building interiors. Other techniques were used to keep buildings comfortable in the summer, ranging from finishing the building exterior in light colours to introducing natural ventilation via thermal stacks.

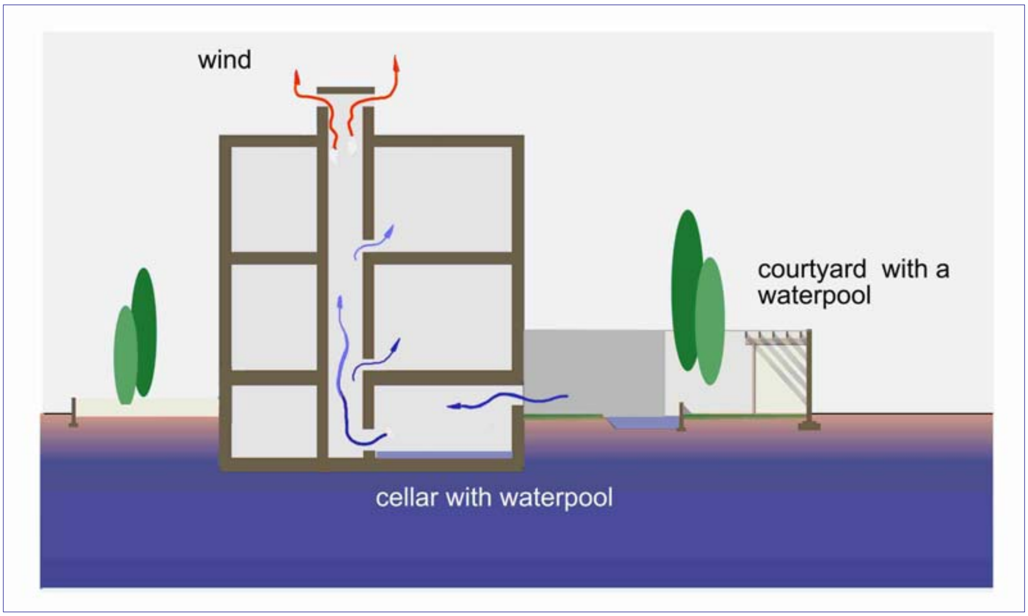

Figure 1-1 Illustration of classical design principles

Since HVAC systems and artificial lighting were developed in the first half of the 20th century, designers could pursue unrestricted designs without making energy and comfort part of the architectural design. These innovations started a design revolution. With the freedom to approach the architectural design as a pure art form, the architects created a design and then passed it on to the constructional and HVAC designers to "fit" the equipment needed to achieve comfort. The results were buildings that have high energy consumption for heating, cooling and artificial lighting that are costly in operation and have a significant effect on the environment.

Efforts to maximize the building energy efficiency over the last decades have focused on efficiency improvements of specific building elements (like the building envelope, including its walls, roofs and fenestration components) and building services equipment (such as heating, ventilation, cooling equipment and lighting). Significant improvement has been made, and most building elements and equipment still offer opportunities for efficiency improvements. However, this approach seems to reach its limits.

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Design teams, including both architects and engineers, design the building in an iterative process from the conceptual ideas to the final detailed design. Buildings have become integrated concepts in which advanced systems work together to reach an optimal performance in energy, comfort and health. Particularly the overlapping field of building technology and building services, namely the responsive building elements, has a great future potential to achieve the next steps in energy savings.

Responsive building concepts

Responsive 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. Responsive building concepts are developed from an integrated multidisciplinary design process, which optimizes energy efficiency and includes integration of human factors and architectural considerations.

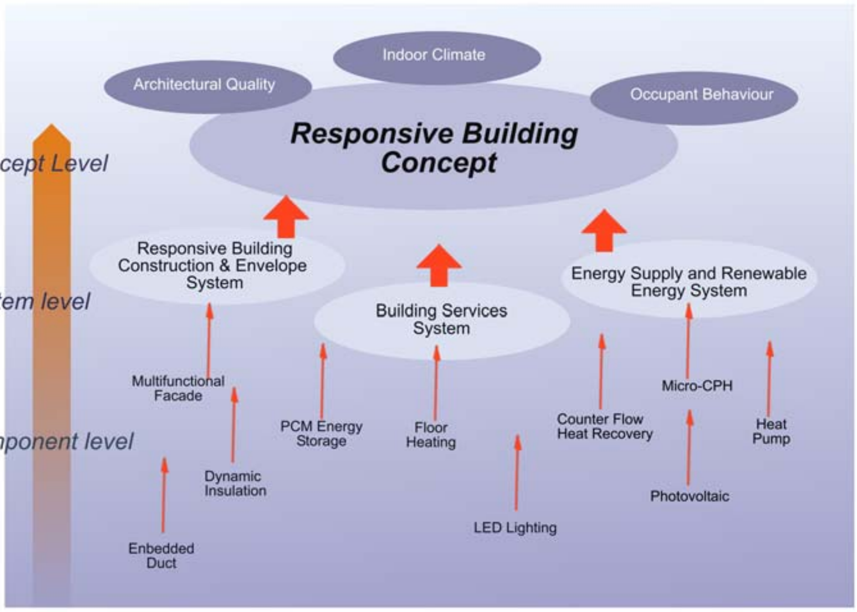


Figure 1-2 Illustration of the Responsive Building Concept

In this respect, responsive building elements are essential technologies for the exploitation of the environmental and renewable energy resources and in the development of integrated building concepts. The challenge is to achieve an optimum combination of responsive building elements and integration of these with the building services systems and renewable energy systems to reach an optimal environmental performance.

Rationale of integrated building concepts and responsive building elements

Integration of responsive building elements with building services and energy systems in responsive building concepts have a number of important advantages:

- Integration of responsive building elements with energy systems will lead to substantial improvement in environmental and operating cost performance.
- It enhances the use and exploits the quality of energy sources (exergy) and stimulates the use of renewable and low valued energy sources (like waste heat, ambient heat, residual heat etc.).
- It will further enable and enhance the possibilities of passive and active storage of energy (buffering).
- It will integrate architectural principles into energy efficient building concepts.
- Responsive building elements lead to a better tuning of available technologies in relation to the building users and their behaviour.
- It enhances the development of new technologies and elements in which multiple functions are combined in the same building element.
- It will lead to a better understanding of integrated design principles among architects and engineers.

Driving forces and implementation barriers

The main driving force for responsive building elements and integrated building concepts is the growing need and awareness for energy savings in the build environment together with increasing requirements for better health and indoor air quality in buildings.

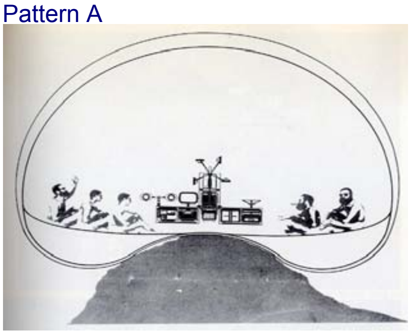
Today, the construction industry is in the early phases of a revolution to reinvent the design process that was used before the introduction of HVAC equipment. Increasingly the awareness arises that the design process needs to be an integrated and joined effort between architects and engineers. However, a number of barriers appear when the borderline between architecture and engineering is crossed; the design process contains a lot of challenges to those who participate in the process. The main barriers for arriving at an integrated design process are the lack of knowledge, information and guidelines, successful examples and expertise. These barriers can hopefully be reduced by the contents of this booklet.

2. RESPONSIVE BUILDING CONCEPTS

Description of responsive building concepts

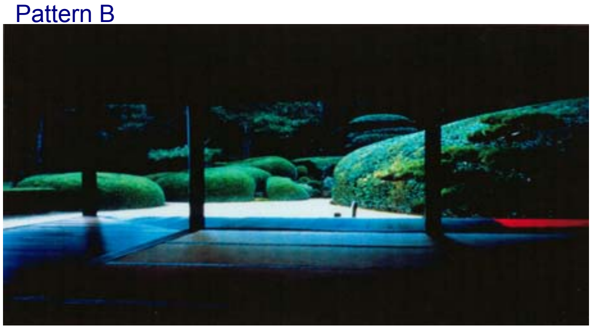
Environmental design and control of buildings can be divided into two very different approaches. In the usual “exclusive” approach, energy efficient building concepts are created by excluding the indoor environment from the outdoor environment through a very well-insulated and air tight building construction. Acceptable indoor conditions are established by automatic control of efficient mechanical systems (pattern A). Next to this, there is a growing interest for developing buildings that cooperate with nature and make use of the environmental conditions available. In this “selective” approach, energy efficient building concepts are created by using the building form and envelope as an intermediate between the outdoor and the indoor environment. Acceptable indoor conditions are established by user control of the building envelope and the mechanical systems (pattern B). It is important that the building is responsive to the fluctuations in the outdoor environment and the changing needs of the occupants.

Pattern A



Energy Efficiency

Pattern B



Well-being

Figure 2-1 Illustration of design approaches to energy efficient buildings

In a responsive building, an optimum must be found between the sometimes contradictory requirements for energy use, health and comfort. From the viewpoint of human coexistence with nature, the approach is to make buildings “open” to the environment and to avoid barriers between indoors and outdoors where from the viewpoint of energy savings, the approach, for certain periods, is to exclude the buildings from the environment. The area between indoors and outdoors herewith becomes a more or less hybrid zone where the energy gains are not only rejected, but are stored, tempered, admitted or redirected, depending on the desired indoor conditions.

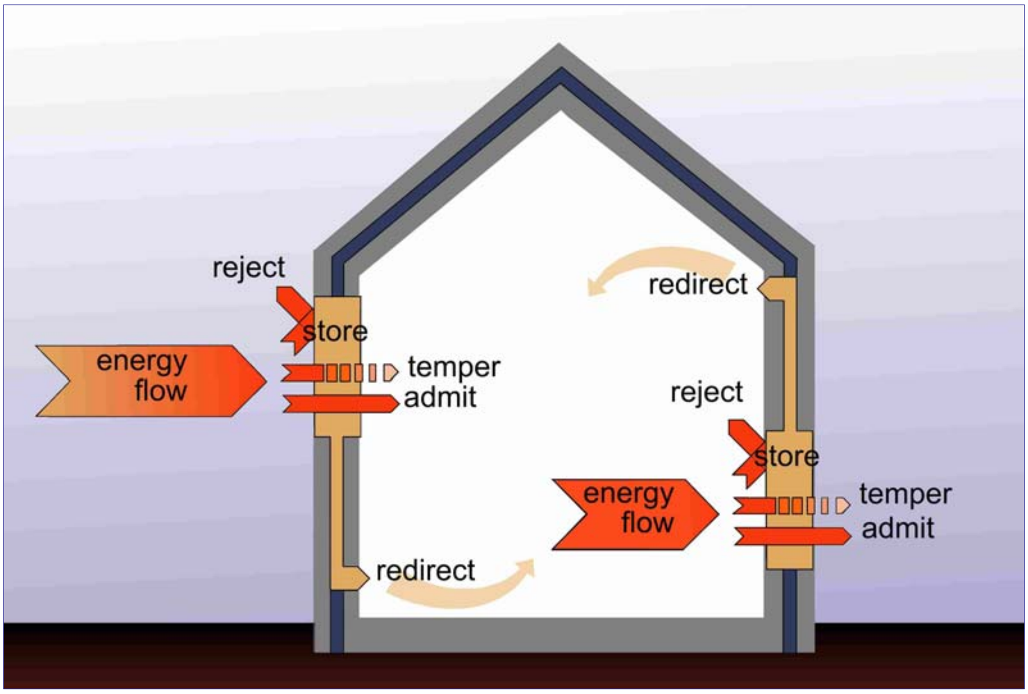


Figure 2-2   Illustrations of the responsive actions of the building envelope

Responsive building elements are essential technologies for the exploitation of the environmental and renewable energy resources and in the development of responsive building concepts. Compared with the classical design solutions we nowadays are able to measure and control the performance of buildings, building services and energy systems with an advanced building management system. This opens a new world of opportunities. Buildings no longer act as ridged objects that need a large heating installation in winter and big cooling equipment during summer to "correct" the indoor climate, but buildings become an additional "living" skin around the occupants keeping them in contact with nature, but at the same time protecting them when necessary.

Classification of responsive building concepts

In the development of existing energy efficient building concepts, the main focus has typically been on the application of only a few of the available technical themes and solutions. Examples are the "Passive House" (super-insulated and air tight envelopes combined with high efficiency heat recovery and passive solar heating), the "Solar House" (renewable energy technologies such as passive and active solar heating and solar cells), the "Smart House" (advanced solutions for demand control and efficient control of fossil fuel technologies) and the "Adaptive Building" (building elements actively respond to changing climate conditions and indoor environmental conditions as required by the occupants).

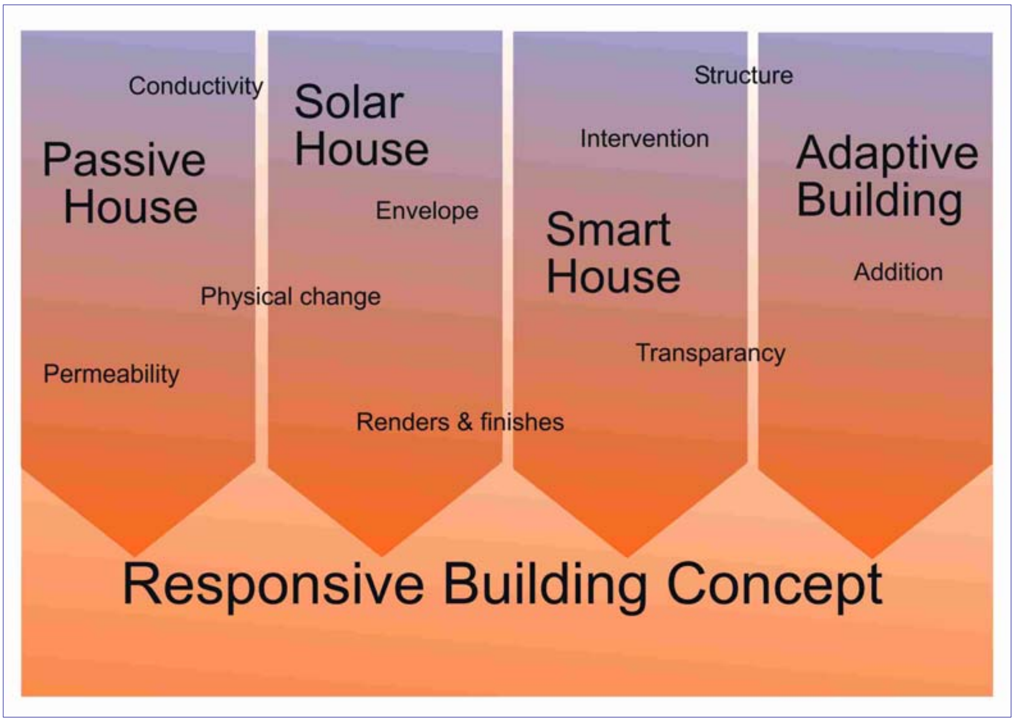


Figure 2-3 Illustration of various building concepts leading to a responsive building concept

The responsive building concepts developed within Annex 44 are design solutions which are optimum combinations of the existing concepts by integration of the full range of technical solutions into one concept. The main difference between responsive building concepts and other energy efficient building concepts is the application of responsive building elements and their integration with building services systems and energy systems in combination with advanced control.

The purpose of the classification of responsive building concepts is to define or specify the concept according to the most important issues.

In Annex 44, a responsive building concept is classified according to the following categories and parameters:

CATEGORY	PARAMETER
Climate	Cold, moderate, warm, hot-dry, hot humid, …
Context	Urban, suburban, rural
Building use	Office, school, residential, ...
Building type	High-rise, low-rise, row-houses, single houses, multifamily buildings, ...
Design approach	Selective, exclusive
Demand reduction strategies	Thermal insulation, air tightness, buffering, reduction of heat and contaminant loads, building form, zoning, demand control, efficient air distribution, solar shading,…
Responsive building elements	Multifunctional facades, earth coupling, thermal mass activation, dynamic insulation, …
Low Exergy Building Services systems	Low temperature heating, high temperature cooling, low pressure mechanical ventilation, …..
Renewable energy technologies	Passive and active solar heating, wind, natural cooling, geothermal heat/cool, biomass, daylight, natural ventilation,..
Efficient energy conversion	CHP, HE gas boiler, heat pump, …
Control strategy	Adaptive/rigid, user control/automatic

Table 2-1 Categories and parameters for classification of Responsive Building Concepts

Examples for illustration

This chapter includes a description of a number of demonstration examples of responsive building concepts.

CATEGORY	PARAMETER
Building	ChristophorusHaus Austria (Stadl-Paura, Austria, 2003) 
Climate	Moderate
Geographic location	48° 05' 02" northern latitude 13° 51' 50" eastern longitude Sea level +370 m
Context	Suburban
Building use	Office (including a café and loading/parking zone inside)
Building type	Single building, low-rise (3 stories). New construction
Design approach	The initiative of the project was the building owner, who contacted a specialist who coordinated the entire planning process and carried out the energetic calculations and optimisations.
Demand reduction strategies	Highly insulated, air tight, buffering, building form, optimized glazing, solar shading, demand controlled ventilation (CO2), efficient heat recovery (80%)
Responsive building elements	Thermal mass activation (floors and walls) with natural night ventilation
Building Services systems	Floor and wall heating and cooling (20 oC < tflow < 32 oC)
Renewable energy technologies	Earth coupling with deep sonds. Active solar collector (5 m2). PV (10kW peak).
Efficient energy conversion	Earth coupled heat pump (COP 4,03 measured), high efficiency fans and heat recovery
Control strategy	Demand controlled ventilation (IAQ and temperature), automatic control of solar shading and artificial light

CATEGORY	PARAMETER
Building	Building of the provincial government (Bregenz, Austria, 1981) 
Climate	Moderate
Geographic location	47° 30' northern latitude 9° 46' eastern longitude Sea level +450 m
Context	Suburban
Building use	Office (including a parking zone and a technical room inside)
Building type	Medium rise (7 stories). Retrofit
Design approach	The "Landhaus Bregenz" was built in the early nineteen eighties. The technical components like ventilation, heating and cooling system were up to standard of that decade. The mains problems are too high room temperatures in summer together with the proprietor's representative solutions to reduce the room temperature and the cooling demand has been elaborated. Architects, building physicists and structural engineers were not involved in this process. The main point of the study was to create an effective energy concept.
Demand reduction strategies	Solar shading, demand controlled ventilation, energy efficient daylight controlled lighting
Responsive building elements	Thermal mass activation with natural night ventilation
Building Services systems	
Renewable energy technologies	Ground water source, geothermal probe and cooling tower
Efficient energy conversion	
Control strategy	

CATEGORY	PARAMETER
Building	Nydalspynten (Oslo, Norway, 2008) 
Climate	Cold
Geographic location	59° 02' northern latitude 10° 05' eastern longitude
Context	Urban
Building use	Office (including parking zone underneath)
Building type	Low-rise (3 stories). New construction
Design approach	The objective for the office building "Pynten" was to achieve a building design with low energy consumption with small environmental impact and good indoor climate. To achieve these objectives, the project tries to exploit passive technologies which are natural ventilation, natural stratification, daylight, passive solar heating and passive cooling.
Demand reduction strategies	High insulation, airtight, optimized glazing area, type and solar shading, daylight utilization, demand control, thermal buffering,
Responsive building elements	Ground coupled air intake (EAHE), thermal mass activation with natural night ventilation
Building Services systems	Preheating and cooling in underground culvert, low pressure displacement ventilation system
Renewable energy technologies	Passive solar, earth coupling, natural ventilation, solar thermal collector (45m2, 7 kWh/m^{2}a),
Efficient energy conversion	Efficient bio fuel boiler
Control strategy	Demand control of ventilation lighting and heating, user control, automatic night cooling strategy

CATEGORY	PARAMETER
Building	WelWonen House (Kampen, The Netherlands, 2005) 
Climate	Moderate
Geographic location	52° 32’ 10” northern latitude 5° 56’ 12” eastern longitude Sea level +0 m
Context	Suburban (On the boundary of city and countryside)
Building use	Residential
Building type	Single house, low-rise (2 stories). New construction
Design approach	The initiative of the concept was taken by the Betonson company in 2004 who wanted to combine two of its own proven concepts, prefabricated thermo-active floor elements and energy piles, into an energy efficient heating and cooling system for dwellings. The primary goal was to reduce the costs for application of a heat pump by adding thermo-active building elements. The first house - of a private owner - that was realised with this energy concept was financially supported by SenterNovem, an agency of the Dutch Ministry of Economic Affairs.
Demand reduction strategies	Relative airtight, minimum thermal bridges, efficient heat recovery (95%)
Responsive building elements	Concrete core activated floor elements
Building Services systems	Floor and ceiling heating and cooling, balanced mechanical ventilation with heat recovery
Renewable energy technologies	Earth coupling with energy piles (heating and cooling)
Efficient energy conversion	Earth coupled heat pump (COP 5,4)
Control strategy	

CATEGORY	PARAMETER
Building	Kaswoningen / solar space dwellings (Culemborg, The Netherlands, 2002) 
Climate	Moderate
Geographic location	51° 56’ 48” northern latitude 5° 13’ 59” eastern longitude Sea level +2,7 m
Context	Suburban
Building use	Residential
Building type	Row houses, low-rise (2 stories). New construction
Design approach	The initiative of the development of the six dwellings was taken by the architectural firm KWSA. The initial idea was to create a dwelling with sheltered outdoor areas. Areas that would be in close contact with its environment. The architects were managing the whole project including tasks that are not commonly performed by the architect, such as the acquisition of the building lot, selection of the contractor and supervision on both the construction phase and cost control. During the whole process of design and construction, there was close consultation between architects and the future occupants.
Demand reduction strategies	Highly insulated, air tight, southwest orientation of glazing, thermal buffering, ventilation heat recovery (95%),
Responsive building elements	Solar space, thermal mass activation, natural night ventilation
Building Services systems	Floor heating system, natural ventilation in solar space, balanced mechanical ventilation with heat recovery
Renewable energy technologies	Passive solar gains, glass facades, active solar collector, PV 12kW $_{peak}$,
Efficient energy conversion	Efficient gas boiler
Control strategy	

CATEGORY	PARAMETER
Building	Mabuchi Motor Headquarters (Chiba, Japan, 2004) 
Climate	Hot-humid
Context	Suburban
Building use	Office
Building type	Low-rise (4 stories). New construction
Design approach	The design of this facility tries to satisfy the client's demands for a comfortable and efficient work space with a long life span, and for high design reliability and safety that also cares about the environment.
Demand reduction strategies	Thermal buffer zones, optimum façade design, natural ventilation in atrium
Responsive building elements	Double skin façade, roof garden, thermal activation and energy storage in concrete slab
Building Services systems	Task-ambient air conditioning with under floor air distribution
Renewable energy technologies	Natural ventilation, Natural night cooling of floor slab
Efficient energy conversion	Ice storage, gas-fired absorption chiller and hot water unit
Control strategy	Demand control of air conditioning and lighting

CATEGORY	PARAMETER
Building	Kanden Electric Power Building (Osaka, Japan, 2005) 
Climate	Hot-humid
Context	Urban
Building use	Office
Building type	High-rise (41 stories). New construction
Design approach	The building is planned and designed with the concept, ‘A model building of environmental symbiosis’, to suggest a vision for new office buildings in the future. Specific plans are as follows; 1) Adoption of the ‘Eaves’ utilizing columns and beams to block a direct solar radiation, 2) Adoption of natural ventilation system to lead a river wind inside the building, 3) Adoption of district heating and cooling system utilizing the river water.
Demand reduction strategies	“Eco-frame” construction, bottom-up solar shading, day lighting
Responsive building elements	Thermal activation of concrete slab
Building Services systems	Task-ambient air conditioning with under floor air distribution
Renewable energy technologies	Natural ventilation, use of river water as source for heating and cooling
Efficient energy conversion	Ice storage system , river water heat pump
Control strategy	Demand control of air conditioning and lighting

Controls for responsive building concepts

To maintain the optimum balance between the energy efficiency and the indoor conditions, responsive building elements need to be controlled. However, controls need to operate with respect to a number of different requirements. The outdoor conditions as well as the availability of renewable resources are variable, and so is the demand for the indoor climate depending on factors like activities, preferences and time of day. If well-designed, the right conditions for the inhabitants and the activities at the given moment can be provided while saving energy by only providing the conditions when and where necessary.
However, in practice, many controls turn out to be poorly functioning, causing discomfort to the user and frequently leading to inefficient operation of the systems.

Adaption
To be able to provide people with the essential control over their environment while considering energy efficiency, it is important to understand some basics of human behaviour to regulate thermal comfort, which is called *adaption*. Giving the user his own control possibilities is very important, for it is proven by various studies that individuals tend to accept a wider range of conditions as comfortable if they feel in control of their own environment.

Usability
In order to design usable controls for operating an energy efficient and comfortable building, those essential design questions need to be addressed:

1. What is the control for?
2. When is the control used?
3. Who is the control for?
4. Where should the controls be located?
5. Is the design intent clear to the end users?
6. Is the system status clear to the users?
7. Are controls well-integrated and energy efficient?
8. How long should a user override last?

Control parameters
The control parameters are the basis for the strategy definition. A control parameter is any kind of information which could have an impact on e.g. the ventilation strategy. The information can be obtained directly by means of dedicated sensors or derived from a set of conditions. The occupant behaviour must be included in the scheme.
The control parameters include:

1. Outdoor climate (temperature, humidity, pollutant level)
2. Building or component characteristic
3. Ventilation system: airflows, pressure difference
4. Indoor climate and comfort requirements
5. Occupancy in habitable rooms (presence, or indirectly by CO_2 level, humidity level, etc.)
6. Odours in service rooms (kitchen, toilets)
7. Humidity in service rooms (kitchen, bathroom)

The use of control variables depend on the type of control strategy that will be implemented.
The lowest level is where the user is the one that processes the information and takes certain actions without any form of artificial intelligence. The most advanced type of control is the Building Management System (BMS) where components can communicate with each other. BMS implies some form of central supervisor that permits monitoring and control of the building from one single point without any interaction of the user.

3. RESPONSIVE BUILDING ELEMENTS

A Responsive Building Element (RBE) is a building component 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.
Within the research activities of the Annex 44, attention has been focused on these responsive building elements whose perspective in the building sector seems to be the most promising. However, the technology of RBEs only stands on the beginning of its evolution.

Principles of responsive building elements

The key principles for an RBE are based on the ability to perform a responsive action based on:

- Dynamic behaviour;
- Adaptability;
- Capability to perform different functions;
- Intelligent control.

The "dynamic" and "adaptable" principles translate into the fact that functions, features and thermo-physical properties of these elements may change over time and suitably fit to different building and occupants requirements or needs (heating/cooling, higher/lower ventilation, etc.) and to different boundary conditions (meteorological, internal heat/pollution loads, etc.).
The optimum balance between the energy efficiency and the indoor conditions is guaranteed by "intelligent" control of the RBEs. Only by integrating the RBEs under the supervision of an intelligent control driven by a suitable strategy, is it possible to effectively exploit their potentialities.

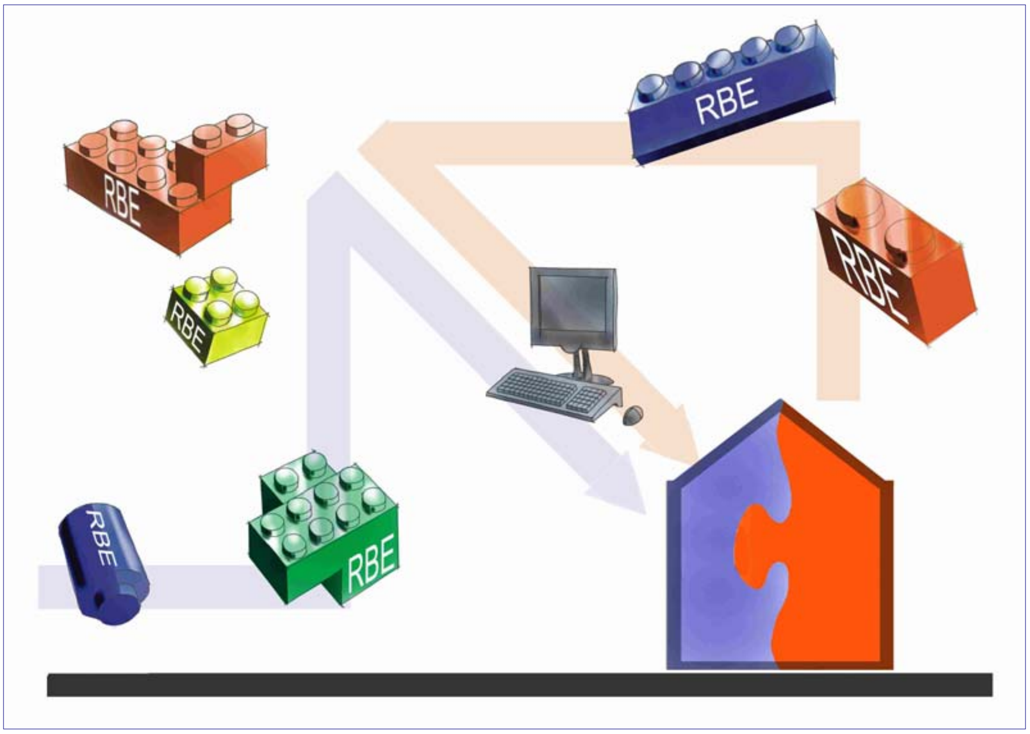


Figure 3-1 Conceptual relation between RBEs, intelligent control and IBC

Some RBEs are well-known and used for a long time (e.g. basic technologies for thermal energy storage and ventilated facades). However, their adoption traditionally lacked integration and control. It was just a dynamic element used in an "unplugged" way. For this reason, their actual performance in the field frequently revealed to be poorer than expected. Other RBEs, are relatively new, like dynamic insulation, or in other cases advanced technologies, only tested in the laboratory so far and not yet applied in practice.

Classification of RBEs

RBEs can be classified based on their responsive action in surface intervention, internal intervention and physical behaviour, which can be divided into heat flux, thermal storage, permeability (ventilation) or transparency (daylight and solar radiation).

Surface and internal intervention

By changing the conditions on or along the surface of a construction, the physical behaviour of the construction will change. Intervention in the inner part of the component can change the energy flow in the construction.

Heat flux related RBEs have a variable (adaptive) thermal insulation performance. The characteristic feature of this category is that the heat flow is proportional to the insulation level and a certain separating area, for instance the glass area or the facade area. Examples of this category of RBEs are double skin facades and dynamic insulation. Heat flux related RBEs can reduce the demand for heating and cooling by increasing the insulation level in winter and decreasing it in summer. Heat flux related RBEs can also control the amount of solar energy that is transmitted through the windows.

Thermal energy storage related RBEs have a capability to store (thermal) energy in time periods with excess heat, and to release this energy again in periods with a heating demand and thereby lead to a reduction of the total energy demand. Examples of this type of RBEs are earth coupling systems, thermal mass activation and phase change material.

Transparency related RBEs have a variable transparency with regard to solar radiation and daylight. The characteristic feature of this category is the choice of transparent material and how its transparency depends of the radiation wavelength (mainly heat or daylight). Examples of this type of RBEs are mainly fenestration and glazed facades.

Permeability (ventilation) related RBEs have a variable (adaptive) permeability, i.e. ventilation performance. The characteristic feature of this category is that the heat flow is proportional to an air flow rate. Examples of this type of RBEs are ventilated facades and embedded ducts. By regulating the flow of outside air, the heat exchange with the outside is controlled. Some ventilation related RBEs include pre-heating of the air before it enters the building.

Based on their technological function (envelope, structure, etc.), responsive building elements are part of the building construction and have to fulfil other requirements. This limits capabilities for a responsive action.

In the table below, the potential responsive actions for the various building components are given. The illustrated responsive building elements along the vertical axis are divided according to their location and structural function in the building. For each responsive element, information along the horizontal axis relates firstly to the mechanism of interaction with the environment and HVAC system, which can either be via the surface of the element or via the interior. Secondly, the information about the category of the element describes the physical behaviour.

The range of application of the RBEs and their conceptual working principles are extremely wide, ranging from building envelope components with “adjustable” U-value and/or variable air permeability, to building structures or components able to store thermal energy, to glazed systems with variable optical properties, and to elements exploiting evaporative cooling.

RBE		Responsive Action						Possible type of RBE
		Intervention		Physical behaviour				
Buiding system	Element	Surface	Internal	Heat flux	Thermal storage	Transparency	Permeability	
Envelope	Wall							AIF(TVF, OVF, PVT, PVO, SC, TM, SA, CA), DI, PCM
	Roof							AIR(TVR, OVR, PVTR, PVOR, SCR,TIMR), TMA(SA, CA) DI, PCM
	Ceiling							TMA(SA, CA), PCM
	Fenestration							AIF (Swindow)
Super structure	Colum/beam							TMA(SA, CA), PCM
	Load bearing wall							TMA(SA, CA), PCM
	Load bearing floor							TMA(SA, CA), PCM
Sub structure	Piles							TMA(CA), EC
	Foundation beams							TMA(CA), EC
Underground structure	Earth to air heat exchangers							EC
Renders and finishes	Partition wall							TMA(SA), EC
	Floor							PMC
	Ceiling							PMC

Table 3-1 Potential applications of RBEs in building constructions

AIF – TVF: *Transparent Ventilated Façade*
AIF – OVF: *Opaque Ventilated Façade*
AIF – PVT: *Integrated Photovoltaic, Transparent façade*
AIF – PVO: *Integrated Photovoltaic, Opaque façade*
AIF – SC: *Integrated solar air/water Collector*
AIF – TIM: *With Transparent Insulation Materials*
TMA – SA: *Thermal Mass Activation – Surface Activation*
TMA – CA: *Thermal Mass Activation – Core Activation*

DI: *Dynamic Insulation*
PCM: *Phase Change Materials*
TVR: *Transparent Ventilated Roof*
OVR: *Opaque Ventilated Roof*
PVTR: *Integrated Photovoltaic, Transparent Roof*
PVOR: *Integrated Photovoltaic, Opaque Roof*
SCR: *Integrated Solar air/water Collector – Roof*
TIMR: *Transparent Insulated Materials - Roof*

Table 3-1 can be a good starting point to stimulate the development of ideas for new RBEs.. Some ideas for future RBEs are given in 3-4.

Technologies

In the research activity of the IEA - Annex 44, attention has been focused on five specific responsive building elements, whose perspective of improvement and widespread implementation in the building sector seems to be most promising. These five RBEs are:

- Advanced Integrated Façades (AIF);
- Thermal Mass Activation (TMA);
- Earth Coupling (EC);
- Phase Change Materials (PCM);
- Dynamic Insulation (DI).

These RBEs are described in the next sections. Further detailed information can be found in the Expert guide - Part II.

Advanced Integrated Façade

Description of principles

An *Advanced Integrated Façade* (AIF) is the outer, weather-protecting layer of a building that can contribute to heating, cooling, ventilation and lighting requirements and can promote interior comfort through efficient, energy saving measures. It exhibits adaptive characteristics that are in tune with both the physical/climatic conditions of a particular location and the indoor environment requirements. AIF is 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*"[1]

An AIF should, therefore, result from an "intelligent design" rather than just an assembly of "intelligent components". The concept of "intelligence" associated with DSF represents *a change from a static envelope to a dynamic and responsive envelope*.

Thermo-physical properties and performance of advanced integrated façades are application dependent and are a function of the operative conditions. They may be obtained through simulations and experimental tests.

Providing general guidelines for designing and using Advanced Integrated Façades is not an easy task due to the great number of different configurations, their dynamic behaviour and the strong connection with the building energy system.

Façade classification

AIF classification is not a straightforward task considering the number of different features and operative strategies. The most common classifications consider the type of ventilation, the flow path and the system configuration as major items.

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

Façade classification is based on the Belgium Building Research Institute's (BBRI) classification for double skin façades. Modifications were accomplished in this classification by the Annex 44 research group, in order to take into account the main specific characteristics of an AIF. This classification, represented schematically in Figure 3-2, divides AIFs into transparent vertical façades (TVF) and other concepts including opaque vertical façades (OVF) and Advanced fenestration systems (e.g. Swindow). These classes are then characterized by a number of different technologies.

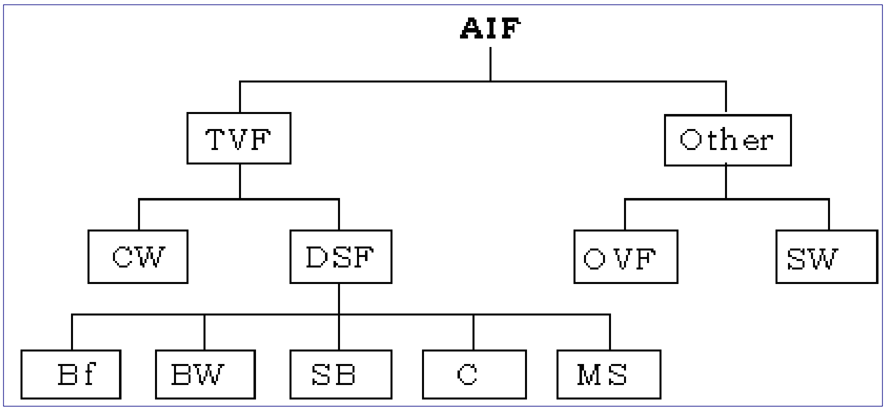


Figure 3-2 Proposed simplified classification of AIF

AIF	***Advanced Integrated façade***
TVF	*Transparend vertical façades*
CW	*Climate Wall*
DSF	*Double Skin Façade*
Bf	*Buffer*
BW	*Box-window*
SB	*Shaft box*
C	*Corridor*
MS	*Multi-storey*
OVF	*Opaque ventilated façades*
SW	*Swindow*

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 of the outdoor environment on the indoor climate conditions. The air gap may use natural, mechanical or hybrid ventilation schemes, or simply act as a still air buffer. Figure 3-3 sketches the façade physics, showing the complexity and impact of solar radiation, conduction, convection and airflow through the double-skin gap.

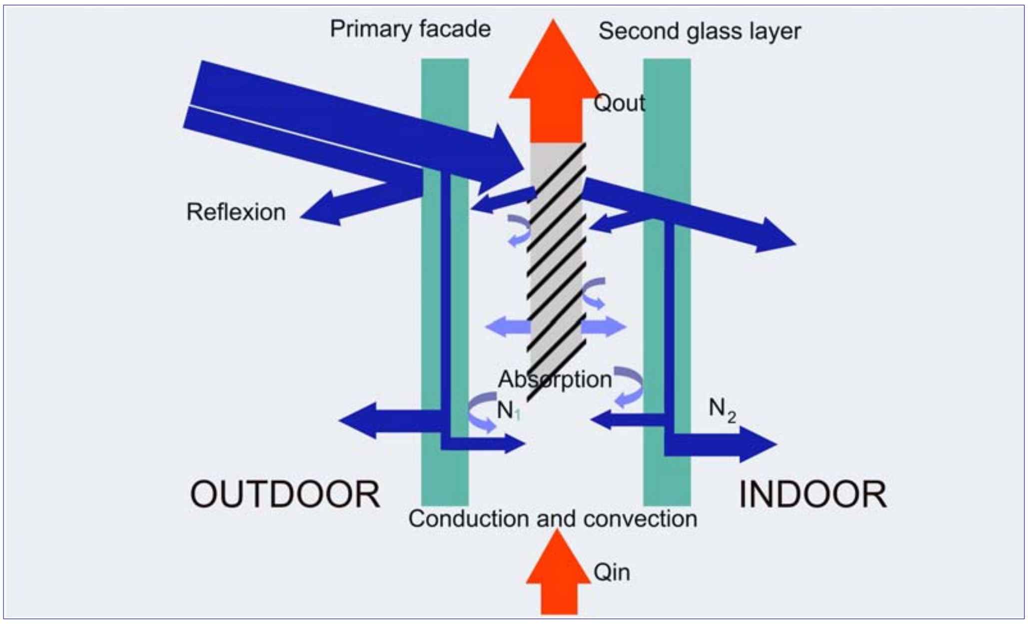


Figure 3-3 DSF/AIF working principles

The main functions that should be provided by a transparent ventilated façade are:

- to recover heat during cold seasons and/or to preheat the 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 increasing the heat gains,
- to extend the use of natural ventilation systems, particularly in the case of high-rise buildings.

Transparent ventilated facades can be divided in two main types:

- *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 connection to the building ventilation system (MV) and a small gap (~10 mm) under the interior pane that allows air to flow into the cavity.
- *Double Skin Façade (DSF):*
  - o *Buffer (Bf)***:** the still air within the cavity acts as a thermal buffer. The cavity is connected to the outdoor air for pressure balance purposes.
  - o *Box-window (BW)***:** The façade is divided both vertically and horizontally, forming a box.
  - o *Shaft-box (SB):* The SB has a similar configuration as the BW, except that the shaft box discharges exhaust air to a lateral building height cavity.

- *Corridor (C):* the façade 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 can be moved from a closed to an open position. In the open position, they no longer act as a second skin.

Opaque ventilated facades

Opaque ventilated façades (OVF), or *Opaque Double Skin Façades (ODS*F), essentially refer to two different configurations: two opaque layers separated by a ventilated air gap, or a transparent layer and an opaque layer (usually massive) separated by a ventilated air gap. The first structure is quite similar to a fully transparent ventilated façade, and the working principle is the same with the only significant difference that there are no short wave heat gains through the façade. The second configuration is called Trombe wall and acts as a large air solar collector during winter time. In modern Trombe walls, there are air vents on the top and bottom of the air gap, between the glazing and the opaque layer. The opaque layer has a relevant thermal mass to capture or temper the solar energy gains. During the heating season, the system is configured so as to direct the heated air into the building. In this way, thermal losses are reduced and the overall free gains are improved. The vents have one-way louvers that prevent convection at night and, thereby, making heat flow strongly directional.

During the cooling season, instead, the vents are configured so as to remove part of the solar gain from the façade (i.e. the vents facing to the interior are closed and the heated air flowing in the air gap is rejected toward the outdoor environment).

Advanced Fenestration Systems

Advanced fenestration systems can consist of windows capable of providing self-adjusting opening areas and/or of windows acting like a small-scale transparent ventilated façade (i.e. ventilated windows).

An example of a window with a self-adjusting opening angle (analysed during the Annex 44 activity) is represented by the so-called Swindow.

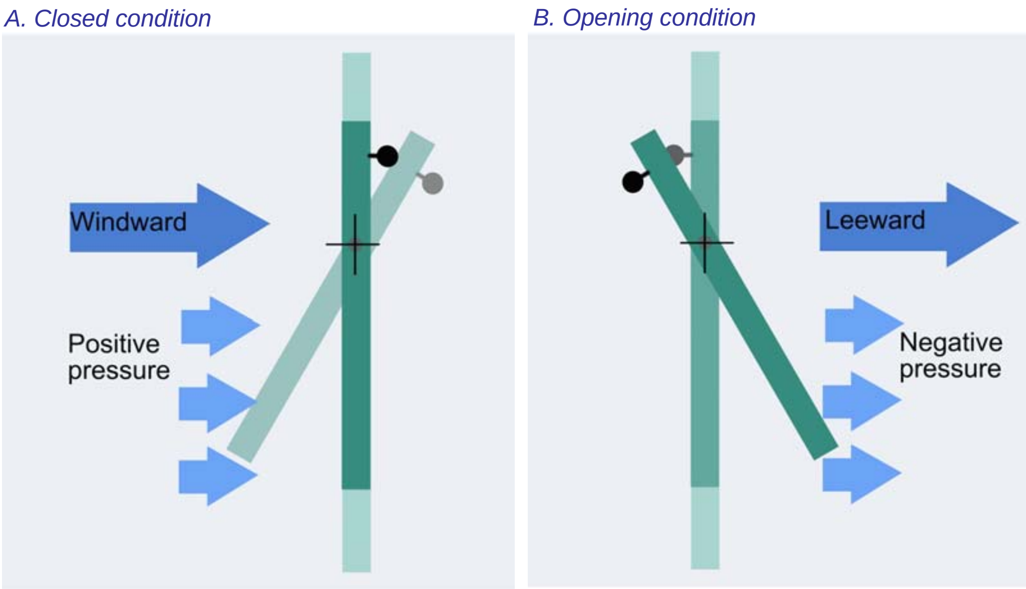


Figure 3-4 Swindow working principle

- *Swindow (SW)*:
  This is an automatically operable window, developed for natural ventilation purposes with the capability of being integrated with 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.
  There are two types of Swindows: air supply and exhaust. The Swindow is at 45° from vertical in the open position when the wind is calm. It then starts to move when the wind blows. The Swindows located on the windward side automatically react to the wind speed, decreasing the opening angle; whilst the Swindows located on the leeward side, due to the negative pressure, tend to increase the opening angle (see Figure 3-4). The Swindow operates even in weak winds and provides unidirectional air flow in the supply or exhaust direction, while limiting the surplus air flow rate.

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), respectively*. Hybrid ventilation utilizes both natural and mechanical ventilation as driving forces.

Flow path
The air flow path is a very important issue that is strongly associated with the AIF integration and the building energy and control systems. Possible arrangements, shown in Figure 3-5, are:

exhaust air (EA), supply air (SA), reversible air flow (RAF), outdoor air curtain (OAC) and *indoor air curtain (IAC)*.

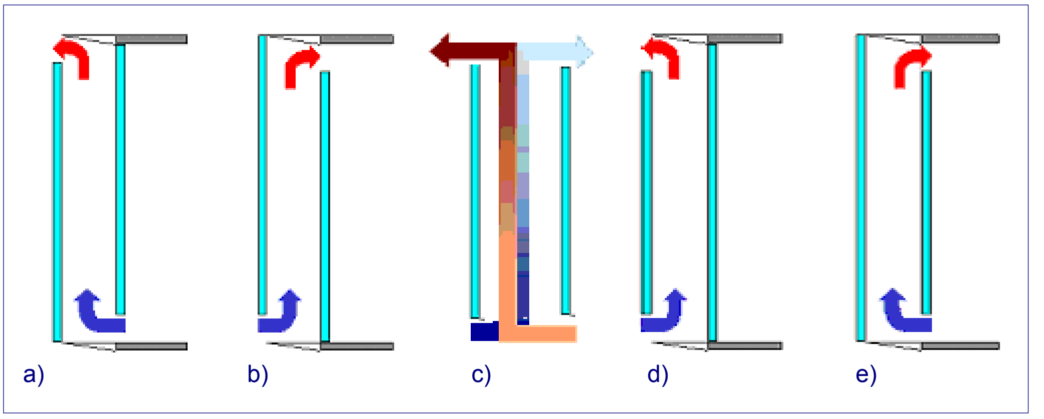


Figure 3-5 AIF flow path: a) EA; b) SA; c) RAF; d) OAC; e) IAC

SWOT-analysis

Figure 3-6 shows the summarized results of a SWOT-analysis of AIFs. The SWOT analysis has been conducted based on an inquiry that has been carried out among the participating countries in the Annex 44 work.

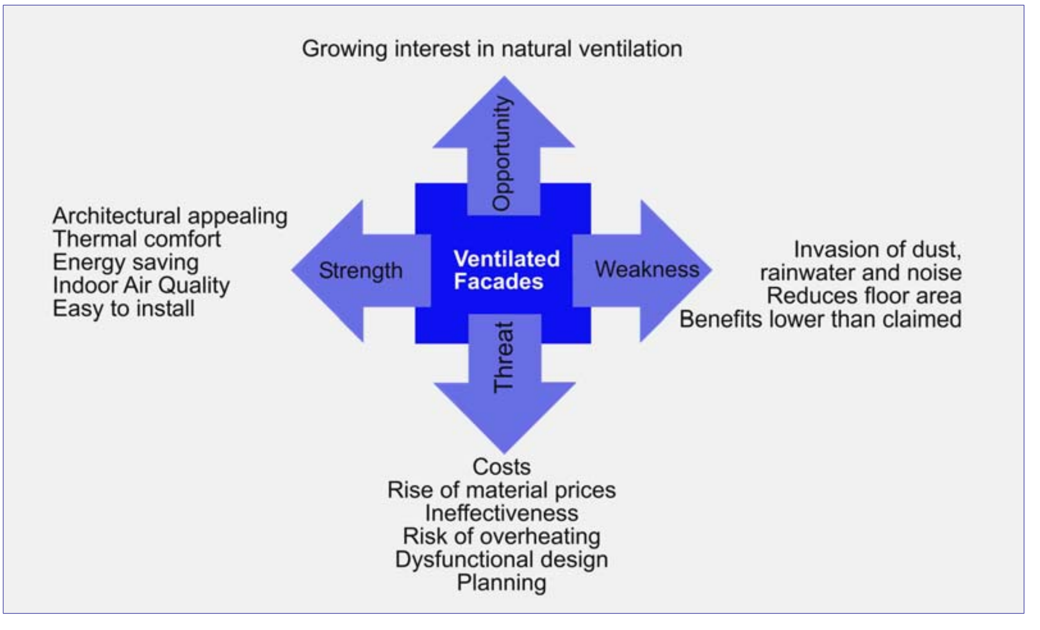


Figure 3-6 SWOT-analysis of AIF

Examples of application

Example of a double skin facade, corridor type, natural ventilated, outdoor curtain air curtain

<u>The Dragonair/CNAC Building</u>

The Dragonair/CNAC Building at Chek Lap Kok International Airport in Hong Kong, China, is an example of a naturally ventilated, outdoor air curtain, corridor DSF (C-NV-OAC). It was built by Wong Tung & Partners and completed in 2002. Meinhardt Facade Technology (HK) Ltd. carried out the facade engineering. The problem of aircraft noise was addressed by the adoption of a double-skin cavity wall system which provides 60 dB(A) of sound attenuation. An 800 mm cavity separates the 19 mm thick external layer of fully-tempered glass and the inner layer, which is an insulated low-E coated unit.

The cavity wall system not only fulfils the engineers' requirements, but also avoids condensation problems through its use of acoustic baffles to ventilate the system. The cavity also facilitates maintenance and improves the building's thermal performance.

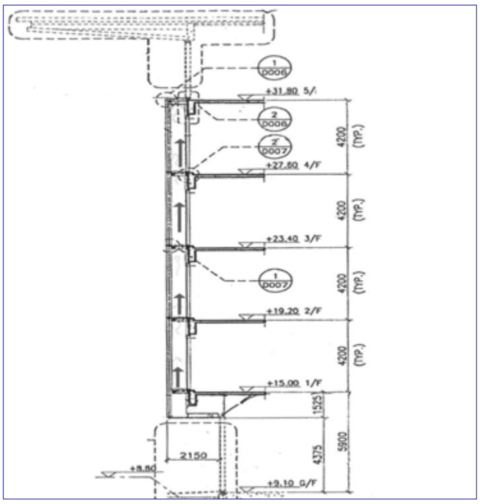


Figure 3-7 The Dragonair/CNAC Building at Chek Lap Kok International Airport, Hong Kong

Example of a double skin façade, multi-storey, mechanical ventilated, outdoor air curtain

Atrium Saldanha

Atrium Saldanha is an office and mall building in Lisbon, Portugal, completed in 1997, using a multi-storey DSF in each two storey (three for the top ones), mechanically ventilated under an outdoor air curtain flow path (MS-MV-OAC). Both fully glazed panes have regular transparent glass separated by a 0.7 m width gap. Shading is provided by manually operated roller blinds within the gap, their colour being white in N and NE facades and black for NW and SW facades.

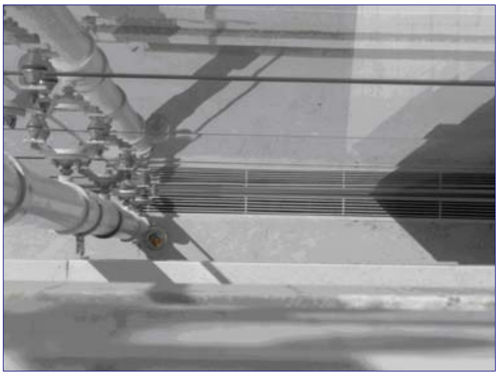


Figure 3-8 The Atrium Saldanha in Lisbon, Portugal

Occupied spaces facing SW experience problems due to both gap air overheat and daylight. A poor ventilation mass flow is insufficient for removing heat accumulated in the black roller blinds (an architectural decision adding ~10K on gap air temperature), which are also responsible for low lighting levels when pulled down.

Example of a double skin façade, box-window, mechanical ventilated, indoor air curtain

Peking Road

Peking Road, in Kowloon, Hong Kong; design strongly emphasizes the green building approach.

The facade layout recognized the different orientations of the building and there was a special interest in exploiting the use of natural daylight in the offices.

The tower features a triple-glazed active wall system, combining three layers of low emissive (low-e) clear glass with a ventilated cavity that results in high light transmission yet a low overall thermal transfer value. The cavity of the DSF (BW-MV-IAC) is mechanically ventilated with a controlled airflow that transports heat gain to the HVAC-unit. Venetian blinds are housed in a 200 mm air gap in the glazing system and are operated by a computerized system based on sunlight sensors.

The south elevation features innovative arrangements to reduce solar gain yet allow increased light transmission at the same time. Outside the windows, aluminium sun shading fins serve as reflectors bouncing light up onto the angled ceiling to transmit more natural light inside while at the same time limiting the entry of direct sun.

Figure 3-9 The Peking Road building in Kowloon, Hong Kong

Example of a shaft box double skin façade, naturally ventilated

ARAG 2000

The ARAG 2000 tower is sited in Düsseldorf, Germany, and is a high rise building with a naturally ventilated shaft box DSF arranged in eight storeys high sections (SB-NV). The flow path depends on the opening of the inner pane allowing fresh air. In each storey, a box window arrangement allows fresh air to be admitted into the space at floor level, via an operable flap, or drawn directly to the shaft. The warm air from the space is exhausted to the shaft at ceiling level. The shaft air is drawn out at the top of each eight storey section. All flow passage areas can be closed providing a buffer configuration (Bf).

In the 70 mm depth gap close to the outer pane (12 mm laminated glass), Venetian blinds provide solar control and the low-e inner pane is provided with windows able open.

Figure 3-10 ARAG 2000 tower in Düsseldorf, Germany

Example of a climate window facade

Technical University of Delft Library

The three facades of this Dutch building are an example of the climate window (CW) configuration. The outer pane is made of low-e double glass units (8-15-6 mm) separated from the 8 mm inner pane by a 14 cm gap. Indoor air flows mechanically driven through the gap to the ventilation system were heat is removed. Shading is provided by automatically operated Venetian blinds within the gap.

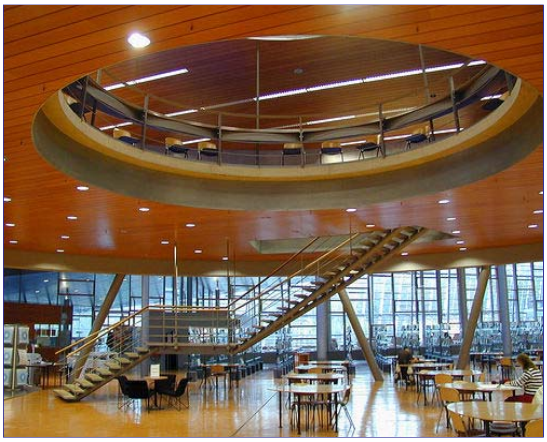


Figure 3-11 Technical University of Delft Library, The Netherlands

Example of a multi-storey double skin facade

Moravian Library

The Moravian Library is sited in Brno, Czech Republic, and has a façade with louvers able to open on the outer pane allowing a multi-storey DSF in the heating season to be transformed into a single skin façade for the cooling season. When closed, the DSF admits air from the bottom into the 550 mm depth gap and releases the heated air flow to the ventilation system at the top.

Shading is provided by means of adjustable shutters close to the inner pane and porous horizontal pathways (in the gap and outside), also used for maintenance, at each storey level.

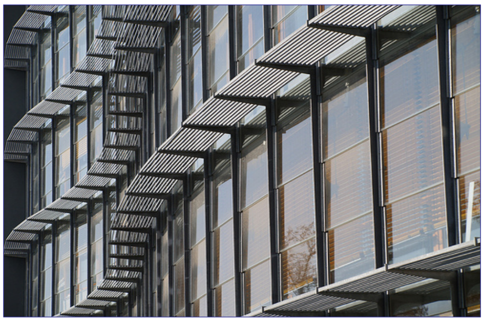
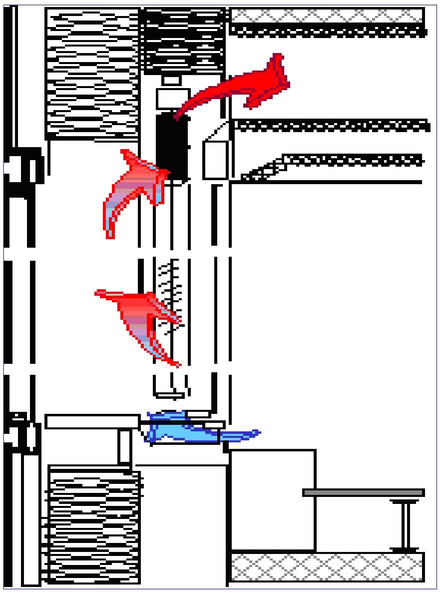


Figure 3-12 The Moravian Library in Brno, Czech Republic

Example of a climate façade, mechanically ventilated

Environment Park

Environment Park, in Turin, is a scientific and technological hub hosting firms, consultancy and research groups dealing with environmental issues. The hub is characterized by the adoption of energy and environment conscious solutions as high performance building envelope, high performance heating and cooling system (heating and cooling beams), low emission wood chip furnace, lighting/daylight control systems. Most of the south-facing façades of the hub buildings are climate façades.



(a)

(b)

Figure 3-13 Environment Park in Turin, Italy a) The monitored climate facade b) Scheme of the working principle of the facade

Example of a climate façade, mechanically ventilated

SOMEC Building

The SOMEC headquarter is sited in Zoppè di San Vendemiano, Italy. The office building presents a two storeys climate façade, facing south.

Figure 3-14 The SOMEC headquarter in Zoppè di San Vendemiano, Italy

The outer pane is a fixed 12 mm clear single gazing. The inner pane is a fixed extra clear low-e double glazing (5+5/15/8 mm) with a pvb layer for acoustic insulation. The ventilated cavity is 714 mm wide and hosts a reflective roller blind on the inside, located at 112 mm from the outer pane. The shading device is automatically controlled by a system equipped with a lux meter placed on the roof of the building. Additional roller shadings, operable by the occupants, are placed in the indoor environment, close to the inner pane.

The exhaust air from all the offices of the two storeys building is collected by the HVAC system and sent to a heat exchanger (air-air) to pre-heat (in winter) or to pre-cool (in summer) the ventilation air. In winter conditions, the air is sent to the channel placed in the lower part of the façade. The air flows along the façade, is extracted in the upper part of the cavity and is exhausted to the outdoor. In summer conditions, a second heat exchanger (air-water) is activated and the air is pre-cooled before entering the ventilated cavity of the façade. To pre-cool the air, the water from a well at 14°C is used. This heat exchanger (i.e. the cooling of the ventilation air of the facade by means of the well water) is activated when the temperature of the air at the exhaust of the façade exceeds 25°C.

Example of a box window, naturally ventilated, reversible airflow

Solar XXI, Lisbon Portugal

The building is located in Lisbon, Portugal, and has a total area of 1500 m^2. It was designed as an example of integrating renewable energies in a service building through the use of active and passive solar energy, natural ventilation and daylight, together with responsive technologies, with a final cost of €1.3M. It also aimed to be an example of a low energy efficient building.

The majority of the glazed surfaces are placed on the south façade to allow maximum solar caption in the heating season. For long periods with no solar radiation, the building uses a set of hot water convectors supplied by a boiler supported by a set of CPC type solar collectors and a hot water tank sited on the roof. The building (on the south façade and between the windows) is also equipped with a set of vertical PV panels (100 m^2; 12 MWh/yr corresponding to 30-50% of power consumption) forming a translucent double skin façade between the panels and the opaque part of the external wall (BW-NV-RAF). Within this gap, the heat is used in the heating season to introduce hot air to the rooms via two openings with top and bottom placements. An additional set of PV panels (95 m^2; 6 12 kWh_p) is used as a car park cover. The two PV systems cover for 74% of the building's electric energy use (2007 yearly data).

Figure 3-15 Solar XXI in Lisbon, Portugal

Figure 3-16 Solar XXI details

Thermal mass activation

Description of principles and concepts

Thermal mass is defined as the mass of the building that has the ability to store thermal energy for heating and cooling purposes. Utilization of the building's thermal mass helps to smooth out variations in thermal loads and to reduce wide fluctuations of the indoor temperature in order to keep it within a comfortable range. Therefore, the thermal mass plays an important role in the thermal performance of buildings and has the potential to bring substantial energy savings. It offers the engineers and architects powerful opportunities to efficiently manage the building's energy consumption. The solar gains stored by the thermal mass can be released back into the room at night time, which can cover a significant part of the heat loss of the building. In summer, the thermal mass can store a large part of the indoor heat gains as well as delay the heat transfer from outside to inside, thus it can reduce the peak cooling loads in the building. An active night ventilation (natural, mechanical or hybrid) can be utilized to remove the excess heat and cool down the thermal mass.

There are many successful techniques/concepts that help to passively utilize the thermal mass of buildings. These applications include passive cooling systems, such as night flush cooling and earth cooling, thermal storage heating system or passive solar heating system.
Besides the passive utilization of the thermal mass where the heat transfer processes in the thermal mass are left to follow only natural manners, there are also (relatively new) building components where the process of heat storage/release can be intensified and, to some extent, controlled. Such elements are commonly called "thermal mass activation", where systems utilize thermal storage capacity of the concrete slabs between each storey of multi-storey building.

Classification of the thermal mass activation concepts and technologies

Depending on its location, there are two basic types of the thermal mass in the building:

- The external thermal mass, such as walls and roofs, are directly exposed to ambient temperature variation.
- The internal thermal mass, such as furniture and purpose-built internal concrete partitions, are exposed to indoor air temperature.

Various combinations of internal and external thermal mass utilization are possible in a building depending on the relative location of the insulation layer. A concrete wall can act either as internal thermal mass: 3-17 b and d, as external thermal mass: 3-17 c and d or as both internal and external thermal mass: 3-17 a and d. The thermal mass of the concrete wall can also be thermally hidden behind insulating materials preventing it from being active: 3-17 e.

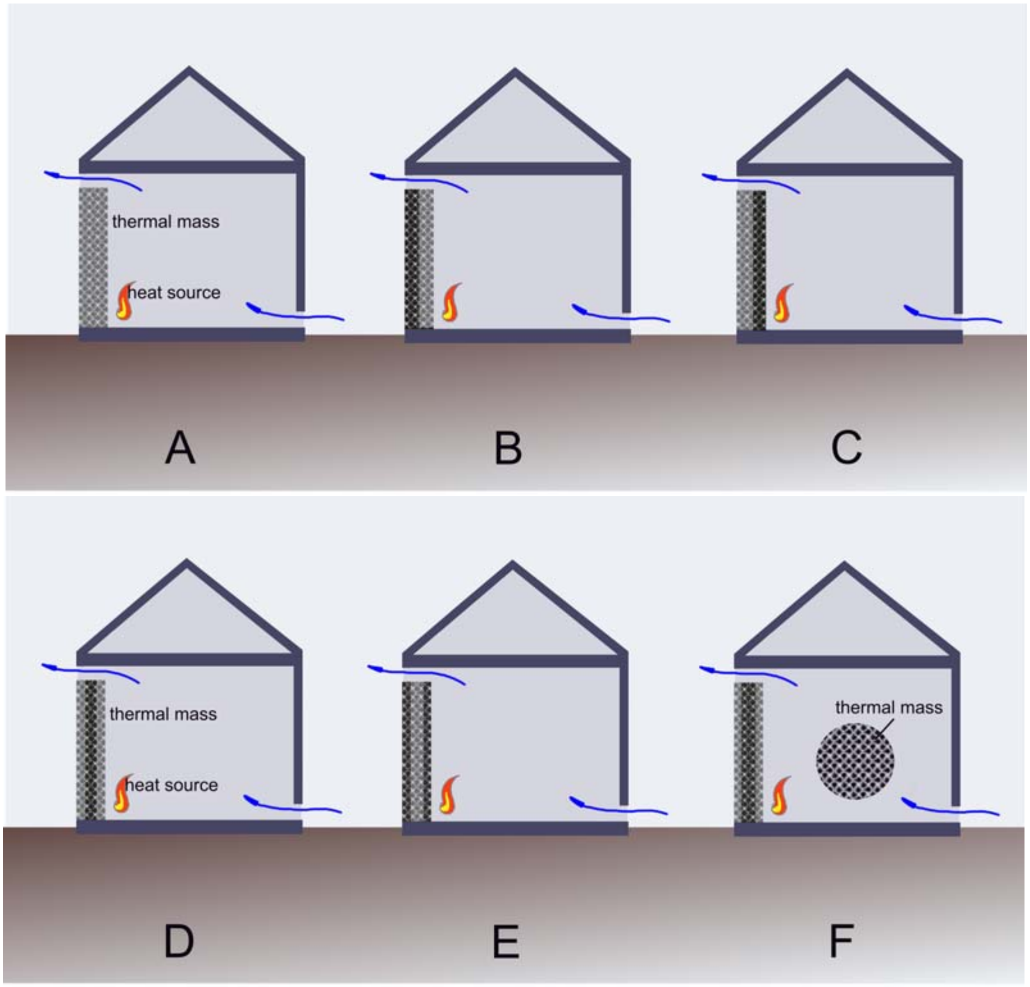


Figure 3-17 Illustration of six simple building models with different relative location of the thermal mass to the insulation and the existence of internal thermal mass

<u>Building types in relation to thermal mass</u>

According to its thermal storage capability, two classes of buildings can be distinguished: the butterfly-type (lightweight) and the elephant-like (heavyweight) thermal mass. Butterfly-type buildings will have highly responsive skins with a great deal of glass and will react quickly to the environment, such as with changes in solar radiation, light and temperature, by altering their properties. Elephant-like buildings have much more thermal mass and lack quick response to the environment and will change temperature slowly - after a period of time.

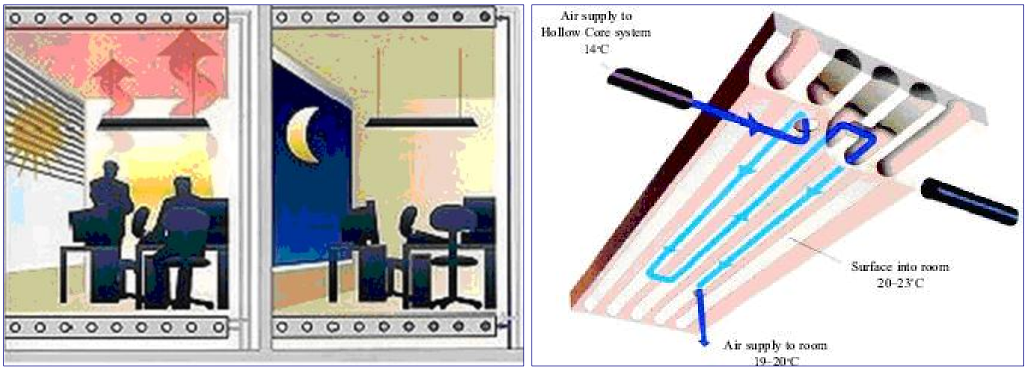
Generally, adobe brick, earth, natural rocks, stones, concrete and other forms of masonry, as well as the water are commonly used materials for thermal mass. The advantages and disadvantages of applicable heat storage materials used in buildings are compared in table 3-2.

Material	Advantages	Disadvantages
Water	Quite compact Free	A water storage tank is required, which means additional costs Leakage is possible
Concrete (stone)	Very stable Can also serve as wall, floor, etc	Expensive to buy and install because of weight
Phase-change material (PCM)	Most compact Can fit into ordinary wood-frame construction	Most expensive Long-term reliability is not yet proven Easy flammability

Table 3-2 Comparison of various heat storage materials

<u>Building component types</u>

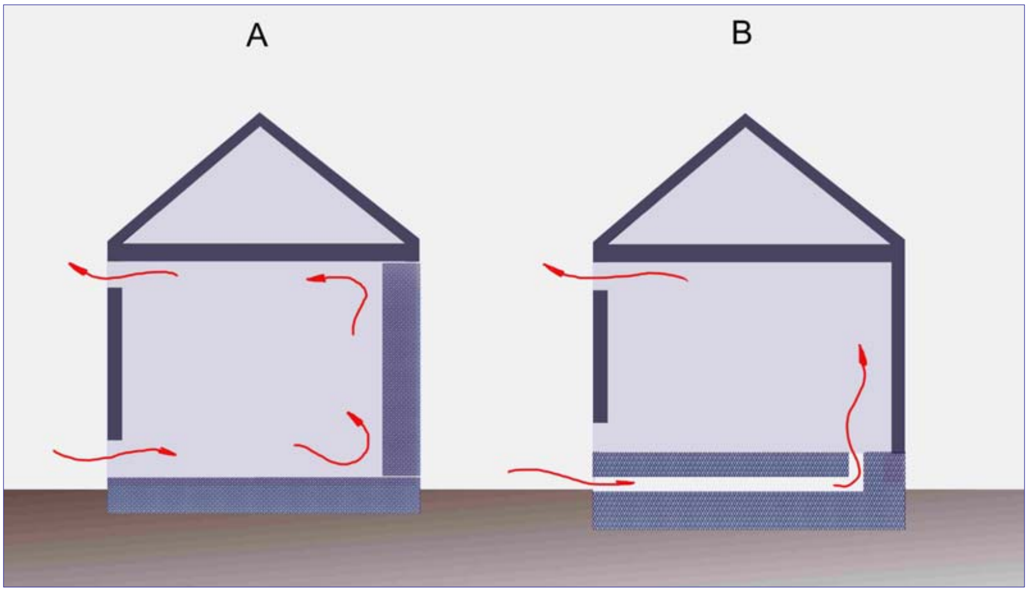
Basically, the thermal mass activation components can be divided into two main categories, according to the “activation principles”: 1) Surface Thermal Mass Activation – SA and 2) Core Thermal Mass Activation – CA; these basic principles are illustrated in figure 3-18.



a) b)

Figure 3-18 Thermal mass activation working principles a) SA activation involves only the surface of the element b) CA activation involves the whole structure (core) of the element.

Core thermal mass activation (“CA”) systems are such heating/cooling systems that are integrated (or thermally coupled) with a building construction having high thermal capacity (floor/ceiling slab, walls etc.). The thermal mass is “equipped” with ducts for circulation of air or embedded pipes (mostly made from cross linked polyethylene; PE-X) for circulation of a heat carrier (usually water). Building components with embedded water pipes are mostly used today.



a) Surface activation b) Core Activation

Figure 3-19 Examples of TMA CA systems.

Besides the division band on the layer of activation, building components can be divided according to the heat transfer media used for the activation. It can be either air (airborne systems) or water (water based systems).

Airborne systems
In airborne components, the cavities are used to circulate air through the concrete slabs. In this way, the concrete mass is heated or cooled.

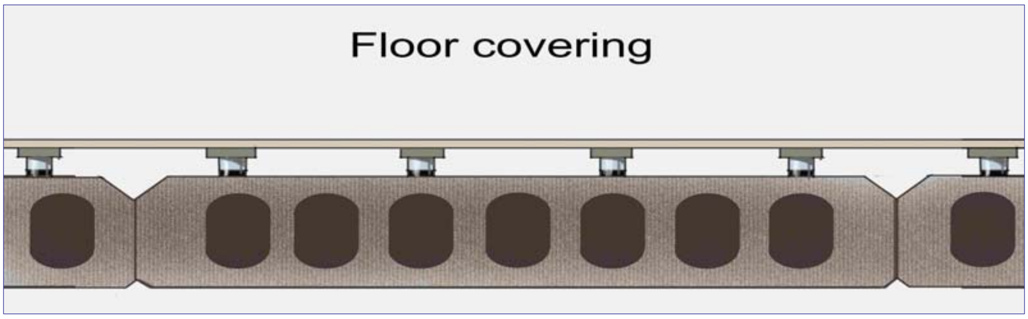


Figure 3-20 Principle of a hollow deck with cavities for air circulation

The circulated air can be also supplied to the premises. The decks are constructed to ensure a large heat exchange surface between the air stream and the concrete. The cavities also allow the air to get through the whole floor construction.

The standard system can be operated both for cooling and heating. The elements are supplied with ventilation air from a main supply duct, which runs along a central corridor. Normally, it is located behind a suspended ceiling. Air is supplied to the rooms through supply diffusers located in the ceiling and the air is extracted from the room through extract grills located at ceiling level.
Furthermore, there is no need for suspended ceilings. There is no need for a ceiling void and, therefore, the storey heights may be reduced by 15-25% per floor.

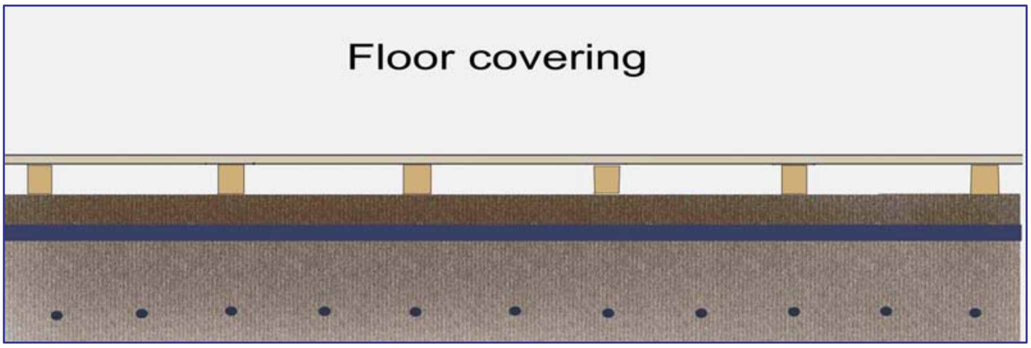
An example of the airborne system is the TermoDeck, which has been developed in Sweden[2]. Ventilation air is led through ducts in a concrete slab placed in the ceiling, which is used as thermal mass and then supplied into the room (see Figure 3-19).
The daily heat loads are accumulated in the thermal mass and consequently extracted during the night. This shift of the loads in the night time allows chillers to be operated using cheaper night-tariff electricity prices. Moreover, the temperatures of the heat carrier are usually close to room temperature. This increases efficiency of mechanical cooling equipment - chiller or a heat pump. The system also gives an opportunity to utilize renewable energy sources like ground heat exchangers etc.

2 Smith, J.T. and Raw, G.J. 1999. The suitability of TermoDeck modules for use in building ventilation systems. BRE (Building Research Esablishment Ltd).

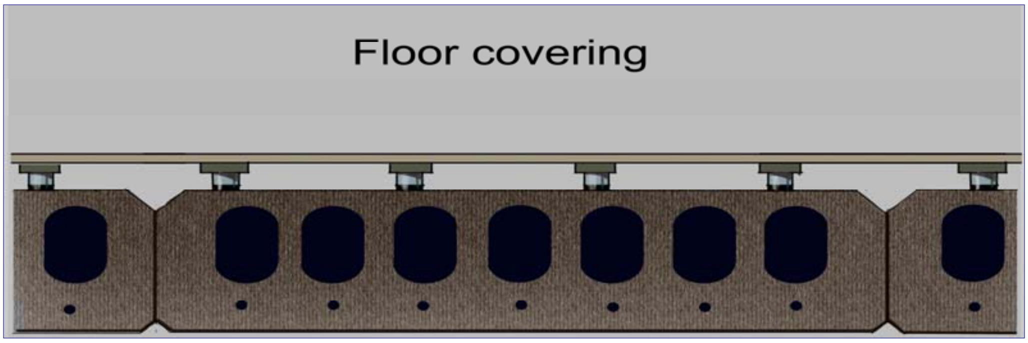
Karlström, S. 2005. TermoDeckRevisted, Master of Science Thesis Department of Building Technology KTH Stockholm

Water based systems

Water based thermo active components are becoming more commonly used in buildings. Figure 3-21 shows two principles of on-site constructed and prefabricated floor constructions.



a)



b)

Figure 3-21 Basic types of currently used water based thermo active building components: a) on-site constructed floor (with insulation); b) hollow deck with integrated pipes

Pipes are commonly installed in the centre of concrete slab among reinforcements. The diameter of the pipes varies between 10 and 25 mm. The distance between pipes is within the range 100 - 300 mm.

If the system is constructed on-site, the pipes are supplied in modules, which include a pipe coil attached on a metal grid and equipped with fittings (see Figure 3-23 and 3-24) A layer of insulation to direct the heat flows downwards, and to prevent noise transmission, it can be installed between the concrete slab and the floor surface (see Figure 3-22).

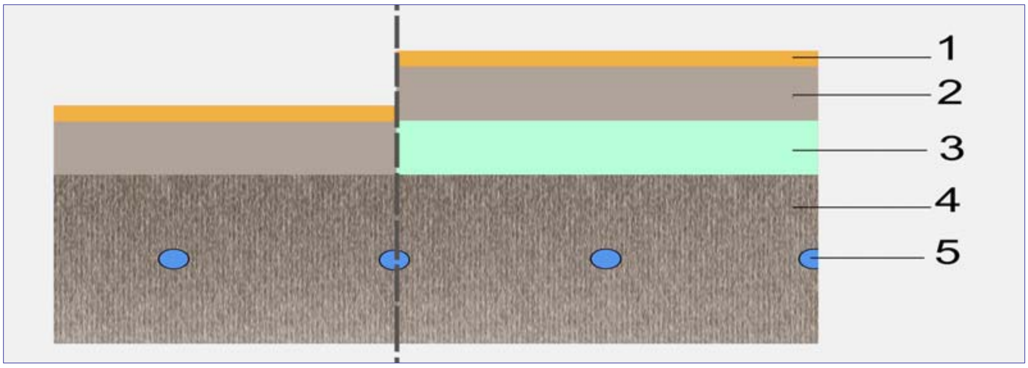


Figure 3-22 TABS with and without acoustic insulation
1 = Floor surface covering
2 = Screed
3 = Thermal/Acoustic insulation
4 = Building structure
5 = Embedded pipes

Another option is to construct the floor as a raised one with the option of leading the channels, pipes and wires in the space gap of double floor. If no prefabricated modules are used or the building shape is more complicated, pipes can be attached manually to the reinforcement. The reinforcement grid with the pipes is then covered by a concrete mass (Figure 3-23).

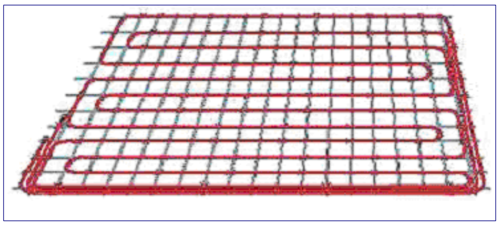


Figure 3-23 The pipe coil module supplied to be embedded in a concrete slab on-site

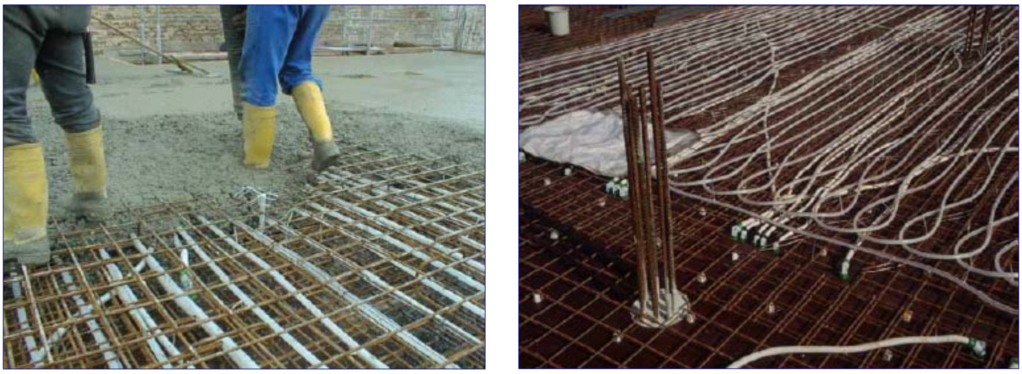


Figure 3-24 Concrete lying on the reinforcement grid with attached pipes

Other types of core activation components

Besides the systems with pipes embedded in various depths in the reinforced ceiling slab or/and wall (eventually in the hollow core slab), there are also systems using capillary micro pipes embedded in a layer at the inner ceiling surface or placed in additional plaster or gypsum layer (see figure 3-25).

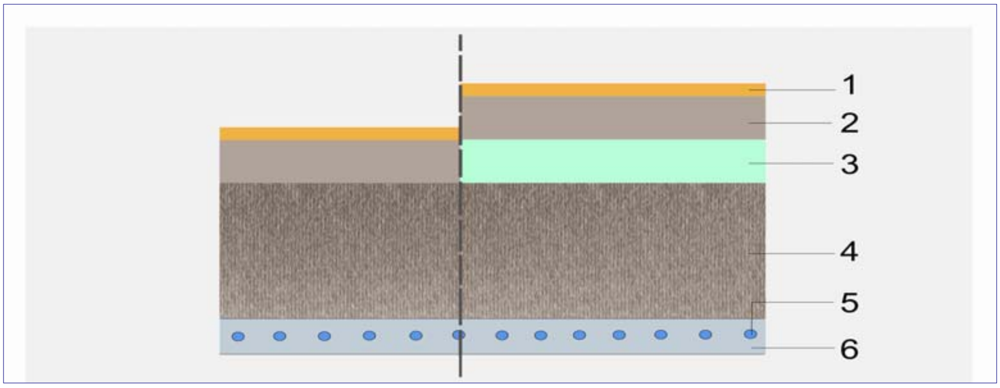


Figure 3-25 Example of TMA CA system: TABS with capillary micro pipes embedded in a layer at the inner ceiling surface with and without acoustic insulation
1 = Floor surface covering
2 = Screed
3 = Acoustic insulation
4 = Building structure
5 = Plastic micro pipes
6 = Plaster or gypsum

Micro-pipe cooling grids can be situated on the floor, attached to the wall or mounted on the ceiling panels as acoustic ceiling elements. The system is especially suitable for retrofit applications with a low thickness of the added construction. An advanced system for the refurbishment and light-structure buildings with the capillary grids embedded in a gypsum board with micro encapsulated Phase Change Material (PCM) was developed by Koschenz and Lehmann (2004)[3]. The application of PCM increases thermal capacity of the construction and promotes active energy accumulation and discharge. According to Koschenz and Lehmann (2004), the PCM can store up to 300 Wh/(m2·day) of latent heat during the phase change. A thermally activated PCM panel system of 50-70 mm thickness has with that a heat storage capability comparable to 300 mm thick concrete slab.

[3] Koschenz, M., Lehmann, B. 2004. Development of a thermally activated ceiling panel with PCM for application in lightweight and retrofitted buildings, In: *Energy and Buildings* Vol. 36

SWOT-analysis

Figure 3-26 shows the summarized results of a SWOT-analysis of TMAs. The SWOT analysis has been conducted based on an enquiry that has been carried out among the participating countries in the Annex 44 work.

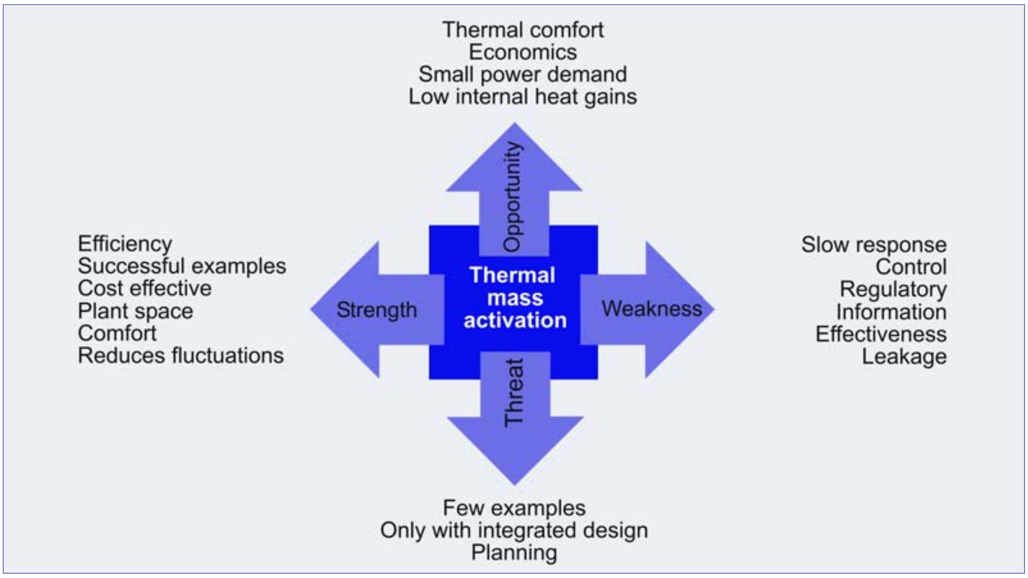


Figure 3-26 SWOT-analysis of TMA

Examples of application

Example of thermal mass activation, core activation principle

KANDEN Building of Kansai Electric Power Company, Inc. (KEPO) in Osaka, Japan

Air conditioning system utilizing building thermal storage (ACSuBTS)

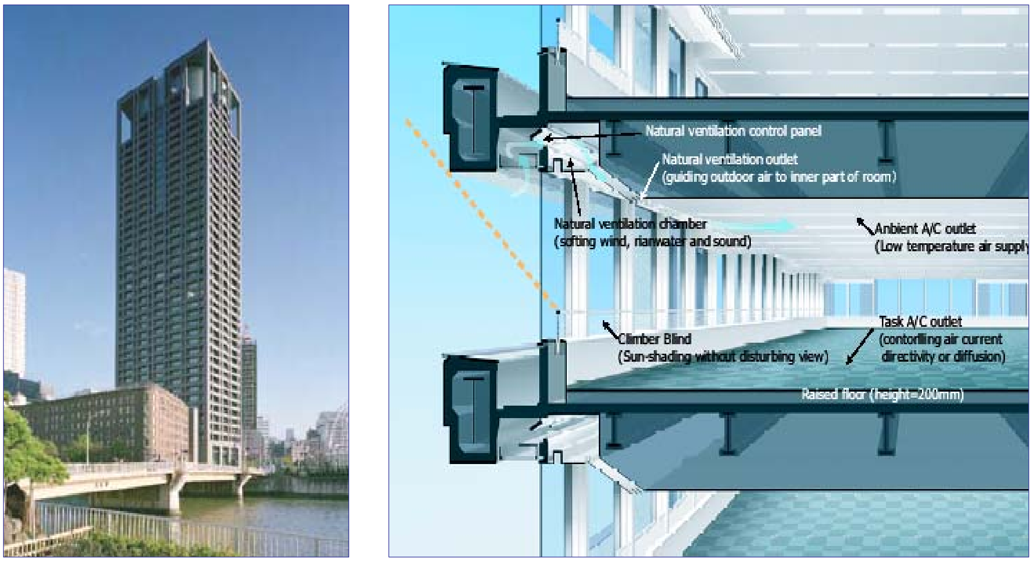


Figure 3-27 Existing application of ACSuBTS - KANDEN Building of Kansai Electric Power Company, Inc. (KEPO) in Osaka, Japan

The classification of the working principle of the Kanden building falls in the TMA – CA working principle. In Japan, an air conditioning system utilizing the building thermal storage capability (ACSuBTS) has been designed and adopted. The system is able to smooth the cooling load without increasing the initial costs by using the large building thermal mass as a thermal storage medium. In summer, by keeping the climate control system operating at night, the floor slabs, furniture and interior materials are cooled down. Then cold exergy stored in the building construction can be used to reduce electricity consumption of mechanical cooling during the daytime peak electricity usage period.

Dampers are installed at supply air ducts in order to change the air supply to the working space or to the plenum chamber. During working hours, the conditioned air from the air conditioning unit is blown directly into the room through the supply duct by opening the changeover dampers. The return air from the room, through the opening in the ceiling panel, is mixed with the air in the plenum and then flows into the air-conditioners. During nights, the conditioned air is blown directly upon the floor slab by changing angle of the dampers and cools down the floor slab.

Example of thermal mass activation, concrete core cooling principle

The Centre for Sustainable Building (ZUB)

Figure 3-28 The Centre for Sustainable Building (ZUB) in Kassel, Germany

The office building belongs to the Centre of Sustainable Building (ZUB), University of Kassel, Germany. The building is an example of new low temperature heating/cooling systems implementation. The ZUB office building consists mainly of three different parts: one part for exhibitions and events, one part for offices and one experimental part for different kinds of research in innovative building technologies and building services concepts. The load bearing skeleton, in reinforced concrete, consists of round pillars with a distance of 5.40 m and flat concrete slabs for the floor/ceiling construction.

A water-based conditioning system with embedded pipes is used for heating and cooling of the offices. In the case of heating operation mode, the system works with water inlet temperatures controlled according to the outdoor temperatures (approx. 24° C). In case of cooling needs, pipes embedded in the floor slab of the basement are used as a ground heat exchanger. Mechanical cooling is not required.

There are two layers of pipes in the floor constructions of the building. The pipes are embedded in the concrete slabs and in the upper floor construction (regular floor heating/cooling). This design was used to be able to test the properties of different systems and their advantages.

Pipes are made in polyethylene with a diameter of 20 mm and a distance of 150 mm. In the basement, the pipes have a diameter of 25 mm. The distribution of the pipes in the slab has a coil shape. Each circuit of the floor radiant system and the active thermal slab system is supplied by approx. 600 kg/h water mass flow rate. The difference between supply and return water temperature is lower than 4-5°C. Individual regulation of the thermal conditions in each room is possible because each room has its own heating/cooling circuit.

Example of thermal mass activation, concrete core cooling with natural/ mechanical ventilation

Office building of Bertelsmann C. Verlag GmbH

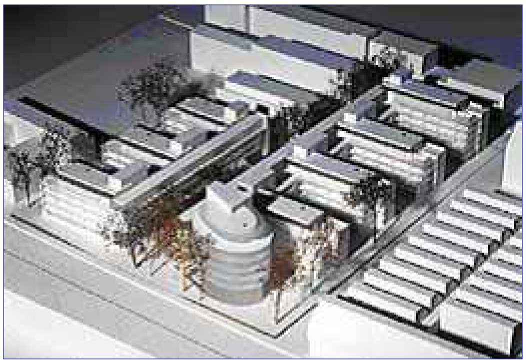


Figure 3-29 Office building of Bertelsmann C. Verlag GmbH, Munich, Germany

The four-stories building consist of two main long parallel buildings, each with additional building wings. The building has offices facing all directions. A slab heating and cooling system is used. It is combined with a mechanical ventilation system and radiators as an additional heating system (see Figure 3-29). Offices are also equipped with operable windows. In the spaces with higher internal loads (conference rooms), an additional cooling was installed. The building is divided in four zones with separate supply-return pipes and control, so they can be cooled or heated independently. The design water temperatures were for cooling 16°C supply / 19 °C return and 24°C supply / 22°C return for heating. The supply temperature is controlled separately for each zone according to an average zone temperature based on several room temperature sensors.

Earth Coupling

Description of principles

Thermal energy storage has been known as a flexible heating and/or cooling technique to dampen daily and seasonal peak energy demands of buildings. Among various thermal storage media, ground is a favourable one due to its massive capacity and availability. Relatively stable temperatures of the ground have made it an effective heat source, sink, and storage medium used in some building energy conservation measures. The high thermal inertia of soil allows the ground to dampen the oscillation of ambient temperature and results in the soil temperature at a certain depth remaining relatively constant independent of daily temperature fluctuations, while being affected more by seasonal changes. The ground thermal storage applications for space heating and cooling can be classified into three forms:

1. Direct method, which conditions indoor environment by increasing direct contact of the building with the ground.
2. Indirect method, which preheats or pre-cools ventilation air using the thermal storage of ground before delivering it to the indoor environment.
3. Isolated method, which uses a heat carrier medium, such as ground water or coolant, to exchange energy between the ground and the indoor environment.

An Earth-to-Air Heat Exchanger (ETAHE) is a typical environmental responsive building element adopting the indirect method. It ventilates air to the indoor spaces through one or several horizontally buried ducts. In this way, the large thermal capacity and relatively stable temperatures of the ground are used to preheat or pre-cool the air, resulting in energy savings.
Figure 3-30 gives a schematic overview of an ETAHE. For most residential and commercial buildings with desired indoor temperatures from 20°C to 25°C, ETAHEs are primarily used for cooling purpose since the corresponding ground temperatures are normally below this range for the whole year. ETAHEs can also be used for winter pre-heating when the outdoor air temperature is lower than that of the ground, but additional heating systems may required.

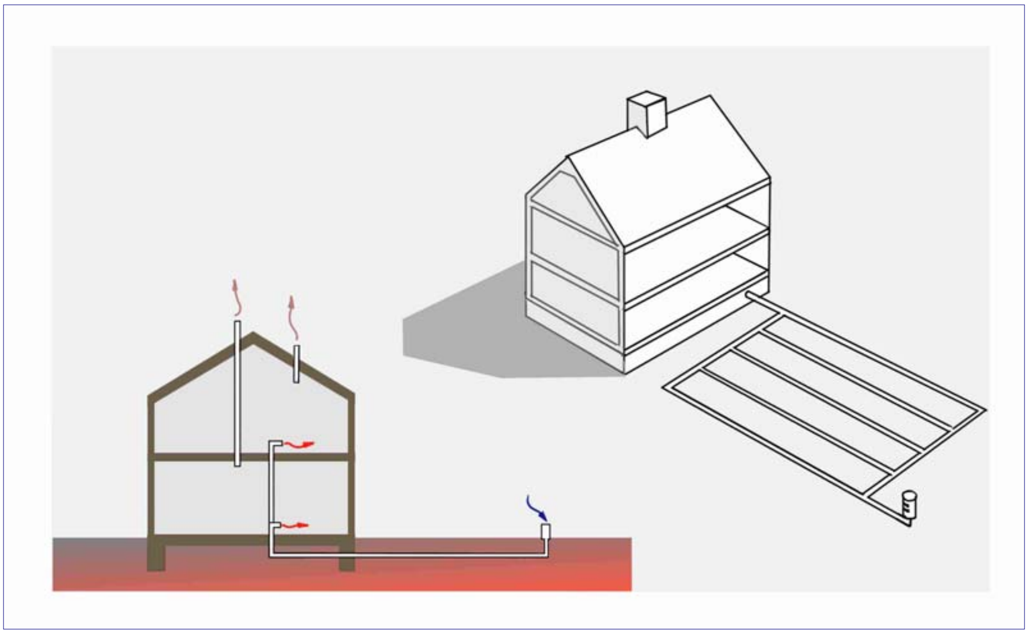


Figure 3-30 Building with an Earth-to-Air Heat Exchanger

The working principle of cooling air with ventilated underground space has been known since ancient times. However, ETAHEs have not been popular due to the uncertainties of the required airflow driving forces. Recently, a large numbers of ETAHE systems have been built in greenhouses and livestock houses, as well as in residential and commercial buildings. ETAHEs are also found applicable in wide range of climates with large temperature differences between summers and winters as well as between days and nights.

To effectively exploit the ground thermal storage, the design and operation of ETAHEs have to be highly dependent on the ventilation systems. Integration of ETAHEs with building service functions is critical for the success of the energy performance. Most existing ETAHEs are installed in mechanically ventilated buildings, in which electrical fans provide the airflow driving forces. In such systems, an ETAHE can be a single duct or multiple parallel ducts made of prefabricated metal, PVC, or concrete pipes with diameters of 10 cm. The typical arrangements for the ducts are:

- Laying the piping in ditches in the surrounding yard
- Laying the piping in the foundation ditch around the building
- Parallel piping directly under the foundation or between the single and continuous strip foundation

In case of the parallel pipe systems, the mutual distance between the pipes should be kept approximately 1.0 meter from each other in order to minimize the thermal interaction. Greater spacing was not found beneficial for extra benefit[4].

The size of an ETAHE depends on the designed airflow rate and the available space. A maximum air velocity of 2 m/s is normally recommended for smaller systems, and larger systems can be designed for air velocity up to 5 m/s. Due to the high velocity and small duct size, large amount of energy has to be spent on the mechanical ventilation systems to deliver air through the ETAHEs.
When ETAHEs are integrated in a building with natural or hybrid ventilation, the duct cross-sectional areas should be much larger than those of the conventional ducts used in mechanical ventilation systems. This change in the ductwork size causes the heat transfer process to become more complicated than the conventional ones. The integration of ETAHE and hybrid ventilation is regarded as a new approach to improve building energy efficiency.

Classification

According to the system configuration, ETAHEs can be classified in open-loop systems and closed-loop system. Figure 3-30 illustrates an open-loop system, which delivers fresh air to the indoor directly extracted from the outdoors. A closed-loop system re-circulates indoor air through ETAHE ducts. Therefore, their inlets are in the buildings. The latter types are used in greenhouses, livestock houses and buildings with separate fresh air inlets. The major benefit of open-loop systems is to provide a path for the outdoor air intake. However, concerns for insects and small animals entering and noise transmission need to be taken in account at the design stage.
In terms of the integration with ventilation systems, ETAHEs can be classified to mechanical and hybrid ventilation systems. The former one is a conventional design and it is used in mechanically ventilated buildings. To reduce the (large amount of) fan energy demand required to drive the air through the duct work, a large cross-sectional duct system is adopted by buildings with hybrid ventilation. The main difference between the two systems appears to be their sizes. Their design operation and simulation may be greatly different from each other.

- Based on the functionality, ETAHEs can be categorized into heating and cooling systems. When an ETAHE is used for winter's pre-heating, it is usually coupled with a heat recovery unit or other heating devices to prevent icing. In summer, a properly designed ETAHE system may fully satisfy the cooling load. When the ETAHE cooling capacity is not enough, the remaining load can be further removed by other measures such as static cooling surfaces (e.g. radiant cooling ceilings or cooled slab).

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4 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, pp 95-109.

SWOT-analysis

Figure 3-32 shows the summarized results of a SWOT-analysis of earth coupling systems. The SWOT analysis has been conducted based on an enquiry that has been carried out among the participating countries in the Annex 44 work.

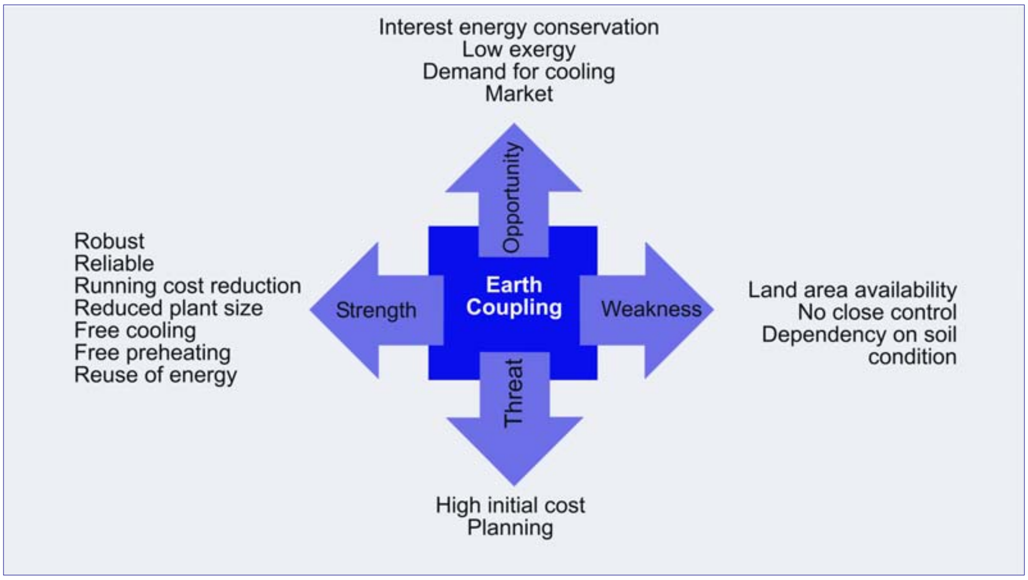

Figure 3-31 SWOT-analysis of EC

Examples of application

Example of earth coupling, mechanical ventilation, closed loop system

Schwerzenbacherhof building, Zurich, Switzerland

The Schwerzenbacherhof building is a commercial building near Zurich, Switzerland, with a heating energy consumption of 144 MJ/m^2 per year for 8050 m^2 of heated surface. It was a major case study in the IEA-ECBCS Annex 28 (Low Energy Cooling)[5]. Figure 3-32 shows the building with the ETAHE inlet. There are two paths for the building to intake fresh air. It can either pass through the ETAHE system under the building or bypass it to air handling units, as shown in Figure 3-33.

Component description

The ETAHE is 6 m beneath the ground surface, which is below ground water level and 75 cm below the building's second basement (unheated) which is below ground water level. As seen in Figure 8 (left), it consists of 43 parallel high-density polyethylene pipes with a one percent inclination. Each pipe has a length of 23 m and a diameter of 23 cm. The mean axial distance between two pipes is 116 cm. Two large concrete ducts were built on-site before and after the pipe system to distribute and collect the air. Drainage to sewage is provided in the intake-side concrete duct (see Figure 8, right). A varying airflow rate during office hours (12,000 m^3/h in winter and 18,000 m^3/h in summer) is generated by two fans in the system.

Figure 3-32 Schwerzenbacherhof in Zürich, Switzerland

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5 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, pp 95-109.

Zimmermann, M. (1995). Ground Cooling with Air, IEA-ECBCS Annex 28 Low Energy Cooling, Subtask 1 Report, Review of Low Energy Cooling Technologies

Hollmuller, P. (2002). Utilisation Des changeurs Air/Sol Pour Le Chauffage Et Le Rafraîchissement Des Bâtiments Mesures in Situ, Modélisation Analytique, Simulation Numérique Et Analyse Systémique, PhD Thesis, Université de Genève, Genève.

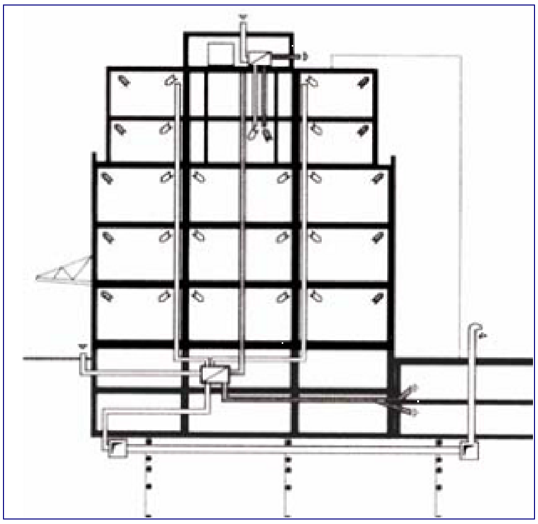


Figure 3-33 Schematic of Schwerzenbacherhof building ventilation system

Example of earth coupling, hybrid ventilation, open loop system

Mediå school, Grong, Norway

Mediå school is a 1001 m^2 one-floor building located in Grong, Norway. An air intake tower for the ETAHE is a triangular cross-sectional vertical duct located north of the building and stands on a 35° slope. The height from the tower's top to its base is approximately 6 m. On each side of the tower there is an opening, which is covered by a metal shield to protect it from rain. Behind the shield, each opening is equipped with a one way damper allowing air entrance when pressure in the tower is lower than outside.

Component description

After passing through the intake tower, the downward airflow is led to a horizontal 1.5 m × 2 m concrete intake duct whose roof is approximately 1.5 m below the ground surface. A damper is installed at the beginning of the duct. A frequency-controlled variable-speed propeller fan with a diameter of 1.4 m is located 1.5 m away from the damper on the leeward side. Its operation is interlinked with the damper opening position. A noise absorber is located 6.3 m from the fan. Six fine filter blocks are installed at the end of the duct. The total distance from the damper to the filters is 11.1 m. The duct has a 5% incline to the inlet direction to allow improved dust removal and drainage. Drainage is located at the base of the air intake tower.

After leaving the intake duct, the air vertically passes through two overlapped horizontal heat exchangers and enters a 2.2 m × 2 m horizontal air distribution duct. This duct has two branches which are below the building's corridor. The air from the intake duct can also bypass the heat exchangers by flowing through two "summer" doors next to the exchangers.

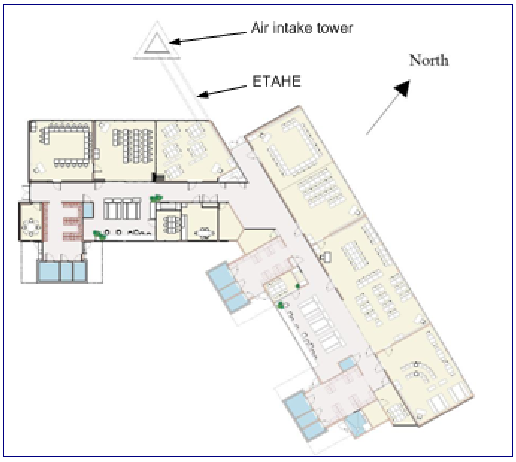


Figure 3-34 Mediå school layout[6]

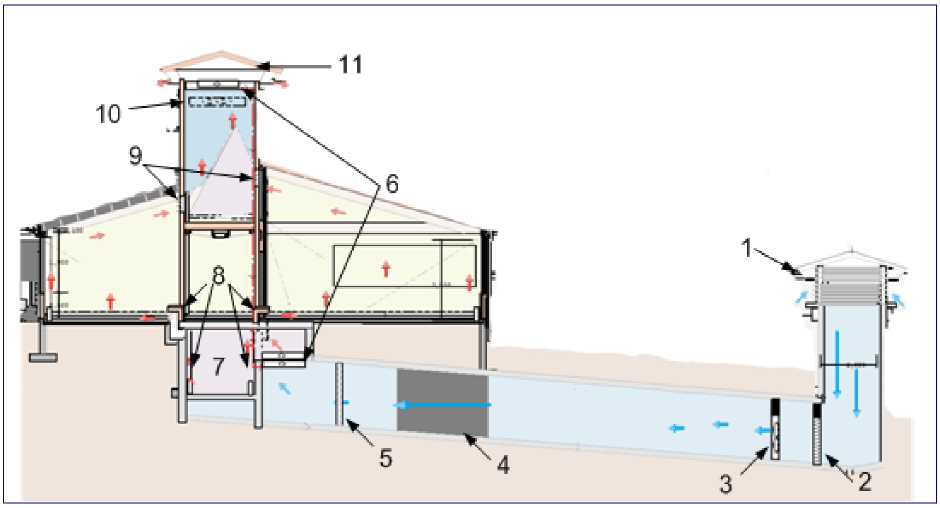


Figure 3-35 Schematic cross section of Mediå school showing air flow paths and location of components. 1: triangular intake tower with openings and vents; 2: damper; 3: supply fan; 4: sound absorber; 5: filter; 6: exchangers for supply air preheating using run-round heat recovery via a circulating water-glycol mixture as well as additional reheating; 7: air distribution duct; 8: units for noise attenuation plus openings and grilles for supply of ventilation air to the classrooms; 9: dampers for extracting exhaust ventilation air from the classrooms; 10: extract fan; 11: triangular roof tower with exhaust vents[7].

6 Tjelflaat, P.O. (2000). The Grong School in Norway the Hybrid Ventilation System. IEA ECBCS Annex-35 (HybVent) Technical Report.

7 Tjelflaat, P.O. (2000). Pilot Study Report - Media School. IEA ECBCS Annex-35 (HybVent) Technical Report.

Phase Change Materials

Description of principles

PCMs are ''latent'' heat storage materials. They use chemical bonds to store and release the heat. The thermal energy transfer occurs when a material changes from solid to liquid, or liquid to solid. This is called a change in state or phase.

PCMs, with melting temperatures between 20 °C and 50 °C, are applied for thermal storage in conjunction with both passive and active storage for heating and cooling in buildings. The PCMs do not only exploit the sensible heat but also the thermal storing capacity due to latent heat.

Introduction of phase change materials into building components can considerably increase their thermal mass, without substantially increasing the weight.

Due to their latent fusion heat, and in smaller part their specific heat, these materials act as energy "accumulators"; absorbing and discharging heat, keeping their temperature unaltered and thus avoiding overheating of the elements in which they are contained.

The fusion latent heat is the energy employed to break the chemical bond; a process that begins when the temperature of the material rises above the melting point. The temperature of fusion is a typical characteristic of the various substances as illustrated in Figure 3-36.

The consequence of this process is that the thermal capacity of the PCM is not constant, but is concentrated in a temperature range close to the melting point of fusion.

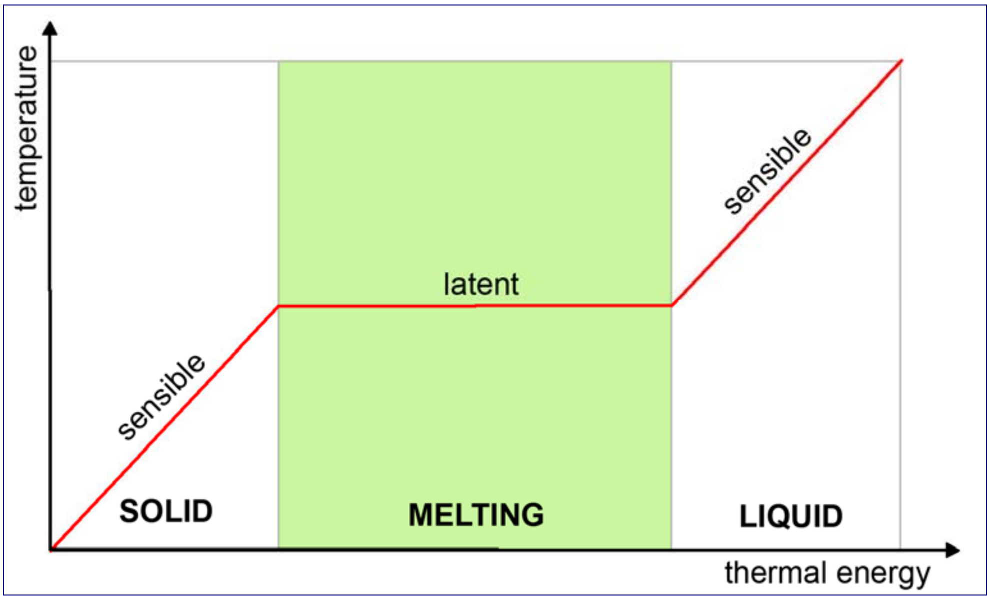


Figure 3-36 Specific thermal energy (stored) vs. temperature

When the temperature is higher than the melting point, the phase change material is liquid and when the temperature is lowered below the melting point, it returns to the solid phase.

The advantage of using of a PCM material compared to traditional construction materials is their higher energy storage capacity, with the same weight and volume. Furthermore, the variable heat capacity allows the building elements containing PCM to have a dynamic behaviour, sensible to the climatic conditions.
The temperature of PCM during the phase change remains almost constant and close to the melting temperature, avoiding the excessive oscillation of the structures or building elements.

Phase change materials can be classified into organic and inorganic compounds and their eutectic mixtures, as shown in Figure 3-37.
The inorganic materials are characterized by a high latent heat of fusion per unit volume. The organic compounds include paraffin and non-paraffin organics. The organic substances are suitable for application in buildings due to several properties in comparison with inorganic compounds. Some of these advantages include their ability to melt congruently, their self-nucleating proprieties and their compatibility with conventional materials of construction.
A disadvantage that has to be considered carefully is their relatively high flammability.

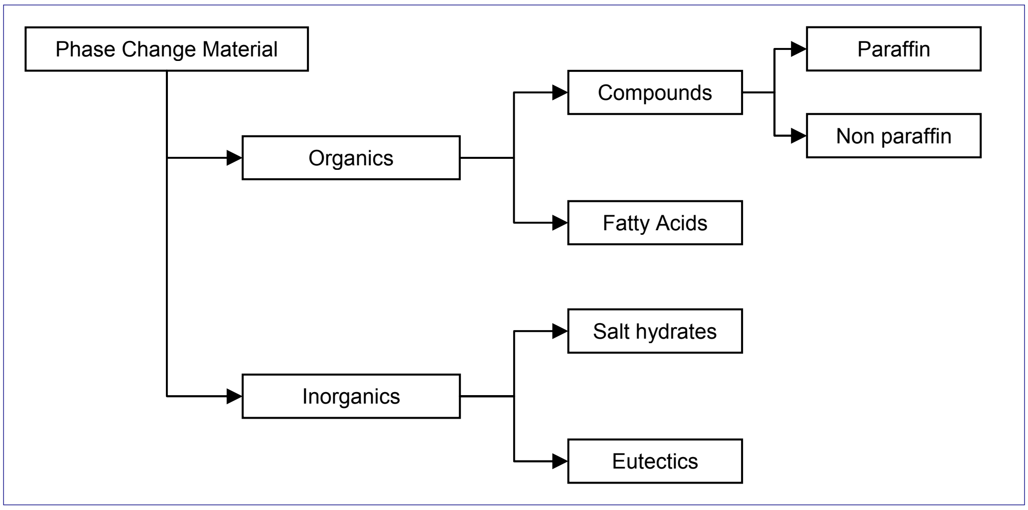


Figure 3-37 Different typologies of Phase Change Materials

The PCMs to be used in the design of thermal storage systems in buildings should contain desirable thermo physical, kinetic and chemical properties recommended as follows:

Thermo physical properties

- Melting temperature within the desired operating temperature range.
- High latent heat of fusion per unit volume, so that the required volume of the storage container able to release a given amount of energy would be as small as possible.
- High specific heat to provide additional significantly sensible heat storage.
- High thermal conductivity of both solid and liquid phases to assist the charging and discharging phases of the storage system.

- Small volume change 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 after 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, non-flammable and non-explosive material for safety.

Application of PCMs in buildings

The application of PCMs in buildings can have different goals. The first scope is utilising natural heat and cold sources, i.e. solar energy for heating or night cold air for cooling, and then reducing the energy demands for heating and cooling. Secondly, increasing the thermal mass of the building leads to improvement of the internal comfort conditions.

The application of PCMs in light weight buildings is promising due to their capability to smooth temperature variations.

Basically, three different types of application are suitable to exploit PCMs in buildings for heating and cooling:

- PCMs in building walls;
- PCMs in other building components (for example subfloor or ceiling systems)
- PCMs in separate heat or cold storage systems.

The first two are (or can be) completely passive systems, where the stored energy (“heat” or “cold”) is automatically released when indoor or outdoor temperatures rise or fall beyond the temperature of melting. The third one is an active system, where the stored energy (“heat” or “cold”) is kept thermally separated from the building structure and the environment by means of a suitably insulated device (storage tank, heat exchanger, …). In this case, the energy is used only on demand and not automatically.

Examples of application

A classification of PCM based on the three different applications.

Wall application

There are several ways PCMs can be applied in the façades. They differ in technology and thermal behaviour, but all of them have the goal of increasing the thermal inertia of the building envelope. One of the possible applications is in *opaque envelope components* (walls and/or roofs), and the other is in the so-called *solar walls.*

Opaque envelope component

A PCM wall is capable of "capturing" a large proportion of the solar radiation incident on the wall or roof of a building. They can be very effective in shifting the cooling load to the off-peak electricity period.

There can be two different configurations depending on the position of the PCM layer within the wall stratification, i.e. with the PCM layer located toward the inside facing side of the envelope component or with the PCM layer located toward the outside.

The first type of application is with an internal latent storage layer, directly (or almost directly) in contact with the indoor environment. The goal of this application is to increase the thermal capacity of the environment where the PCMs are applied. The PCM layer stores and releases the internal and solar gain, keeping the temperature constant around the melting point. When the indoor temperature decreases, the PCM will release the thermal energy to keep the comfort conditions within the internal environment.

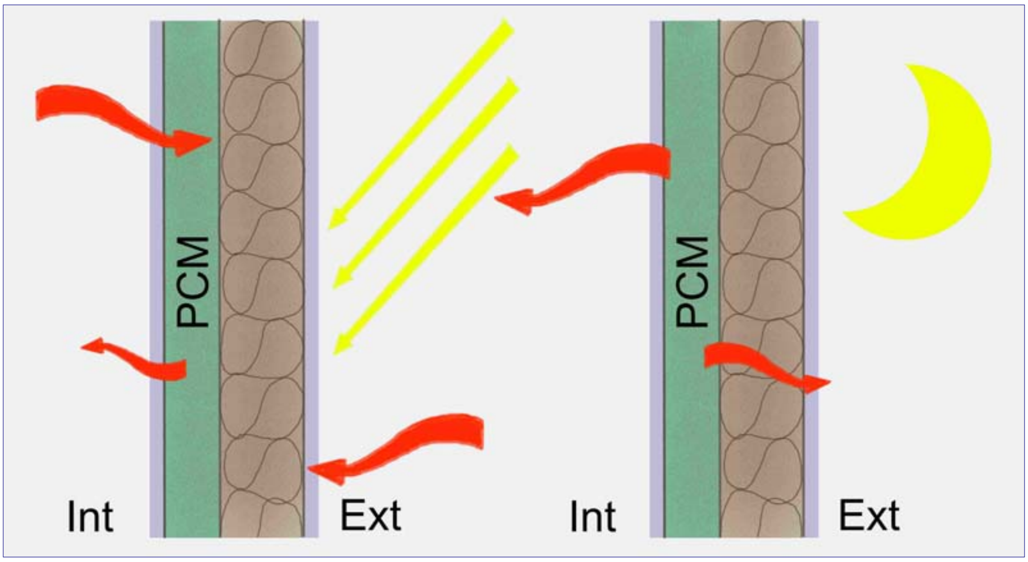


Figure 3-38 Scheme of PCM application on the inner side of the wall

The second type of application is on the external side of the wall. The PCM layer has the function of collecting and storing the thermal energy that comes from the outdoor environment, in particular due to the direct solar radiation incident on the external surface.
During the day, the PCM stores the energy, changing its phase from solid to liquid. During the night, when the temperature decreases under the melting temperature, it will freeze and release the energy stored.

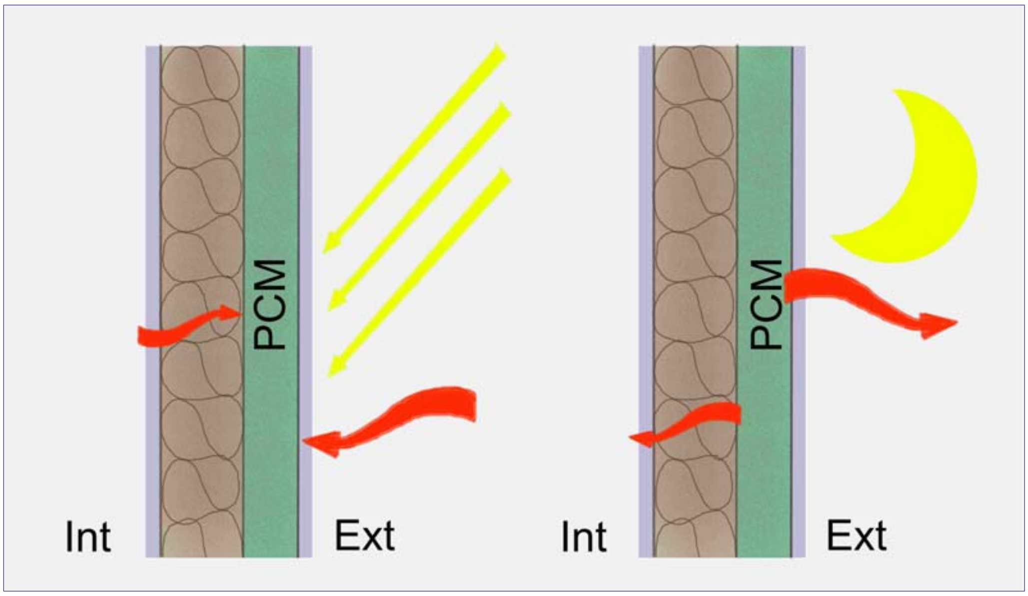


Figure 3-39 Scheme of the application of PCM on the external side of the wall

Solar wall
The solar wall is another application where PCMs can be successfully used for thermal energy storage. Traditionally, a solar wall is made of a transparent – glazed – layer (facing the outdoor environment, an air gap and an opaque wall (facing the indoor environment).
The opaque layer works by absorbing part of the solar radiation incident on its outer face and then conducting this energy through the wall. The outside surface of the opaque component is usually painted with a dark colour to increase the absorption. After the heat is transmitted by conduction through the opaque layer, it is distributed to the indoor space by radiation and, to some extent, by convection from the inner face.

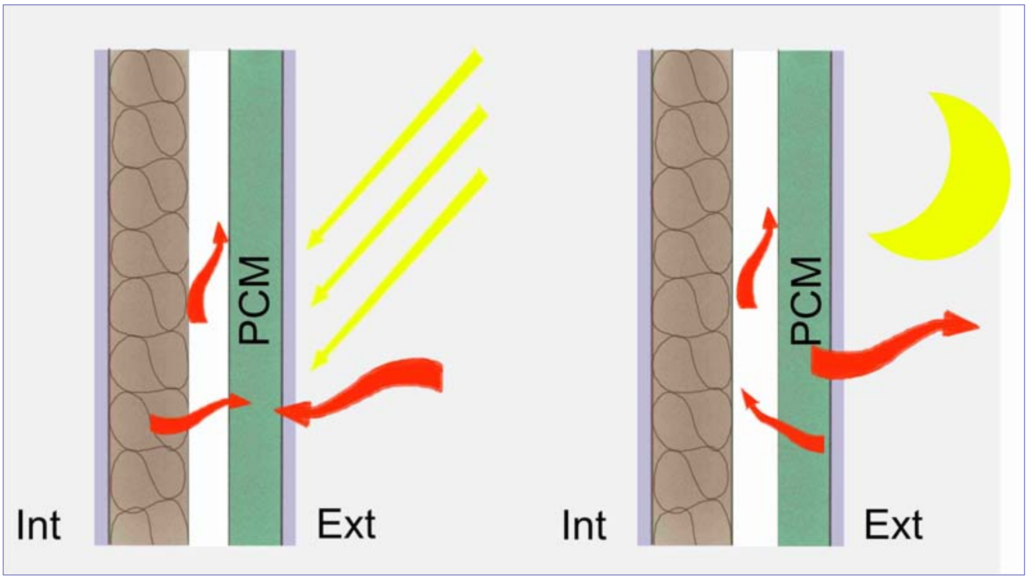


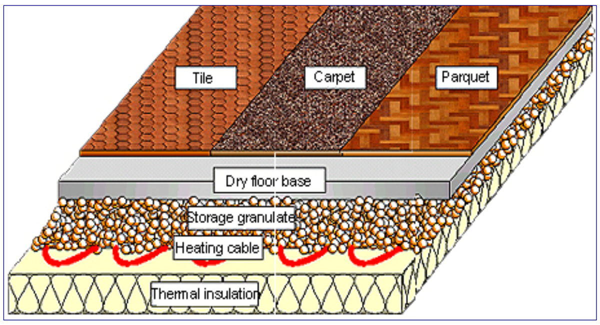
Figure 3-40 Scheme of the application of PCM in a solar wall

Under floor application

The use of PCM in floor layers or in subfloor heating and cooling systems can reduce the overheating of floor areas directly exposed to the solar radiation. The PCM, in fact, can stabilize the surface temperature in a range close to the melting temperature.

When the floor is directly irradiated by the sun and/or when the internal free gains are higher than the heating loads, the PCM in the floor structure can absorb and store this excess energy that otherwise would cause an overheating. The energy that is stored during the day can be easily removed if necessary with a hydronic system, or used afterwards for heating the building during the night.

Furthermore, in winter, this PCM based floor can avoid or reduce the temperature oscillations due to the duty cycle of the heating system.



a)

b)

Figure 3-41 A typical configuration of a floor heating system coupled with PCM
b) Example of a PCM container for floor

Ceiling air exchanger

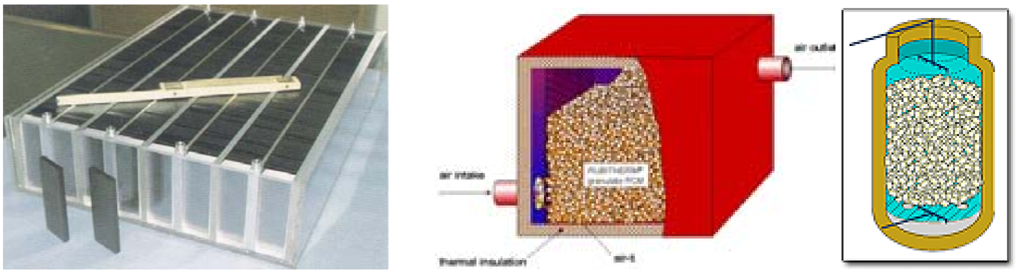
The ceiling air exchanger exploits the thermal mass of the ceiling slab and the “artificial” thermal mass of the PCM. The working principle is similar to that of the floor application, even though the typical configuration is quite different.

In fact, in this case the PCM is usually not directly embedded into the ceiling layers, but is located in a suitable false ceiling system. The PCM is installed in the void between the ceiling and the false ceiling (in theory, it could also be a floor and an elevated floor). Air is circulated in the cavity by means of independent fans, or using the air conditioning system. A flow is created between the ceiling slab and the PCM cassettes (or bags), thus increasing the heat exchange rate.

The aim is to store cold air at night and release it during the day, by means of a mechanical ventilation system. This allows directly removing part of the internal heat load from the indoor environment and smoothing out temperature peaks.

Thermal Storage unit and air exchanger applications

The last application is the use of PCMs in building installation appliances. Due to their high latent heat and the possibility to (almost) freely choose the temperature at which the energy can be stored (i.e. phase transition temperature), PCM can profitably substitute water as storage medium under some circumstances. By using phase change material (PCM) instead, compact storage units with high heat storage capacity will be feasible for many applications in the heating and ventilation systems.



a) b) c)

Figure 3-42 Picture (a) and schemes (b and c) of typical storage devices based on PCM

SWOT-analysis

Figure 3-43 shows the summarized results of a SWOT-analysis of PCMs. The SWOT analysis has been conducted based on an enquiry that has been carried out among the participating countries in the Annex 44 work.

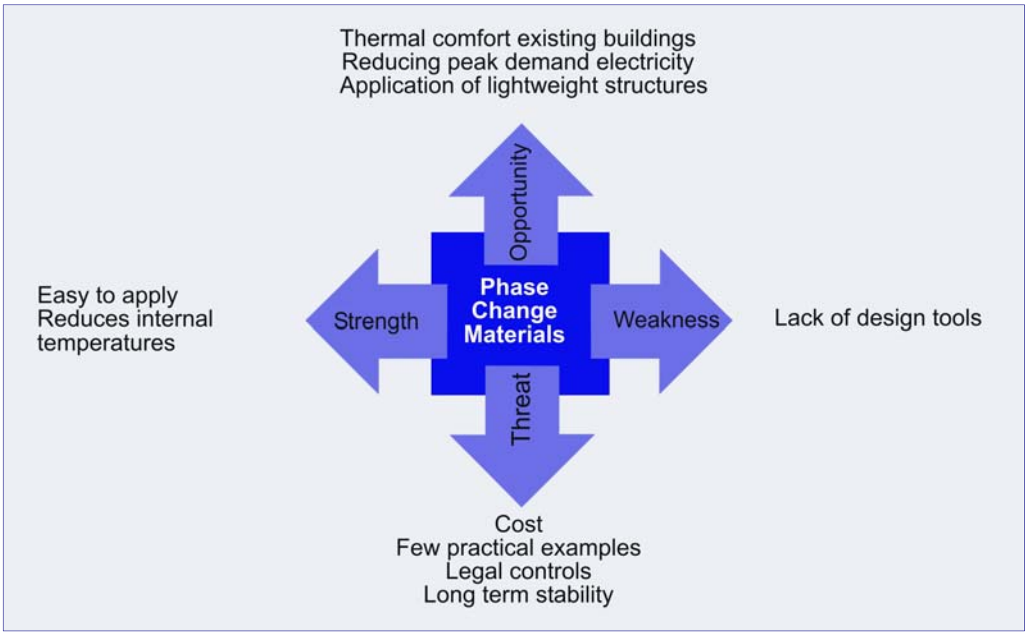


Figure 3-43 SWOT-analysis of PCM

Examples of application

Example of PCM in a retrofitted house

The “3-Litre” House (DE)

The “3-Liter Haus” in Ludwigshafen (Germany) is a residential building built in the 1950s (Figure 3-44). Now, after a retrofitting, the energy demand is 30 kWh/m²year, corresponding to three litres of oil per square meter per year.

The thermal insulation is a new insulation material with graphite and the internal plaster is mixed with micro encapsulated (5 µm) phase change material, in particular paraffin with a melting point of 24 °C and a latent heat of 180 J/g (BASF Micronal). The PCM is positioned in the inside layer of the wall and contributes to improve the thermal inertia of the internal environment through the increase of the thermal inertia of walls. The ventilation is mechanical combined with heat recovery. The blinds are made of insulated window shutters. The heat and electricity generator is a fuel cell, type SOFC (Solid-Oxide-Fuel-Cell), with a thermal power of 2,5 kW and 1kW electricity. In the first heating season, the measured energy consumption was 24,7 kWh/m²a.

Figure 3-44 "3-Litre" house and fuel cell

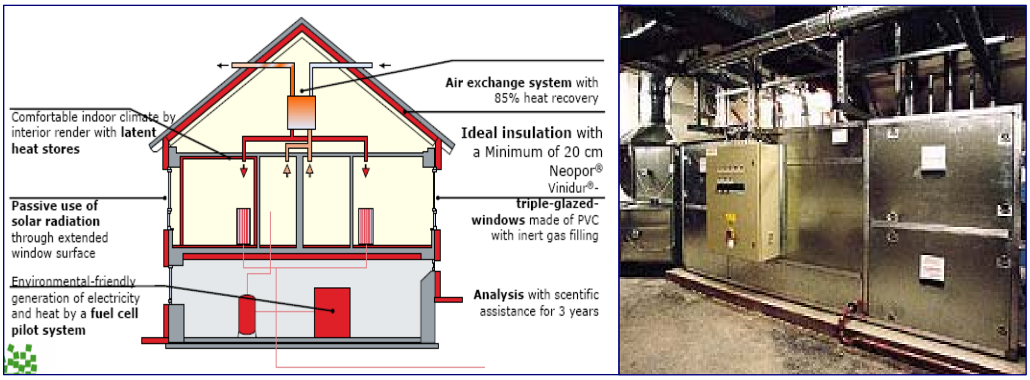


Figure 3-45 Schematic cross-sections and air handling and heat recovery "3-litre house"

Example of PCM in a new build building

Domat EMS building, Ems, Switzerland

The “Domat EMS“ building (CH) is a new constructed building for elderly people. In some houses, the south façade is a solar wall with a latent heat storage layer (GLASSX type). The façade is transparent and allows passing of daylight with a light diffusing effect. The construction is made of a series of low emission layers that allow an excellent thermal insulation and, at the same time, permit daylight to pass through the façade. To avoid overheating during the summer, a surface with a plastic transparent prismatic layer is included. This reflects or transmits the solar radiation as a function of the solar incident angle. The phase change material is hydrates salt, contained in plastic modular containers.

Figure 3-46 Domat Ems building - Overall picture and some construction details

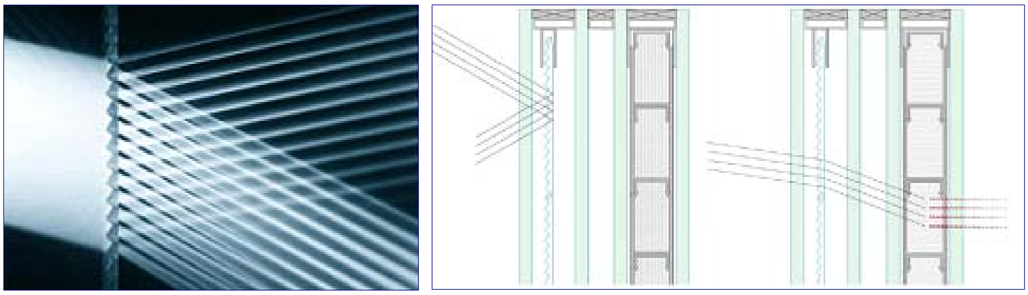


Figure 3-47 Domat Ems building - Particular of the south facing solar wall

Example of PCM in a retrofitted office building

Building of Stevenage Borough Council (UK)

The building of Stevenage Borough Council in UK has been retrofitted. PCM application has been one of the measures to improve the indoor comfort conditions. In order to reduce the peak cooling load and exploit night ventilation, a ceiling with PCM (Cool deck type) combined with a mechanical ventilation system was installed. The type of PCM used is Climator C24, which hydrates salt in multilayer envelopes, having a melting point of 24°C.

Figure 3-48 Picture of the "Stevenage Borough Council" building - construction details of the PCM based ceiling

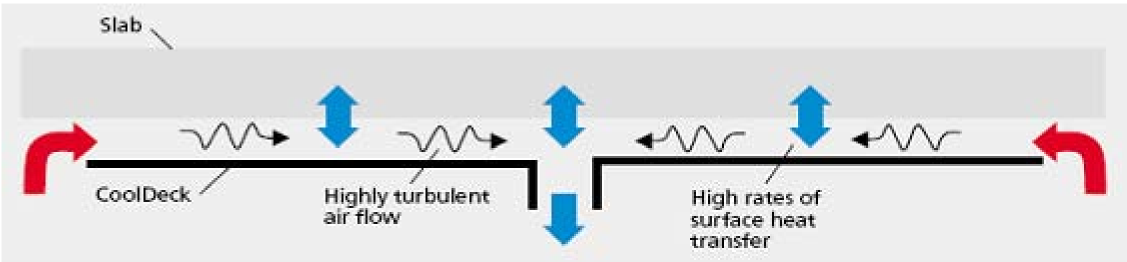


Figure 3-49 Stevenage Borough Council" building - Scheme of the working principle of the PCM based ceiling

Dynamic Insulation

Description of principles

Dynamic insulation (DI) describes a novel, energy efficient approach to deliver fresh filtered ventilation air to the interior of a building through an air-permeable, dynamically insulated building envelope. The concept and working principle of this technology, DI, is illustrated in Figure 3-50. Ventilation air enters the building pre-tempered (cooled in summer and heated in winter) using energy that would otherwise be lost and also filtered of airborne particulate matter (PM), which means that the DI element acts as the ventilation source, heat exchanger and air purification system.

The DI concept then effectively uses a combination of conventional insulation and heat exchange characteristics of a wall to pre-heat fresh air for ventilation. It is regarded as a possible method for reducing building envelope heat losses while achieving better indoor air quality.

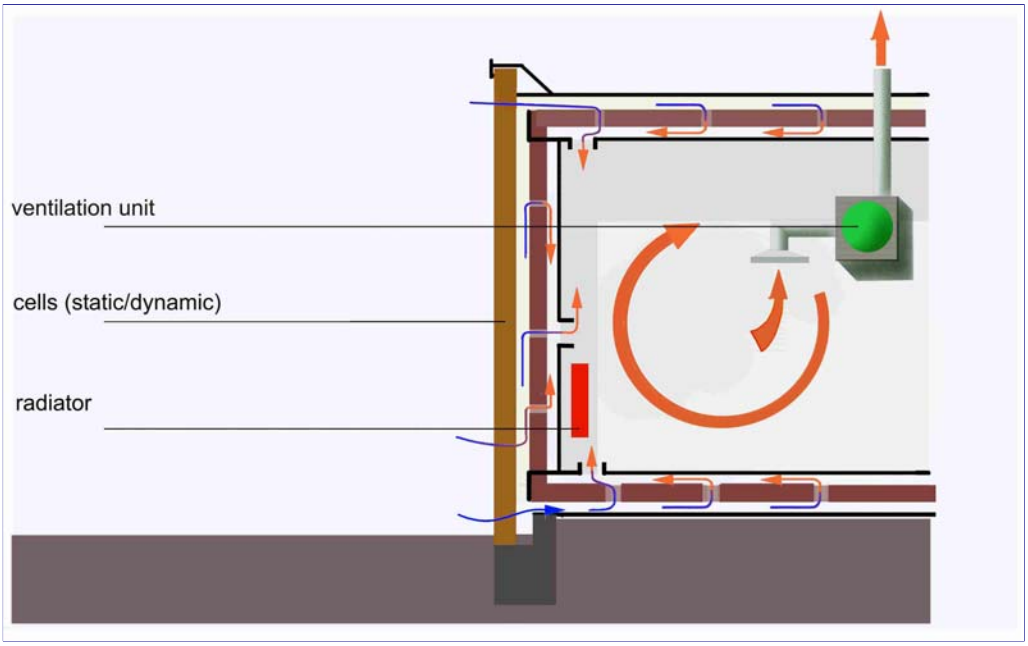


Figure 3-50 DI concept and working principle

The existing technology of DI can be divided into two categories:

1. *Cavity wall design*: this configuration adopts cavities to circulate the fluid (mostly air) in the wall. The airflow direction in the cavities is generally parallel to the wall – wall acting as a heat exchanger.
2. *Breathing wall design*: this allows the gas (mostly air) transfer through the permeable insulation. The interaction of the gas phase and solid phase can also act as a contra-flux mode heat exchanger.

Even though ventilated walls using a combination of air cavities have been presented, most of the structures of DI system currently adopt the latter concept because of its easy implementation. The research and application of DI systems currently focus on the *breathing wall*. In this kind of structure, the interaction of air and solid phase acts as a contra-flux mode heat exchanger.

Concerning energy consumption, the following benefits are claimed for the application of breathing wall:

1. Less energy is required to maintain a certain indoor air temperature, thus the operating costs for space heating and cooling are reduced. Previous research suggested that the energy saving of using breathing wall in a building is about 10%. Simulation by Krarti (1994)[8] of a room with a dynamic insulated wall showed that the overall energy saving may reach 20%, while the simulation results by Baily (1987)[9] pointed out the energy saving during a heating period vary from 7% to 14% without any additional equipment such as a heat pump.
2. As minor heat loss can be achieved by using a thin dynamic insulated wall, it is possible to avoid the need of using a thick wall construction to meet the building regulations. This will also reduce the construction cost.
3. By using breathing wall, the wall becomes the air supply and distribution system, thus reducing the cost of installing ventilation ducts.
4. As a breathing wall is generally working in contra-flux mode, it also prevents the water vapour transmission into the interior environment; reducing the risk of mould growth and condensation.

Besides the advantage of energy saving, the fibrous structure in breathing wall may also offer an effective, low energy solution to the air pollution problem in the surrounding environment, since the breathing wall can act as an air filter, which helps remove airborne particulates. Therefore, it helps to provide a better indoor air quality and healthier indoor environment.
The dynamic insulated wall component usually consists of the following main sub-layers:

1. The external envelope sub-layer. This could be a prefabricated reinforced concrete slab or a perforated metal sheet. The supply air can be introduced from the bottom or top of the external envelope sub-layer.
2. The breathing wall sub-layer, which may consist of layers of breathing materials, such as compressed straw board, mineral wool and thin paperboard, or cellulose fibre insulation. These materials create low pressure drop between interior and exterior, thus allowing the air to enter the room.
3. An air gap is generally used to separate these two sub-layers.

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[8] Krarti M. 1994. Effect of airflow on heat transfer in walls. *Journal of Solar Energy*, v 116, n 1, pg 35-42

[9] Baily N R. 1987. Dynamic insulation systems and energy conservation in buildings. *ASHRAE Transactions*, n 93, pt 1, pg 447-466

Besides the configuration of these sub-layers, other considerations in the real breathing wall system design include:

1. *Pressure difference between indoor and outdoor for inward airflow can normally be achieved by means of a fan.*
2. *Solar energy should also be considered in order to increase the performance of a breathing wall component. For example, a layer of outer glazing could raise the temperature of incoming air.*
3. *A heat pump or heat pipe unit can be inserted in the exhaust air duct to pre-heat the incoming air.*

SWOT-analysis

Figure 3-51 shows the summarized results of a SWOT-analysis of Dynamic insulation. The SWOT analysis has been conducted based on an enquiry that has been carried out among the participating countries in the Annex 44 work.

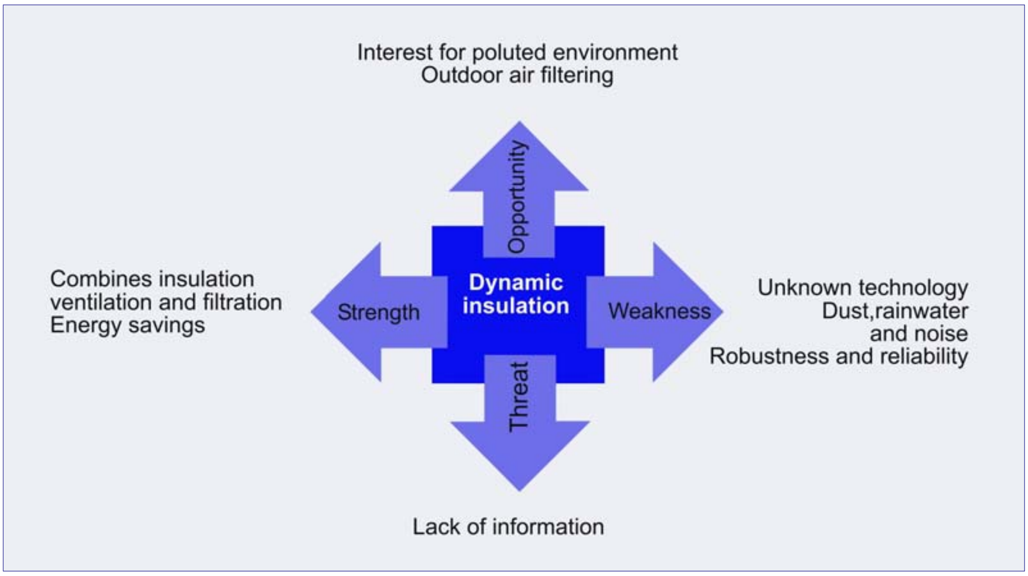


Figure 3-51 SWOT analysis of Dynamic insulation

Example for illustration

Application of Dynamic insulation in a residential building

Balerno project, city of Edinburgh, UK

The Balerno project is a 4-bedroom detached house, supported by the Carbon Trust and features a dynamic breathing roof forming part of the air handling and Mechanical Ventilation Heat Recovery (MVHR) system.

Figure 3-52 Photographs from the Balerno project construction phase

The distinguishing feature of this house is a DI roof, fitted with *Energyflo*™ cells, feeding the supply side of an exhaust air MVHR system (Figure 3-53).
Built to Scottish 2005 building standards, the whole-house static U-value was determined to be 0.45 W/m^2K. In operation, this fell to 0.23 W/m^2K and 0.30 W/m^2K in September (late summer) and November (early winter) respectively. These falls are a consequence of dynamic heat recovery, solar gain (in September) and other dynamic effects from a DI system that constitutes 32% of the total building envelope area.

Figure 3-53 The Energyflo cell (courtesy of EBP)

Ambient outdoor counts averaging 3673 sub-micron (fine to nano) particles per cm^3 were observed over an 8-hour sampling period. By comparison, the counts downstream averaged 378 sub-micron particles per cm^3. Ultra-fine and nano particle counts were thus reduced by more than 90% after passing through the Energyflo™ cells.

Future responsive building elements

Only a few technologies have been investigated and described in the context of IEA Annex 44. However, the technology of RBEs only stands on the beginning of its evolution. To stimulate the development of new ideas for new RBEs, see Table 3-1. Potential applications of RBEs in building constructions can be a good starting point. In the pictures below, some ideas are given.

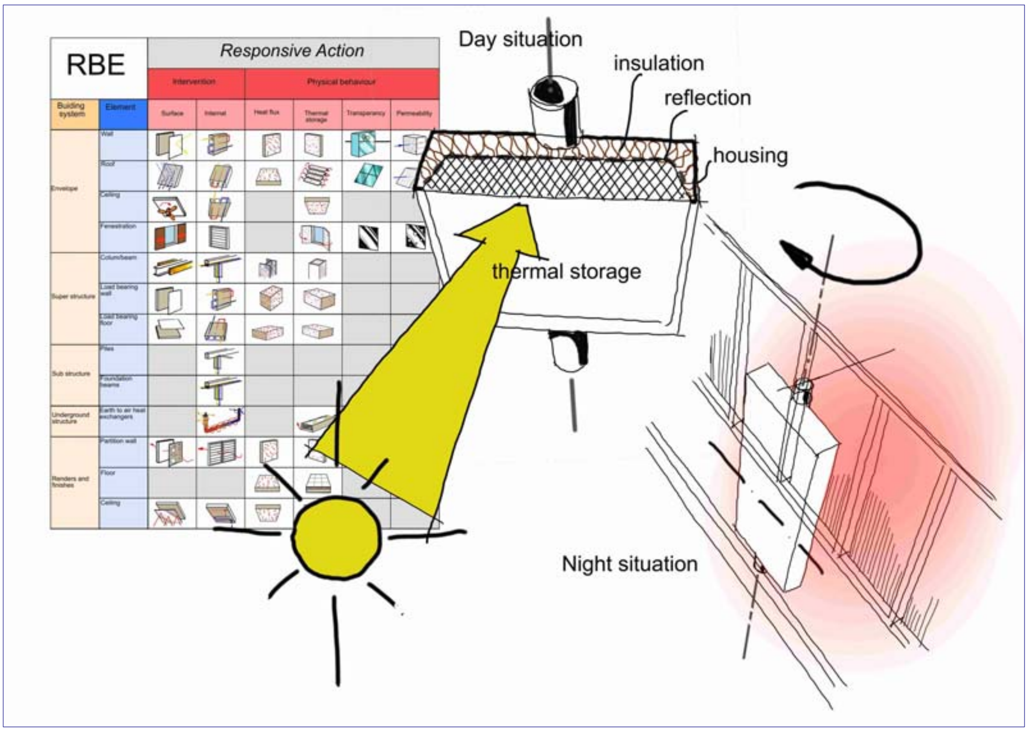


Figure 3-54 Activating the thermal mass in combination with ventilation.

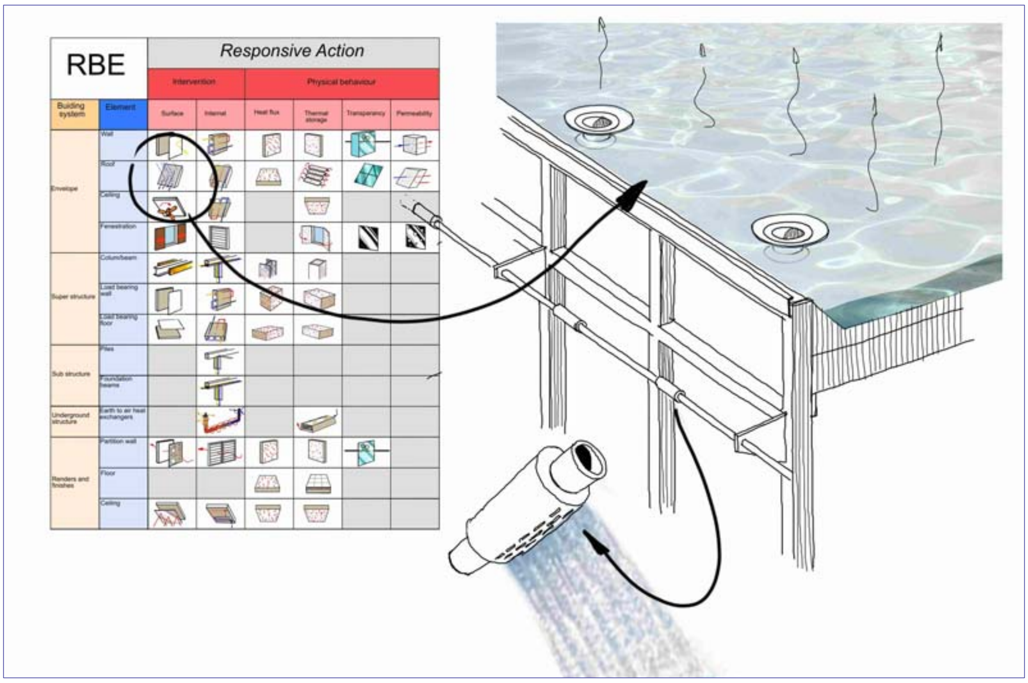


Figure 3-55 Activating the water layer on a roof.

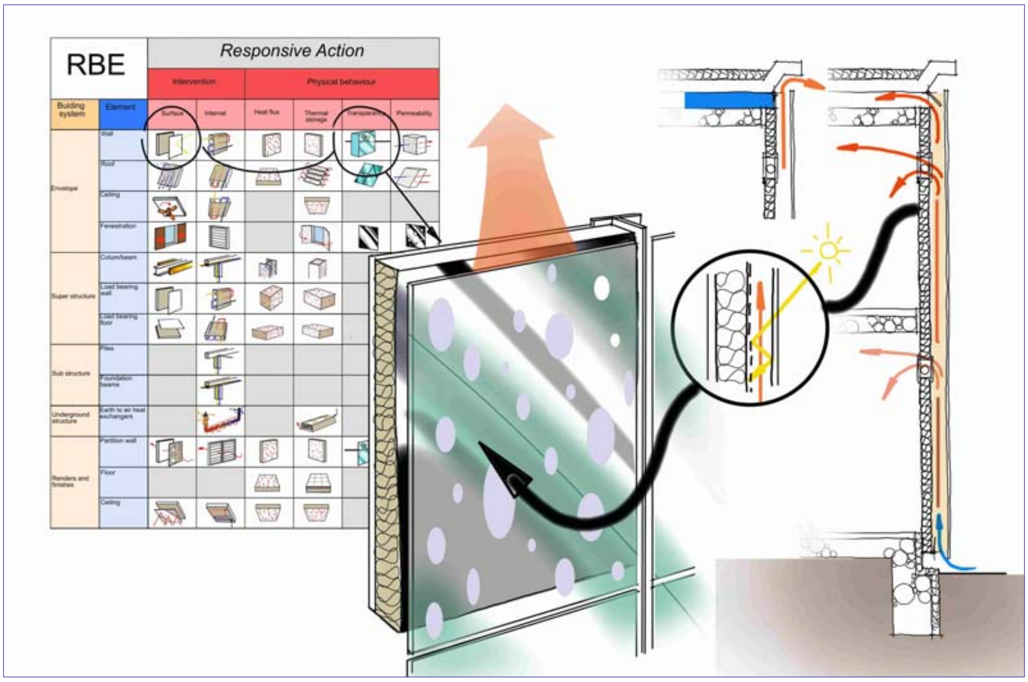


Figure 3-56 Activating a wall and roof at the surface

4. THE INTEGRATED DESIGN PROCESS

The integrated design philosophy

From component to concept

Efforts to minimize the building energy efficiency over the last decades have focused on efficiency improvements of specific building elements and building services equipment (component level). Significant improvement has been made.

However, the performance of individual elements often depends heavily on the performance of the system they are part of;i.e. the performance of a heat pump depends on the performance of whole heating and cooling system, which consists of a source, a distribution and a delivery part, respectively. The performance of a well insulated window no longer depends solely on the insulation level of the glazing, but also on the window frame, the spacers, etc. Innovations were shifting from the component level to system level.

Also the system level approach is no longer appropriate. Buildings have become integrated concepts in which advanced systems work together to reach an optimal performance in energy, comfort and health. And particularly in the overlapping field of building technology and building services and the responsive building elements, lies a great future potential to achieve the next steps in energy savings.

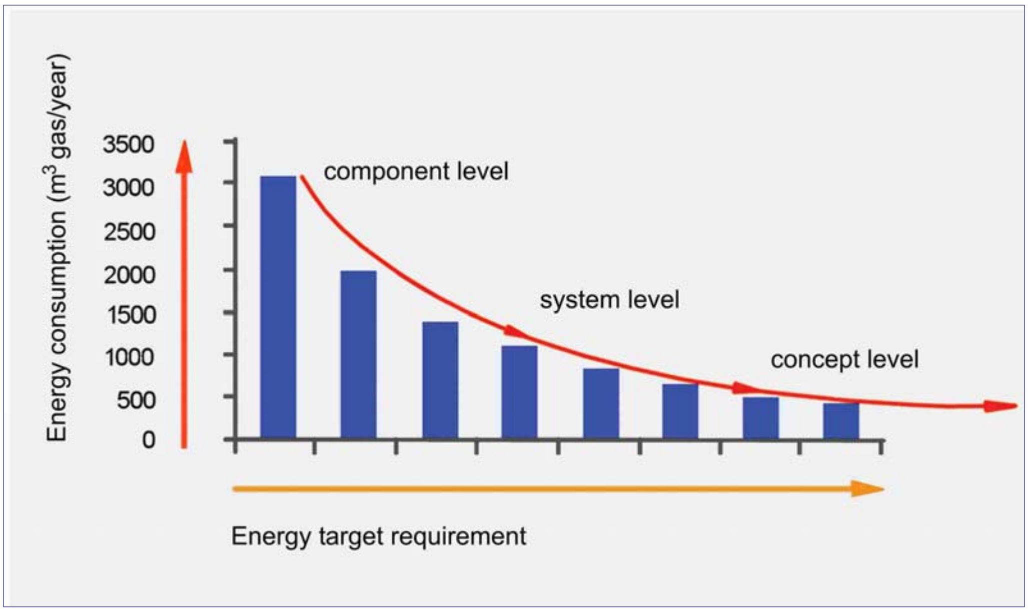


Figure 4-1 Increasing energy demands

With the integration of responsive building elements and building services, building design completely changes from designing individual systems to designing integrated building concepts.

The building concept

Building concepts in the context of this booklet are design solutions in which an optimal environmental performance is realized in terms of energy performance, resource consumption, ecological loadings and indoor environmental quality. The 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 developed by an integrated multidisciplinary design process.

An integrated building concept includes all aspects of building construction (architecture, facades, structure, function, fire, acoustics, materials, energy use, indoor environmental quality, etc). It can be defined with three parts:

- the architectural building concept,
- the structural building concept and
- the energy and environmental building concept

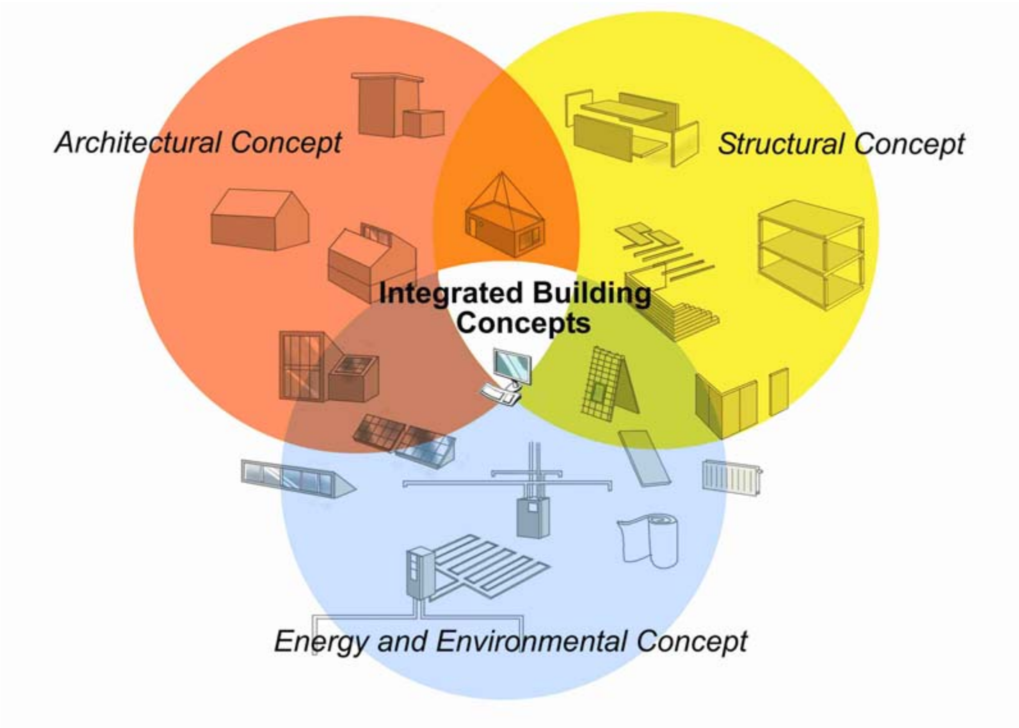


Figure 4-2 Integrated building concepts

This corresponds to the professions involved in the building design and each concept is developed in parallel by the three professions using their own set of methods and tools - but in an integrated design process leading to an integrated solution.

The integrated design process

A building concept can only be developed by an integrated design approach.
Design teams, including both architects and engineers, are formed and the building design is developed in an iterative process from the conceptual design ideas to the final detailed design. Energy use in the building and HVAC equipment size are reduced without the use of sophisticated technologies, but only through an effective integration of the architectural and HVAC designs. The integrated design approach achieves this improved energy utilization through the relationship between the building, its architecture and the HVAC equipment. Besides this, the integrated design approach also achieves an improvement in the environmental performance of the building, as well as fewer construction problems and lower costs.
In a sequential design process, the engineer at the later stages of design more or less acts in a reactive way and thus corrects the architectural design. The risk of poor design concepts being developed are therefore higher. There are a number of serious consequences if proper decisions are not made at the conceptual design stage. The building will almost certainly cost more to build and operate (e.g. it often takes huge air conditioning equipment and much energy to compensate for poor orientation, window placement etc.). The cost is not only in terms of money, but also in the depletion of non-renewable resources, in the degradation of the environment and also often in poorer building performance in terms of comfort. Inefficient buildings contribute significantly to pollution and the greenhouse effect, which is likely to negatively alter life on earth.
An integrated design process ensures that the knowledge and experience gained by an analytical consideration of design is formalized, structured and incorporated into the design practice.
In the integrated design process, the expertise of the engineers is available from the very beginning at the preliminary design stage and the optimization of the architectural and HVAC designs can start at the same time as the first conceptual design ideas are developed. The result is that participants contribute their ideas and their technical knowledge very early and collectively. The concepts of energy and building equipment will not be designed complementary to the architectural design, but in a very early stage as an integral part of the building.

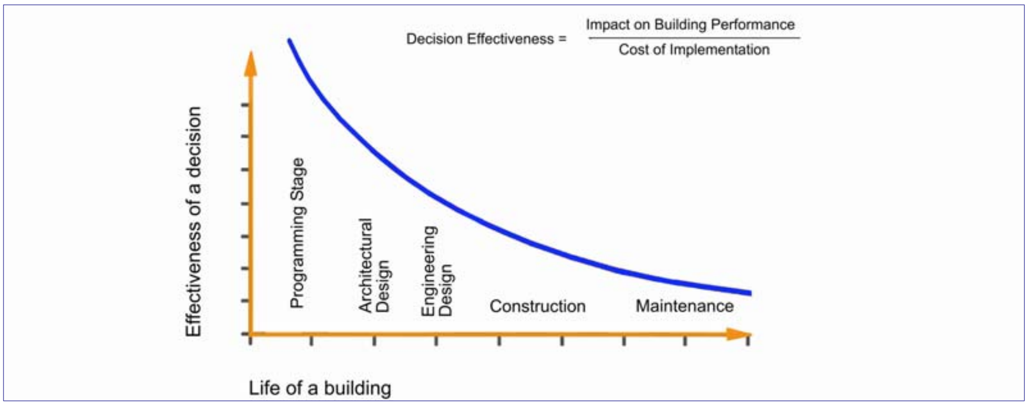


Figure 4-3 Effectiveness of decisions made in different phases of a building's lifetime

Implementation barriers

A number of barriers appear when the borderline between architecture and engineering is crossed.

Architects belong to the humanistic arts tradition while the engineer belongs to a technical natural science tradition. This often creates problems for architects and engineers working as a team as the communication between the two groups rely on a common language and in this case the languages are very different at the outset.

The integrated design process is a holistic method that intertwines knowledge elements from engineering with the architectural design process to form a new comprehensive strategy to optimize building performance. This implies evaluation and weighting of very different building performance characteristics that often are non-comparable, which requires willingness from all participants to reach acceptable compromises.

The goal of integrated design is an improved and optimized building performance for the benefit of the building owner and the occupants. Changes in design process and methods will require investment in education and will always be more expensive for the designers in the beginning. Therefore, it cannot be expected that architects and engineering consultants will be the main drivers for these changes unless the building owners and clients recognize the benefits and are willing to contribute to the investments needed to implement the changes.

Design strategy

Boundary conditions

As in the classical design approach, a sustainable design should start with a thorough analysis of the environmental conditions and determine the beneficial environmental design conditions like location of the building, sheltering, optimal orientation, solar and wind optimization and protection, ground coupling possibilities, etc. This mostly takes place in relation to the architectural and esthetical design considerations, but is the first step in achieving a more energy saving design.
Next to this, comfort requirements and IAQ need to be considered. Fixed and uniform conditions as stated in the last decades can be transformed in adaptive conditions relating to the place, function, time and activity in the building. Also, the consideration to follow local climates can lead to a large energy saving potential.

Technical solutions

In order to reach an integrated technical design solution and to develop an Energy and Environmental Building Concept, it is necessary to define and apply a certain design strategy. In Annex 44, the design strategy is based on the method of the Trias Energetica method described by Lysen (1996). This Trias Energetica approach has been extended in the Annex 44 work with technologies that will be applied, depending on the design step.

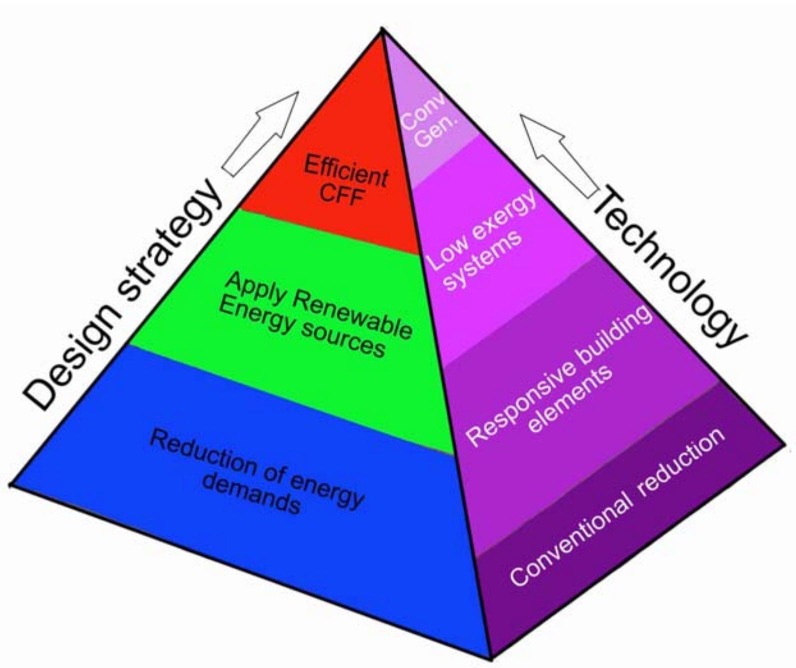


Figure 4-4 Illustration of Annex 44 Design Strategy and corresponding technologies. CFF: Clean fossil fuels.

The left side of the pyramid shows the design strategy, and the right side shows the technical solutions in each of the steps. The figure clearly positions the responsive building elements as a technology that falls in the first step “Reduction of energy demands” as well as in the second step “Apply renewable energy sources”.
An integrated design strategy starts at the bottom of the pyramid and applies the strategies and technologies as follows:

Step 1. Reduce energy demand
Optimize building form and zoning, apply well insulated and air tight conventional envelope constructions, apply efficient heat recovery of ventilation air during heating season, apply energy efficient electric lighting and equipment, ensure low pressure drops in ventilation air paths, etc.
Apply Responsive Building Elements if appropriate including advanced façades with optimum window orientation, exploitation of daylight, proper use of thermal mass, redistribution of heat within the building, dynamic insulation, etc.

Step 2. Apply renewable energy sources
Provide optimal use of passive solar heating, day lighting, natural ventilation, night cooling, earth coupling. Apply solar collectors, solar cells, geothermal energy, ground water storage, biomass, etc. Optimise the use of renewable energy by application of low exergy systems.

Step 3. Efficient use of auxiliary energy
If any auxiliary energy is needed, use the least polluting fuels in an efficient way, e.g. heat pumps, high-efficient gas fired boilers, gas fired CHP-units, etc. Provide intelligent control of the system including demand control of heating, ventilation, lighting and equipment.

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.

Application of the design strategy

A roadmap for application of the design strategy in the various design stages is given in the next table 4-1. The heating, cooling, lighting and ventilation design of buildings always involve all steps when it is consciously recognized as in an integrated design process that each of these steps is an integral part of the heating, cooling, lighting and ventilation design, better buildings result.

	Heating	Cooling	Lighting	Ventilation
Step 1	*Conservation*	*Heat Avoidance*	*Day lighting*	*Source Control*
Basic Design	1. Surface to volume ratio 2. Zoning 3. Insulation 4. Infiltration	1 Façade Design 2.Solar Shading 3.Insulation 4.Internal heat gain control 5.Thermal mass	1.Room height and shape 2.Zoning 3.Orientation	1. Surface material emission 2. Zoning 3. Local exhaust 4. Location of air intake
Step 2	*Passive Heating*	*Passive Cooling*	*Daylight Optimization*	*Natural Ventilation*
Climatic Design	1. Direct solar heat gain 2. Thermal storage wall 3. Sunspace	1.Free cooling 2.Night cooling 3.Earth cooling	1.Windows (type and location) 2.Glazing 3.Skylights, light-wells 4.Light shelves	1. Windows and openings 2. Atria, stacks 3. Air distribution
Step 3	*Application of Responsive Building Elements*	*Application of Responsive Building Elements*	*Daylight Responsive Lighting Systems*	*Hybrid Ventilation*
Integrated System Design	1. Intelligent facade 2 Thermal mass activation 3. Earth coupling 4. Control strategy	1. Intelligent facade 2 Thermal mass activation 3.Earth coupling 4.Control strategy	1 Intelligent façade 2.Interior finishes 3.Daylight control strategy	1. Building integrated ducts 2. Overflow between rooms 3. Control strategy
Step 4	*Low Temperature Heating System*	*High Temperature Cooling System*	*High Efficiency Artificial Light*	*Low Pressure Mechanical Ventilation*
Design of Low Exergy Mechanical Systems	1 Application of renewable energy 2. Floor/wall heating	1.Application of renewable energy 2.Floor/wall cooling	1.LED	1. Efficient air distribution 2. Low pressure ductwork, filtration and heat recovery 3. Low pressure fan
Step 5	*Heating System*	*Cooling System*	*Artificial Lighting*	*Mechanical Ventilation*
Design of Conventional Mechanical Systems	1. Radiators 2. Radiant panels 3. Warm air system	1.Cooled ceiling 2.Cold air system	1.Lamps 2.Fixtures 3.Lighting control	1. Efficient air distribution 2. Mech. exhaust 3. Mech. ventilation
Step 6 Intelligent Control	Advanced sensor techniques, model based and adaptable control algorithms, user interface, ….			

Table 4-1 Typical design considerations at each design phase

Step 1: Basic design focusing on reduction of energy demands

In the first state of the design, the focus is primarily on the reduction of demands for heating, cooling, lighting and ventilation by means of reducing internal heat loads and optimization of day lighting and reducing the heating, cooling and ventilation energy.

The priority here is the reduction of internal and external heat loads. The internal heat loads can be reduced by the use of energy saving equipment as computers, copiers etc. and by installing energy saving electric lighting. The most effective method here is maximizing the daylight autonomy of rooms and thus reducing the energy use for electric lighting. As the efficacy of daylight is much higher that artificial light this counts for both reduction of electric energy consumption in lighting as for reducing the energy consumption in cooling.

The next step is to find an optimum in reducing the heating and cooling gains by an optimal surface to volume, ratio, zoning, shading, insulation level and a demand controlled ventilation level. A special effort is required when applying long term heat storage. In that case, heating and cooling gains over a year need to be tuned to each other to avoid long term imbalance.

Decisions at the first step determine the size of the heating, cooling and lighting loads and reliable fabric design is essential for minimizing the need for services. Poor decisions at this point can easily double or triple the size of the mechanical equipment needed. Where appropriate, designs should avoid simply excluding the environment, but should respond to factors like weather and occupancy and make good use of natural light, ventilation, solar gains and shading when they are beneficial.

It should be possible to modify the design at an early stage in order to reduce the capacity, size and complexity of the building services, which can reduce the capital cost of the services without having to remove features from the design.

Step 2: Climatic design through optimization of passive technologies

The second step involves optimization of natural and “free” gains from sun, wind and thermal storage through application of direct solar gains, free cooling, thermal mass and natural ventilation. Effective functioning of these measures directly relates to the outdoor climate as available wind and sun conditions, day-night rhythm and earth temperature.

Proper decisions at this point can greatly reduce the loads as they were created during the first step leading to the wanted reduction in size and complexity of the building services.

Step 3: Integrated system design and application of responsive building elements

Step 3 contains the design of integrated systems with responsive building elements. In this step, the activation of building elements by building services enhances the further employment of building components. Energy gains in building elements are actively controlled by changing and influencing the physical behaviour and properties of the building components. Examples of the performance of these responsive building elements are described further in chapter 3.

Step 4: Design of low exergy mechanical systems

In order to realise the comfort conditions required, mechanical systems for heating, cooling, lighting and ventilation are applied to handle the loads that remain from the combined effect of the previous steps. Priority lies with low exergy mechanical systems in order to enhance the application of renewable energy sources. This involves the energy generation part, the energy distribution part and the energy delivery part of the mechanical systems. A tuning of generation, distribution and delivery is, therefore, crucial to reach an efficient and optimal performance.

Step 5: Efficient design of conventional mechanical systems

Step five consists of designing the (conventional) building services. Herewith it is important to ensure that the services operate in harmony without detrimental interaction or conflict. Many energy problems can be traced to a conflict between building services, and many conflicts between services are control issues. An energy efficient design strategy should avoid this and the underlying reasons for conflict should be identified and eliminated to prevent carrying a flawed design forward. It is not a good policy to hope that the control system will resolve the conflicts.

Step 6: Design of intelligent control for optimized operation

The intelligent control of the energy transport is crucial in order to come to a proper and efficient operation of the building, building services and renewable energy systems and to reach optimal energy efficiency. The systems, therefore, need to be fed with the design considerations and must be able to tune to the different external and internal climate conditions and the comfort requirements of the building occupants. Advanced sensor techniques together with sophisticated control algorithms are still under development and need further improvement which is also the case for interfaces for user control and user/system interaction.

Example for illustration

Example of integrated design approach.

The importance of a comprehensive approach to energy utilisation is illustrated by a parametric study conducted for the design of a new office building in Copenhagen, where the influence of the glazing area relative to the total facade area on primary energy consumption was modelled. Any increase in the glass area facing east or west resulted in increased heating or cooling demands. The obvious conclusion based on this condition alone would be to minimise the glass area. Conversely, increasing the glass area to 45% of the facade area strongly decreases the electricity demand for lighting. When primary energy demand for heating, cooling and lighting are considered together, then increasing the glass area to 40% of the facade area results in increased total energy savings, see figure 4-5. The savings in electricity from day lighting have a dominant influence because of the assumption that thermal energy is produced with an efficiency of 67% versus an efficiency of 27% for energy in the form of electricity. It should be emphasized that the conclusions will always be case specific as they depend on the specific climate, the type of energy production and distribution, the type of glazing, etc.

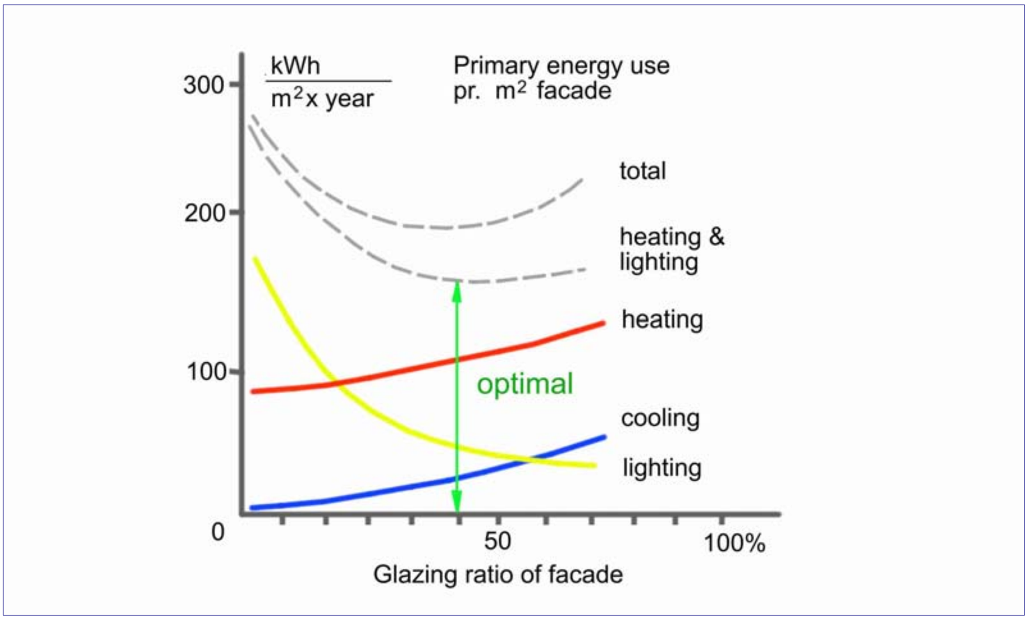


Figure 4-5 Primary energy use per m2 double glazed windows facing east or west in Copenhagen/Krestensen and Esbensen

The Annex 44 integrated design process

The iterative process

The Annex 44 integrated design process (IDP), creates a synergy of competencies and skills throughout the process by the inter-disciplinary work between architects, engineers, and others right from the beginning of the process. It ensures that different knowledge of specialists is introduced at an early project phase and takes into account a wide variety of opportunities and options from the very outset. It involves modern simulation tools, and leads to a high level of systems integration. It enables the designer to control the many parameters that must be considered and integrated when creating more holistic, sustainable buildings. The building design is developed in an iterative process from the conceptual design ideas to the final detailed design.

It is important to consider the whole process, structuring it into clearly defined sequences to improve the overview of goals, activities, actors and products and to switch between them. The intermediate workflows in each rough phase can be characterized by iteration loops.

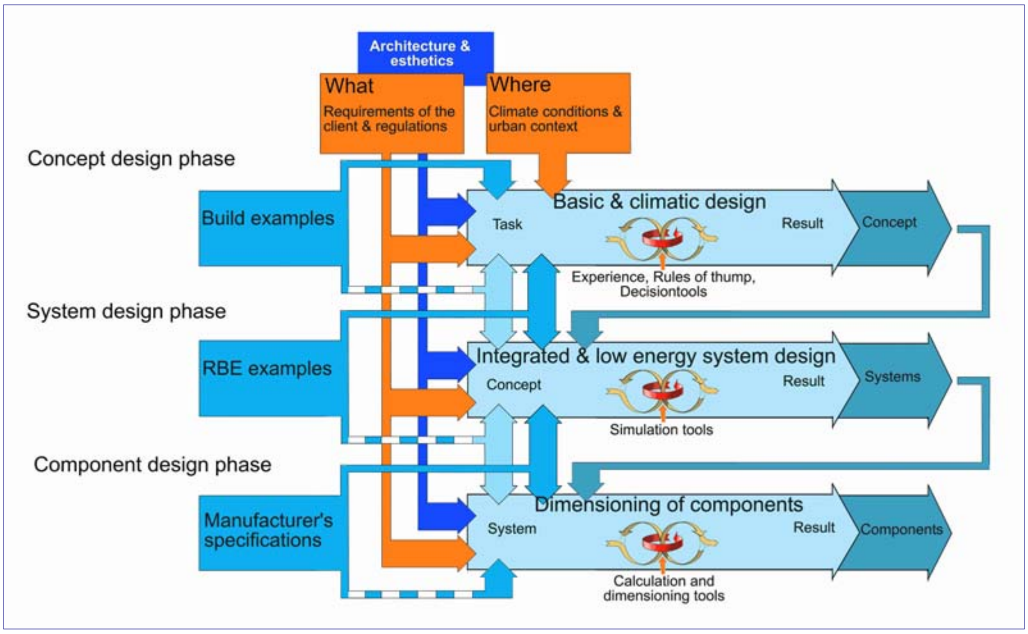


Figure 4-6 Design Process of Responsive Building

It is important to consider the whole process and structuring it into clearly defined sequences to improve overview of goals, activities, actors and products and to switch between the sequences. The intermediate workflows in each rough phase can be characterized by iteration loops.

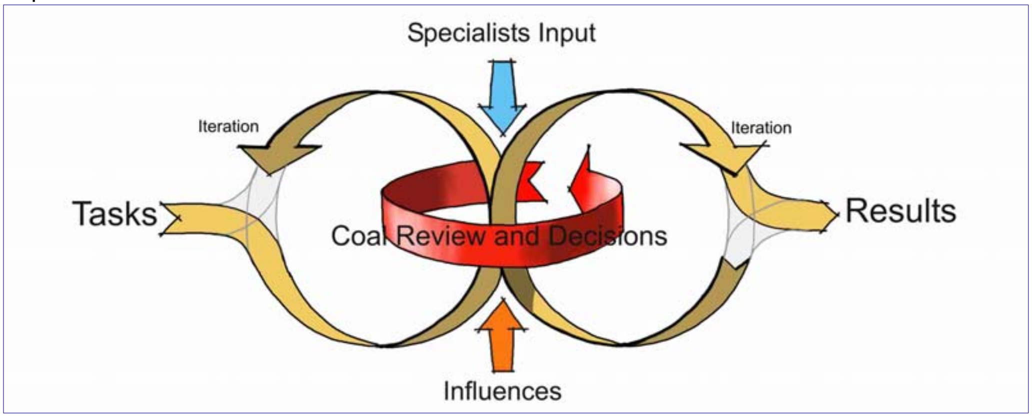


Figure 4-7 Iteration loops in the design process stages

The loops provide problem-oriented analyses of design alternatives and optimization based on the design strategy presented in Figure 4-8 a t/m c (separated figures from figure 4-6), and taking into consideration input from other specialists, influences from context and society that provide possibilities and/or limitations to design solutions as well as evaluates the solutions according to the design goals and criteria.
The actual design process is made up of a number of roughly-defined phases, which demand individual iterations within the phases, and is accompanied by a continuous review of project goals, objectives and criteria, which serve as a “roadmap” throughout the entire design process.

Main design phases

The Annex 44 integrated design process includes the following main phases:

Phase 1: Where to build and what to build;
The climate characteristics of the building site are essential to understand for responsive building design. The climate data is useful not only for estimating the heating and cooling load of the building, but also for creating passive design concepts.
Analysis of the site potential; including wind, sun and landscape, urban development plans, analysis of clients’ profile and chart of functions, create a roadmap of energy system principles, renewable energy systems, indoor environment and construction solutions. The outcome is an analysis of the context, site and building design potential and a road map of possible design strategies.

Phase 2: Development of design concept

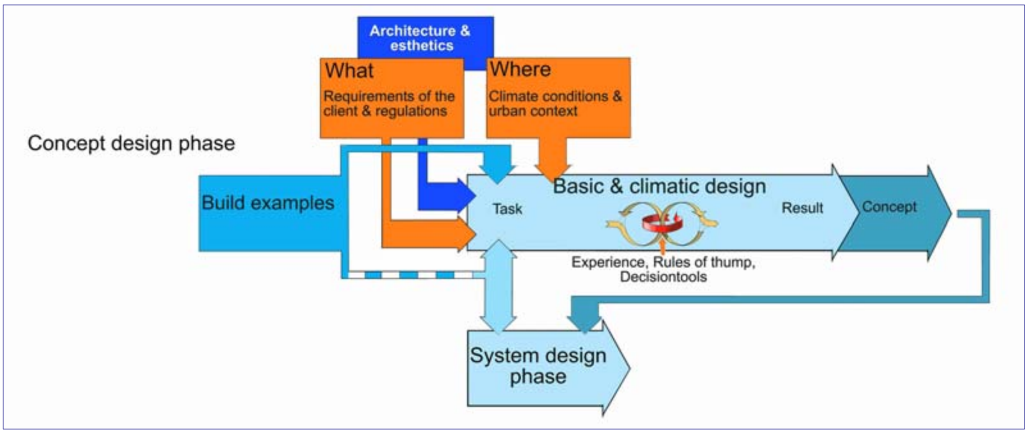


Figure 4-8a

During the sketching process, architectural ideas and concepts, functional demands as well as principles of construction are linked to energy and environmental building concepts and indoor environment through application of the design strategy. Different conceptual design solutions are developed and their relative, estimated merits are continuously evaluated, including architectural qualities, with the goals in the building design brief. The outcome is an integrated building concept.

Phase 3: System design and preliminary performance evaluation

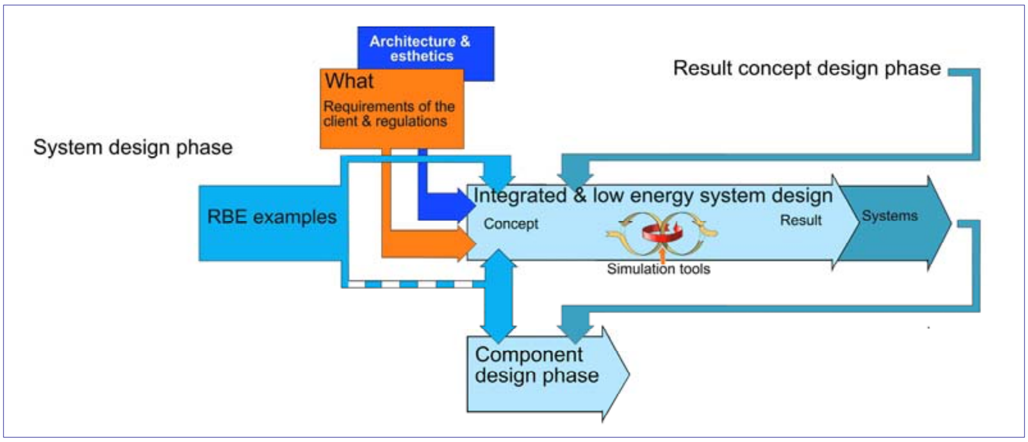


Figure 4-8b

In the system design phase, the building concept develops into specific architectural and technical solutions and systems through sketches, additional calculations and adjustments. Architectural, space and functional qualities, the construction and demands for energy consumption and indoor environment converge in this phase. The basic building form and its site location are determined after a series of functional analysis, design strategy step 1. At the same time by applying step 2-4 in the design strategy, a frame of responsive design is built considering various ideas of integration of passive and active systems as reflected in the design concept explicitly with consideration of RBEs and renewable energy technologies.

Phase 4: Component design

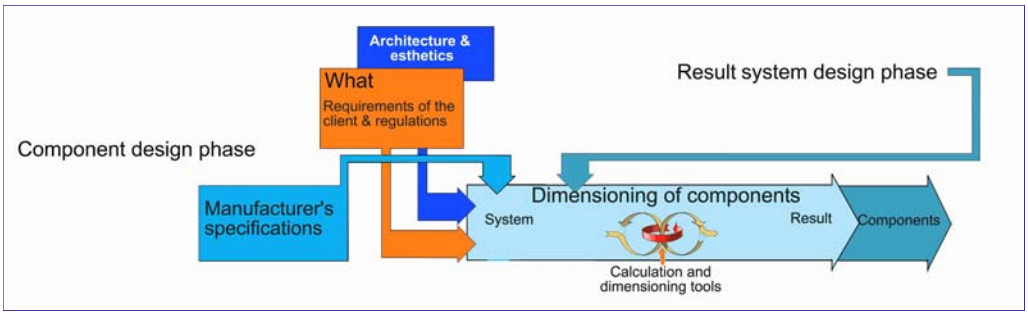


Figure 4-8c

In this phase after the performance of system design is confirmed, the final design will be completed. Here, technical solutions are refined and design documents are created including final drawings and specifications in cooperation with building companies, suppliers and product manufacturers. The outcome is a comprehensive description of the entire project.

Phase 5: Operation and management
As mentioned previously, many energy problems can be traced to a conflict between building services, and many conflicts between services are control issues. An energy efficient design strategy should overcome this and the underlying reasons for conflict should be identified and eliminated to prevent carrying a flawed design forward.

Design methods and tools

In order to facilitate the integrated design approach, different types of design methods and tools can be used which makes it possible to select the most suitable technical solutions for the specific building and context in a strategic way.

Annex 44 Expert guide – Part I describes design methods and simulation tools that can be used for the selection of RBC and the evaluation of RBEs for inclusion in the design. It attempts to classify methods and tools according to Annex 44 RBC design phases and present some examples of developed methods and tools.
The methods and tools enable both qualitative and quantitative evaluation of those techniques and the results can be fed back to the decision on the choice of techniques and their specification. There are different kinds of methods and tools applicable in different phases of the design process and for different kinds of RBEs and other techniques.
Methods and tools suitable for the Annex 44 RBC design phases are:

Phase 1:
The phase *building location and what to be build* requires decision instruments in the form of design process methods. In many countries, green building rating systems have been developed that go beyond the requirements of building regulations and codes and that result in overall indicative quantitative targets for the energy/environmental performance.

Phase 2:
During the phase *design concept* technology prioritisation tools are needed to:

- Facilitate integrated design approach early in the design phase
- Facilitate communication between building services engineers and architects
- Help communication between clients and the design team

Design prioritisation tools are very useful at the early design phase of a building in order to facilitate discussions between clients, designers and engineers before the building design progresses to a phase where systems and technologies cannot easily be changed. Such discussions will lead to decisions on which RBEs would be considered for the building.

Phase 3:
The *system design* phase requires design simulation tools which can be used to evaluate the applicability of the selected RBEs. Such tools should have the capability to take all issues related to energy, climatic and surrounding conditions and residents' lifestyle into consideration.
During the phase *performance evaluation,* energy/environmental simulation tools are required to evaluate the performance of RBEs for the specific building; such tools would be integrated with detailed energy and environmental conditions simulation tools to predict the performance of RBEs for the specific building. If the required performance specified in phase 2 (concept design) is not achieved, then the proposed RBEs need to be reconsidered by going back to the phase 2.

Phase 4:
The phase *component design* requires detailed energy/environmental simulation tools which would be similar to those required for phase 3 in performance evaluation. At this point of the design process, detailed sizing of RBE components is considered together with its integration with all building systems.

Phase 5:
The phase *operation and management* increasingly attracts more attention in terms of energy performance. In Europe, the introduction of the Energy Performance in Buildings Directive (EPBD) requires energy performance certificates to be displayed in public buildings. Energy performance certificates are also required for domestic buildings. Although in many cases, this is based on predicted energy performance. Operational performance is also required and for this integrated monitoring, evaluation tools would be an important addition to the existing design tools.

Design guidance and recommendations

The survey of the case study buildings reported in the state-of-the-art review shows that the following issues need to be addressed in order to realize successful Integrated Building Concepts:

- A special emphasis of the design work from the very beginning of the project, inspired by a committed client and with a dedicated inter-disciplinary co-operation and expert input (energy simulations).
- A need to set specific performance requirements and specification for the different building components and systems, and refer to these during the design and construction process.
- An improvement of design and prediction tools in order to facilitate the design of integrated building concepts.
- The development and optimization of standardized components for responsive building elements.
- Documentation of the performance of integrated building concepts by measurements.
- The development of appropriate design guidelines.

User Guidance and Recommendation.

This part shows what kind of “user guidance and recommendation” has been developed for the integrated design methods and tools. The user guidance and recommendation connects the RBEs developer and the expert in other existing techniques with outside practitioners, who make the decisions. An example of an existing case and the fundamental structure is proposed here.

Example for illustration:

Design Process: Dutch Embassy in Canberra, Australia

In order to illustrate the Annex 44 integrated design process, the newly built chancellery of the Dutch embassy in Canberra, Australia is used as a case study.

The current chancellery is a curved two-storey building from the 1950s built in traditional Dutch style (e.g. brickwork). It is situated in a 7800 m2 green area in the embassy district.

Figure 4-9 Current chancellery of Dutch Embassy in Canberra, Australia

The existing chancellery of the Dutch embassy in Canberra, Australia does not meet today’s standards on functionality, comfort and sustainability. After a study into the possibility of renovation, it was decided to design a new building. The newly-built construction is a round two-storey pavilion with a centrally placed atrium that connects all other surrounding spaces.

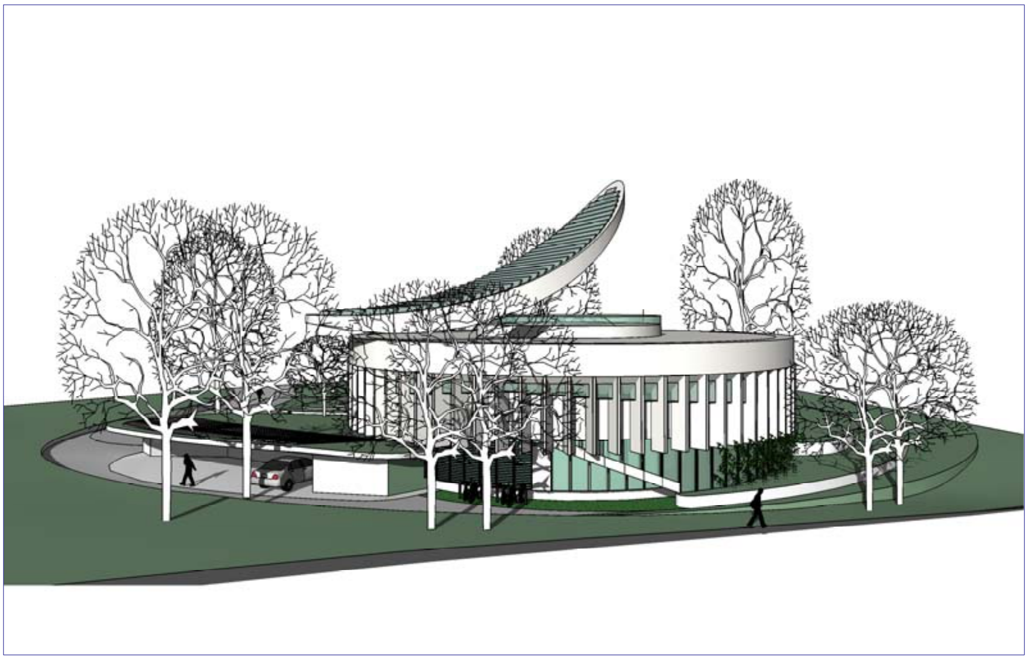


Figure 4-10 Conceptual design of Dutch Embassy in Canberra, Australia [illustration credit: Rudy Uytenhaak Architects]

Phase 1:

Where to build - Building location

Knowledge of climate characteristics of the building site is essential in order to define the starting points in the design of responsive building concepts. Notion of these characteristics provide insight into the potential energy flows that can be harvested on-site and therefore the possible effective (passive) design solutions.

The following parameters are relevant in a climatic context:

- General climate
- Ambient temperature
- Humidity
- Sun path and radiation levels
- Wind patterns
- Precipitation and evaporation
- Soil and vegetation
- Urban context

Canberra is located in the south western part of Australia and has a relatively dry, continental climate with warm to hot summers and cool to cold winters. In January, the warmest period of summer, the average daily extremes in temperature are 13.0 ˚C to 27.7 ˚C. July, the coldest period in winter, has average daily extremes of 11.2 ˚C and -0.2 ˚C. Because of its inland location, humidity in Canberra is quite low at around 37-40% in summer (at 3pm).

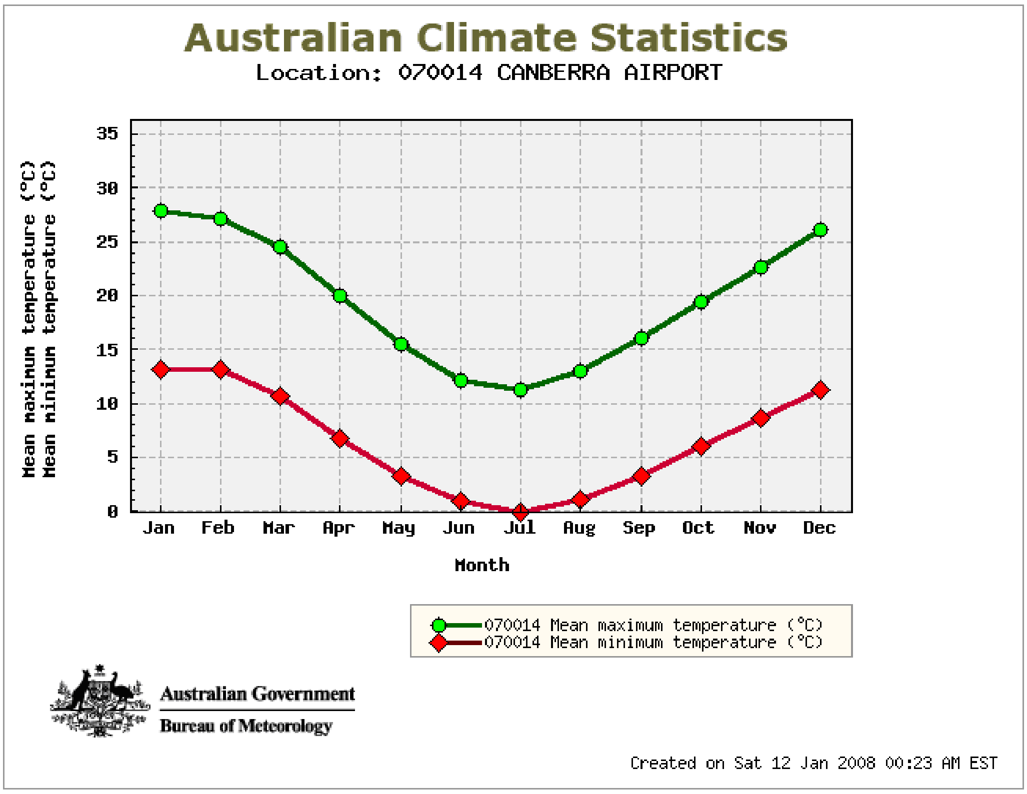


Figure 4-11 Average minimum and maximum temperatures throughout the year

As Australia is located at the southern hemisphere, the sun travels from east to west and peaks out in the north. Canberra is very sunny. On average, there is 7.6 hours sunshine per day, ranging from 5 to 6 hours in winter to 9 hours in summer. The average solar radiation is 17.5 MJ/m^2, ranging from 8.2 MJ/m^2 in June to 26.4 MJ/m^2 in January. The highest solar altitude of 79 ˚ is reached in Australian summer and the lowest solar altitude of 32 ˚ is reached in winter (see sun path diagram).

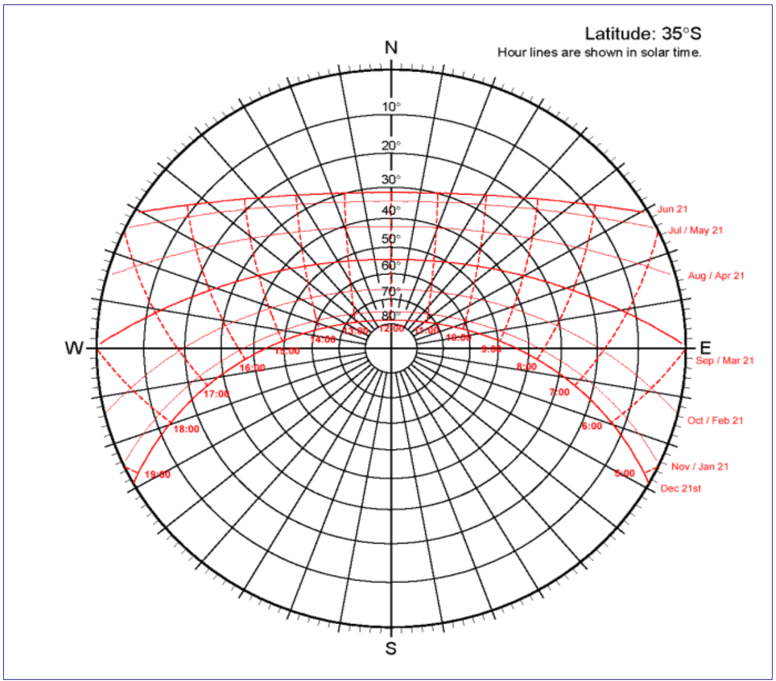


Figure 4-12 Stereographic sun-path diagram Canberra (35 S) [source:www.luxal.eu]

Canberra is not very windy. The prevailing wind direction is northwest. During the summer period, western and eastern winds occur during reasonable parts of the day. The north western and western winds carry dry hot desert air in summer and cold air during the winter and night-time.

The average annual rainfall is 629 mm with an average of 108 rain days a year. The rainfall is evenly distributed throughout the year with 65.3 mm in October and 39.6 mm in June. Average annual evaporation in Canberra is 1677 mm, however this can range from around 8 mm/day in summer to as low as 1-2 mm/day in winter.

The thin top layer of the Canberra soil consists of coarse, grained sand. Below 15 to 30 cm, the soil becomes more clayish. This type of soil can easily erode on sloped land. The urban area of Canberra is stripped from its natural vegetation, but to the mountains in the southwest most of it still exists.

Location

The embassy grounds measure 7800 m^2 which house the current chancellery and the private house of the ambassador. The chancellery is situated in a green area which contains many trees.

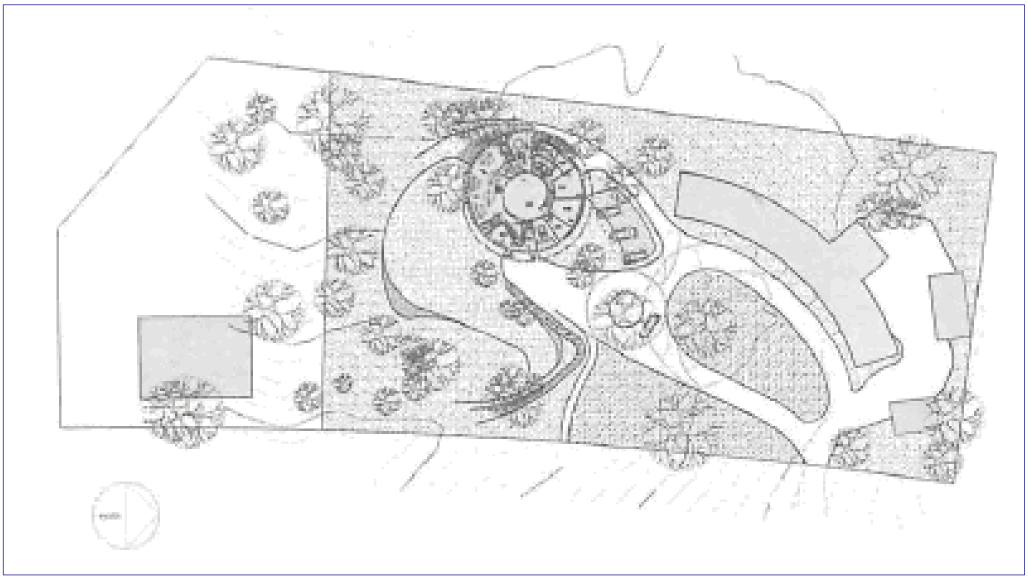


Figure 4-12 Site plan of the proposed Dutch Embassy in Canberra

Considerations for the building design

- Canberra has relatively warm summers and cool winters. The somewhat large diurnal and seasonal variations in temperature allow for passive cooling techniques such as night-time ventilation and earth coupling.
- The air in Canberra is relatively dry. Therefore, the design should take humidity control into account, preferably from passive means such as water bodies, vegetation or from air cooling through embedded ducts.
- The high air temperatures in summer call for measures to reject all solar radiation from entering the building during the time in which the building is occupied. On the contrary, during the winter, all solar radiation is welcome. In spring and autumn, solar radiation from certain sun angles is undesired.
- Daylight control is necessary throughout all times of the year to prevent hindrance in indoor temperatures.
- Prevent the negative effects from the north western winds by either adverting the wind flows or preliminary treatment.
- The temperate eastern winds are welcome.
- Use a rainwater catchment and storage system for flushing toilets and include water-saving measures throughout the building.
- Careful consideration of terrain and vegetation is necessary in order to prevent soil erosion.

What to build – building brief

This stage includes definition of design goals, objectives and criteria as well as preliminary feasibility studies. In this phase, the building type and the proper size of the building are discussed, taking surrounding conditions into consideration.
Analysis of site potential including wind, sun and landscape, urban development plans, analysis of clients profile and chart of functions create a roadmap for the indoor environment, energy system principles, renewable energy systems and structural solutions.
The following parameters are relevant in this context:

- Spatial requirements
- Sustainability requirements
- Functional requirements

Spatial requirements

- Embassy building which can employ 20 people.
- The building includes 800 m2 of office and meeting spaces.
- Allow for the future possibility to combine another department from Sydney.

Sustainability requirements

- Added focus on sustainability.
- High priority on the preservation of existing trees.

Functional requirements

- Industrial, Flexible and Demountable (IFD) construction techniques with a light footprint.

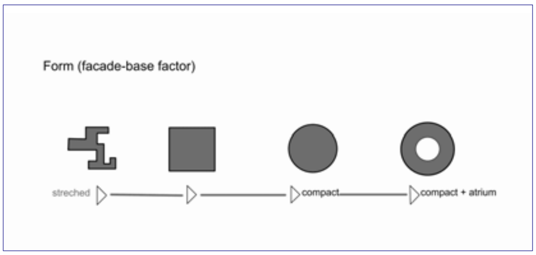
Phase 2

Development of design concept

As a starting point, two values were expected in the initial design concept: an 'installation-less building' with indoor conditions that maintain 'forever spring'. This resulted in a compact building with an atrium. The atrium is the central place of the building which functions as the main component for indoor climate control. The neighbouring zones are kept comfortable due to their connection to the atrium. To ensure comfortable temperatures and daylight levels throughout the seasons, the roof of the atrium is provided with a horizontal screen that controls the amount of solar radiation to suffice the needs. The decisions led to this concept as explained below.

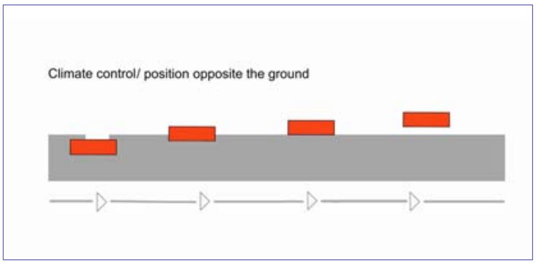
Heating and cooling strategy

Initial conceptual design studies include the impact of some relevant design parameters on the heating and cooling strategy; building shape, position of building volume with respect to the surface grade and the conceptual envelope design. The following figures show the different options that were considered.



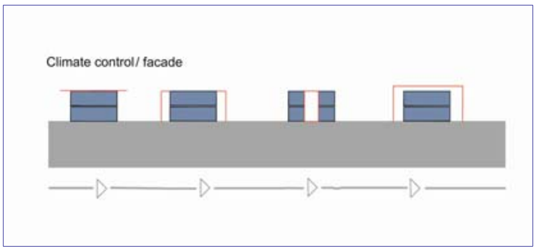
Compactness of the building layout

Compact building design minimises facade area in relation to a given volume and, therefore, it minimises initial heat losses. However, when compact volumes get too large, the innermost areas become cut off from the outdoor environment. This can be solved by the inclusion of an atrium.



Position of building volume with respect to surface grade.

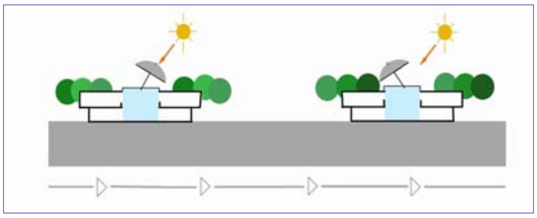
The earth's large thermal storage capacity can be used for tempering large daily and seasonal variations in the climate. The building volume can be fully or partly buried. Alternatively, the building volume can be elevated to allow passive cooling from air flows.



Conceptual envelope design. The building form and envelope can be used as an intermediate between the outdoor and the indoor environment to establish acceptable indoor environmental conditions.

Sunshade concept

In order to maintain spring conditions, the architect proposed a rooftop mechanism that functions as a parasol / solar mill. It shades the atrium from the sun to prevent overheating and can be turned away in cold periods to enable passive heating strategies.



Parasol / solar mill

The concept of the parasol functions as a sun shading device during the warmer periods and allows solar radiation to enter the building in colder periods.

Phase 3:

System design and preliminary performance evaluation

Figure 4-14 Final sketch plan

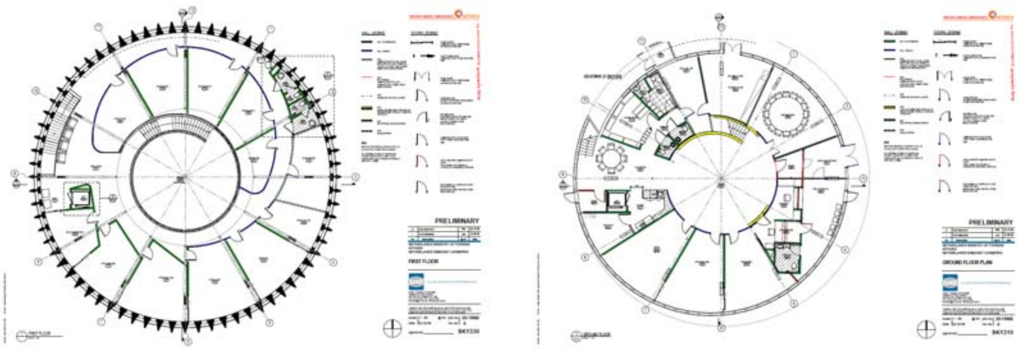


Figure 4-15 Ground floor and first floor

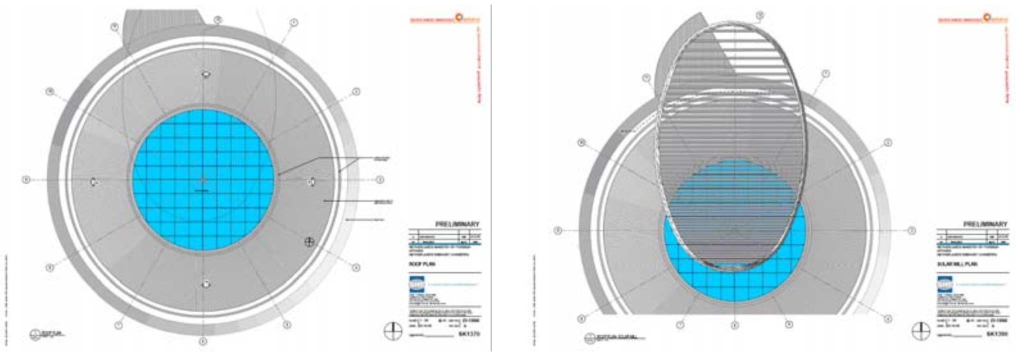


Figure 4-16 Roof plan and solar mill plan

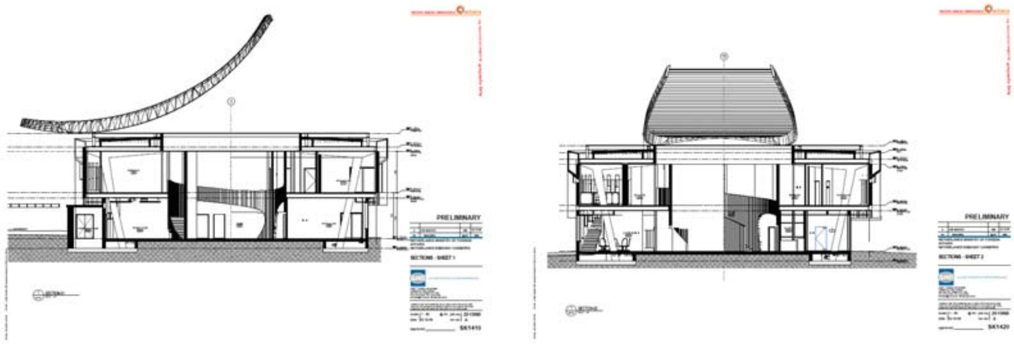


Figure 4-17 Cross sections

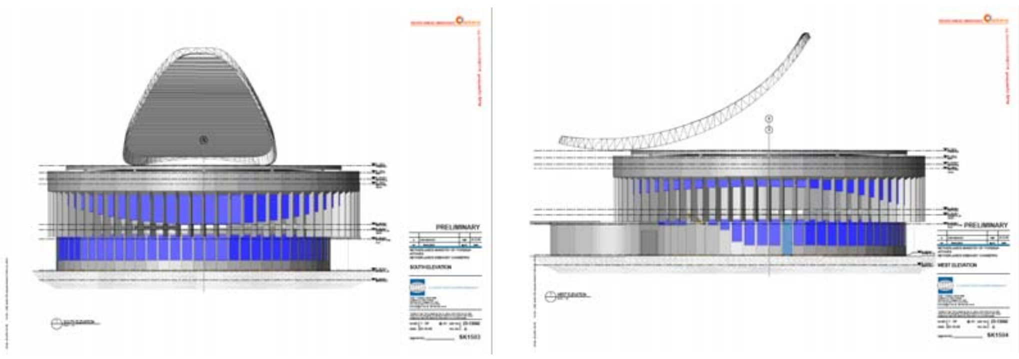


Figure 4-18 South and west elevation

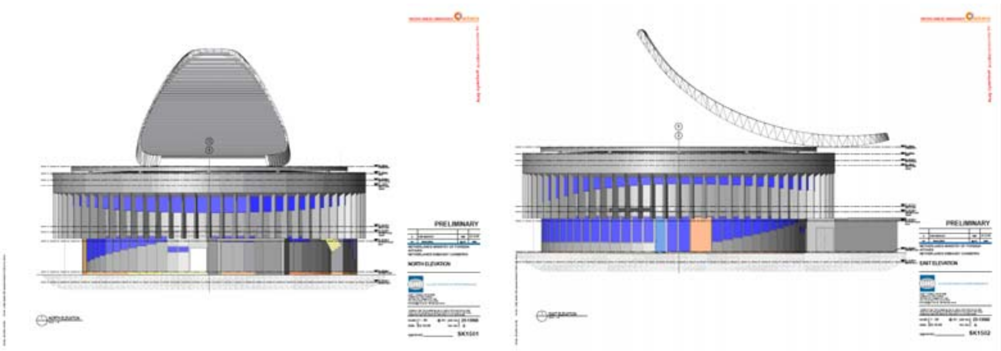
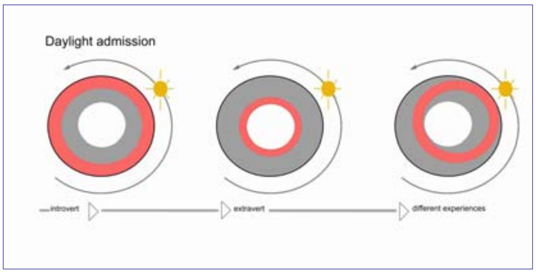


Figure 4-19 North and east elevation

Zoning

Through zoning, different spaces with identical comfort needs are grouped and placed within the building layout according to energy provided from the local climate.

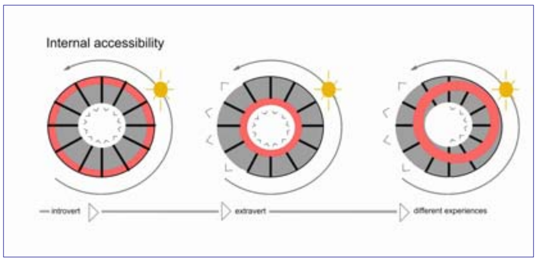


Internal accessibility

The corridor can be placed on the inside or on the outside of the perimeter of the building. An alternative is the placement of the corridor towards the sun in order to use the corridor as a buffer space. By doing so, the habitable rooms do not experience increased direct solar radiation levels during the middle of the day.

Daylight admission

Energy performance estimations on the preliminary design concept showed significant energy demands for lighting. Therefore, it was decided to optimise the use of natural light to minimise the needs for artificial lighting. In conformity with the zoning discussed earlier, a strategy for daylight admission can benefit from the same concept.

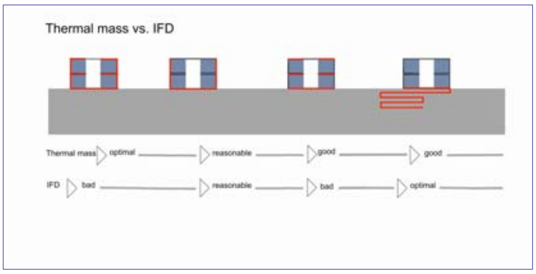


Daylight admission

The presence of the atrium and the use of the corridor as a buffer space still allow sufficient illumination from natural light.

Thermal mass vs. IFD

Massive building elements (e.g. stone, concrete) have the capacity to store large amounts of thermal energy; tempering fluctuations in temperature. On the contrary, massive buildings are less flexible to adjustments and require more effort during the demolition phase. This is in conflict with the requirement from the client to implement the (IFD) building concept.

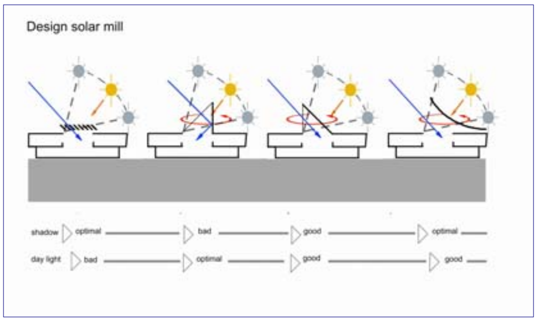


Thermal mass vs. IFD

The use of massive building elements is not in accordance with the IFD building concept. Alternatively, the earth's thermal storage capacity can be used as a substitute to massive building elements. The building construction can be lightweight and, thereby, answers to the IFD concept.

Solar mill development

By controlling the amount of solar radiation, the solar mill also controls the amount of daylight to enter the building. A movable element on top of the atrium is able to change its orientation in order to shade the atrium when needed without interfering with sufficient illumination from natural light.



Solar mill development

The solar mill is designed to rotate about the axis of the building to constantly face the sun and provide shading to the atrium. In terms of energy, the solar mill is the most important feature. Always perpendicular to the sun, its solar panels catch maximum sunlight, generating sufficient power for lighting and computers in the embassy. Furthermore, the outer surface of the windmill is equiped with Photovoltaic cells.

As these cells are always located to the sun, this provides a 30% higher electricity production.

Phase 4

Component design

Additional solar regulation

The solar mill on top of the atrium protects the building from direct solar radiation. At times, the solar gains are too high. An additional textile sunshade can be placed on the inner side of the atrium. This sunshade can be altered and behaves like a diaphragm. In a fully closed state, it also acts as an additional layer of insulation.

External shading.

Shading is also provided by the eaves and the 72 vertical shading elements evenly spaced around the building perimeter. The first floor overhangs part of the ground floor and provides some shading to the ground floor windows. The ground floor windows are assumed to be completely shaded by trees and the like, and are not exposed to any direct solar radiation.

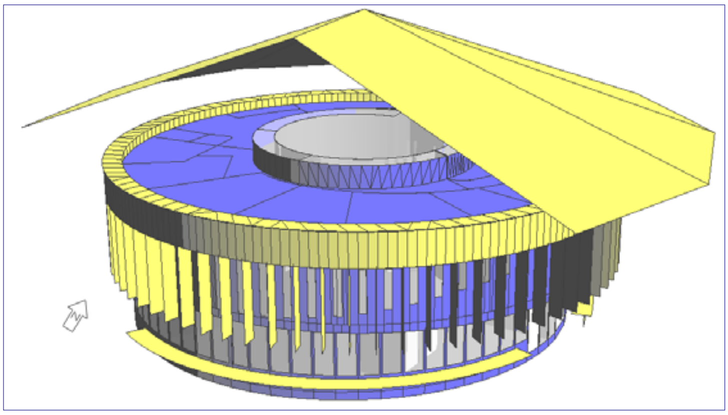


Figure 4-20 IES Model with modified shading from the solar mill [Rudy Uytenhaak Architects]

Both floors have a variable window height over the perimeter of the building. Small windows on the eastern and western side of the building minimise negative impact of low sun angles, and large windows on the northern and southern side allow natural light to enter the rooms concerned.

Mechanical services

The proposed mechanical systems are intended to maintain moderate comfort conditions inside the building whilst being as energy efficient as possible, towards the objective of designing a net zero energy building.

The mechanical services installations for the building consist of several systems:

- **Ground Source Heat Pump System** to supply cool and warm water to the building for the purposes of maintaining comfort conditions. This system uses the stable ground temperatures to provide a heat sink or source;
- **Earth to Air Heat Exchanger System** to temper the incoming outside air. This system uses the relatively stable temperature of the ground to pre-cool or preheat air through series of buried ducts;
- **Passive Heating/Cooling Systems** to control the internal space temperature is achieved via hydronic floor heating/cooling pipes and wall heating/cooling panels;
- **Outside Air Ventilation Systems** that supply tempered outside air to the building to maintain indoor air quality;
- **Exhaust Air Ventilation Systems** to exhaust contaminated air;
- **Building Management System** to monitor and control the operation of the above systems.

Ground Source Heat Pump System Design

The preliminary calculated building peak sensible cooling load is approximately 45 kW (excluding outside air tempering). It is expected that 8-10 ground loops will be required to meet this load. The ground loops will consist of a Ø32 mm pipe loop extending 100 m deep. These loops are installed in a Ø100 mm bore hole and then sealed with grout. Minimum loop separation is 5 m, with a preferred separation of 7-8 m. The loops will be connected by header pipes installed at a depth of 0.6 – 1.0 m. These headers (or 'run outs') return to the external plant enclosure to connectwith the circulating equipment. The final location of the ground loops and the number of run outs required is yet to be determined.

In order to provide redundancy and increased staging ability, it is proposed to provide two heat pumps in a lead/lag configuration, each sized at 75% of the required building peak load. This arrangement allows for increased energy efficiency as only one smaller compressor is required to operate at low load conditions.

Earth to Air Heat Exchanger System

The earth to air heat exchanger requires approximately 400 m of Ø250 mm in ground ducts to provide the required outside air quantity of 775 l/s.

The exchanger has been located outside the building footprint to avoid the structural implications associated with disturbing the ground below the building. It has been located under the area which is to be newly landscaped in order to minimise disturbed area.

The ducts will be buried at depth of 2 m with a fall of 1.5 – 2% to drain condensate to a collector located at the end of the return header.

Passive Heating/Cooling Systems

The pipe work manifolds for each zone will be located in the walls behind access panels. The water flow to the floor and wall systems will be controlled by the BMS to maintain the space temperature within set point.

Outside Air Ventilation Systems

Outside air is supplied to circulation spaces by overflow from the office and other supplied spaces. The atrium has been provided directly with outside air as this area may be used for functions and events.

Outside air will be drawn into the earth to air heat exchanger through an intake tower located above the external plant enclosure. The tower will take air from 3m above ground level, with an incoming air velocity of 2.5 m/s at full air volume.

Air will be drawn from the intake tower through the earth-to-air heat exchanger and distributed into the building by the air handling unit, which is to be located in the external plant enclosure.

Final conditioning of the air will take place in the air handling unit coil. Air will be supplied off the coil at a temperature within the building temperature set point, corresponding to a reset curve dependant on ambient temperature. Cool water is provided from the ground loops, warm water from the heat pump.

Distribution inside the building will be via sheet metal ductwork. Air volume to each space will be varied using variable air volume terminals. Air volume will be controlled by CO_2 sensors located in each space served.

Exhaust Air Ventilation Systems

Exhaust air ventilation is provided to the following rooms: Staff & Public Toilets, Staff Shower, Cleaner's Room and Static Archive. It is yet to be determined whether the technical room and external plant room will require mechanical ventilation.

Australian code requires all exhaust discharges to be separated from outdoor air intakes by a minimum of 6m. Due to this requirement, the exhaust discharges have been reconfigured to discharge all exhaust at roof level, allowing the natural ventilation intakes integrated within the first floor shading fins to be maintained.

It is proposed to interlock the operation of the exhaust systems with motion detectors or light switches within that space as an energy saving measure. Alternatively, fans will run on a time schedule corresponding to the building operating hours.

Each of the fans will communicate with the BMS to receive start/stop signals and report run/fault status.

Building Management System

The building will be provided with a Building Management System (BMS) for the purposes of:

- control and monitoring of mechanical services plant;
- alarm receipt and reporting;
- metering, logging and data retrieval and reporting; and
- interfacing with lift, fire, UPS, generator and security systems.

Controls

Operation of the controls is critical to the success of the project and needs to be carefully managed. The following controls will be used:

- Lighting control for office spaces will be automated using occupancy detection devices.
- Daylight dimming control will be provided for each luminaire.
- Daylight dimming or switching for the atrium and circulation spaces.
- CO_2 control of the ventilation
- The control and management of the ventilation and heating/cooling system combined with the ground coupled duct.

Grey water system

A rainwater collection unit on the roof is connected to the building's grey water system. The water will be stored in underground tanks and supply re-used water for toilet flushing and irrigation. Filtered water is foremost used for gardening (complemented with rainwater collection at the garden). Abundant water can be used for flushing the toilets as well.

Construction

The basis of the construction was the application of sustainable building materials which could be re-used in case of demolition and the incorporation of a high degree of (spatial) flexibility. This is achieved by minimising the amount of columns in the spatial plan.

The main structural concept consists of laminated wooden columns with complementing coupling rods made of steel. The prefabricated wooden boxed floors contribute to the structural stability. The circular beam is also made of laminated wood.

Laminated wood is available locally and has advantages when it comes to re-use. The use of steel is avoided except when its structural properties are beneficial. This is the case with rods that carry tensile loads. Made from steel, the rods can be designed much slimmer than elements made of wood.

Figure 4-20 Structural drawing

5. BUILDING PERFORMANCE PREDICTION

Building performance prediction accuracy

In the design of responsive 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 obtain an optimization of the building performance. When expressed in suitable indicators as primary energy use, environmental load and/or the indoor environmental quality, the building performance simulation provide the decision maker with a quantitative measure of the extent to which the design solution satisfies the design requirements and objectives.

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 – so that the results are reliable and comparable. Traditionally, building performance simulation is based on a deterministic approach. However, to be able to compare different design alternatives against each other, it is also necessary 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.

The different sources for uncertainties can be divided into four different categories:

- Uncertainties in the physical model of the building and its technical systems;
- Uncertainties in the software and the numerical solution of equations;
- Uncertainties introduced by the operator of the software;
- Uncertainties in selection of scenarios and parameter estimation.

The first two categories of uncertainties are dealt with and minimized in the development and validation of the simulation models and software tools, while the latter two are dominating in the application phase.

Uncertainty analysis and sensitivity analysis

An *Uncertainty Analysis* determines the total uncertainty in model predictions due to imprecise, known input variables, while a *Sensitivity Analysis* determines the contribution of the individual input variable to the total uncertainty in model predictions. The sequence of the two analysis methods is quite arbitrary as it is an iterative process, especially for large models, as is the case for simulation of the performance of integrated building concepts.

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. The 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. If so, a sensitivity analysis is performed to identify the most important parameters. These are then defined more precisely and an uncertainty analysis evaluates if the uncertainty has decreased to an acceptable level. If not, the iterative process is repeated until an acceptable level is found and/or the actual level of uncertainty is known. Usually, after the initial screening analysis, it is only necessary to run the process one or two times to reach acceptable results. A number of different mathematical methods for sensitivity analysis can be found in the literature. Based on the available information, the Morris method[10] is evaluated as the most interesting for sensitivity analysis in sustainable building design. A description of this method and examples of application can be found in Annex 44 Expert Guide – Part I.

Benefits and barriers

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 predict a lower potential of passive technologies.

In many cases, evaluation of a design solution is based on a calculation of the thermal comfort expressed by a performance indicator like PPD and/or the number of hours the temperature is higher than a certain value. Due to the complexity of modelling buildings and technical systems and the variation of boundary conditions and possible user scenarios, it is actually irresponsible to base decisions on a single calculation using a single sample of input parameters. An uncertainty analysis gives much more information about the performance and a much better background to make decisions.

The main barrier, however, for application of uncertainty analysis in building performance assessment is the increase in calculation time and complexity.

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 value 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.

[10] Morris, M.D. (1991). Factorial Sampling Plans for Preliminary Computational Experiments, Technometrics, Vol. 33, No. 2, pp. 161 – 174.

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INTERNATIONAL ENERGY AGENCY (IEA)

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 co-ordinates 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 develop and facilitate the integration of technologies and processes for energy efficiency and conservation into healthy, low emission, and sustainable buildings and communities, through innovation and research.

The research and development strategies of the ECBCS Programme are derived from research drivers, national programmes within IEA countries, and the IEA Future Building Forum Think Tank Workshop, held in March 2007. The R&D strategies represent a collective input of the Executive Committee members to exploit technological opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy conservation technologies. The R&D strategies apply to residential, commercial, office buildings and community systems, and will impact the building industry in three focus areas of R&D activities:

- Dissemination
- Decision-making
- Building products and systems.

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 (*)):

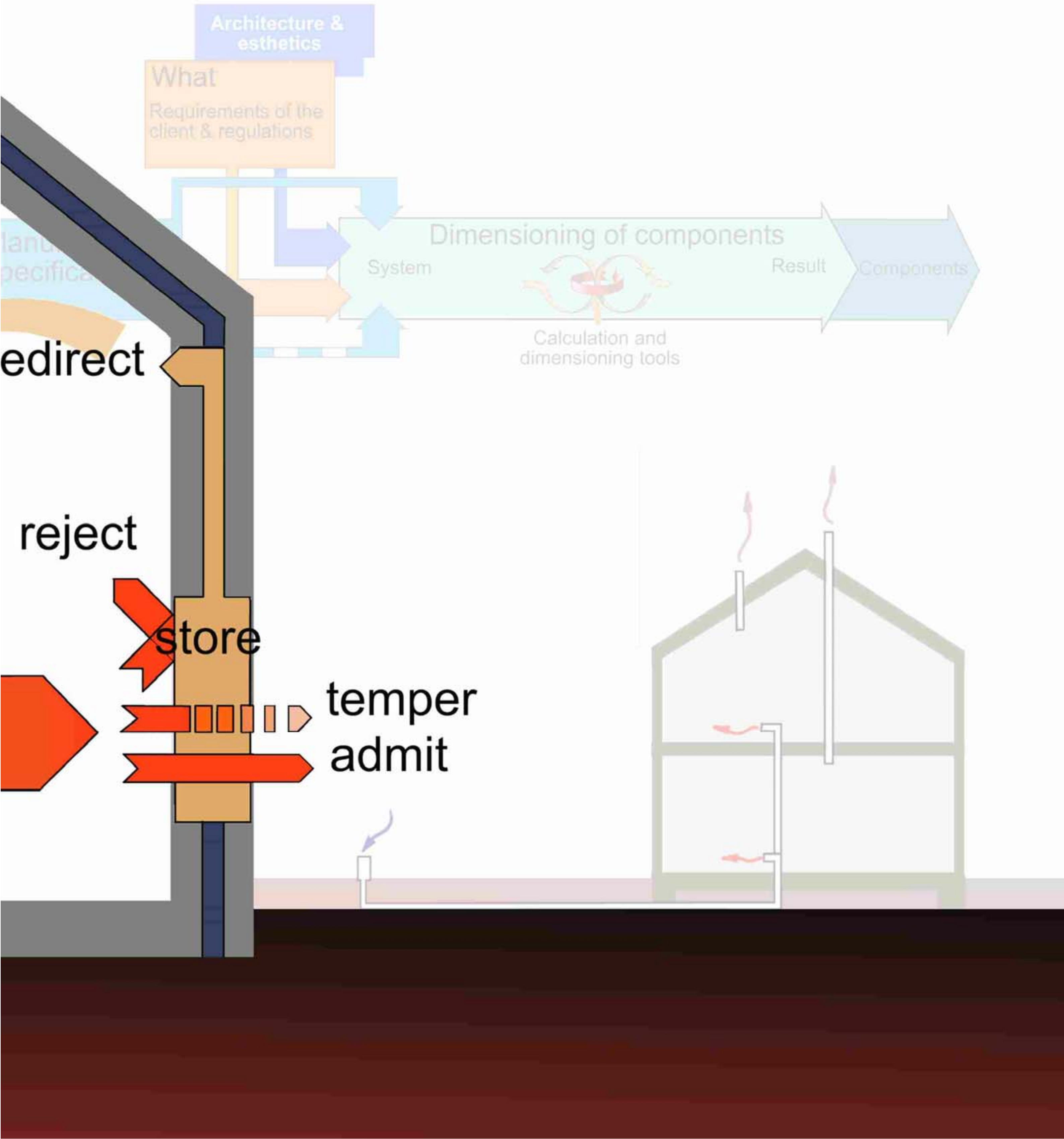
Annex 1: Load Energy Determination of Buildings (*)
Annex 2: Ekistics and Advanced Community Energy Systems (*)
Annex 3: Energy Conservation in Residential Buildings (*)
Annex 4: Glasgow Commercial Building Monitoring (*)
Annex 5: Air Infiltration and Ventilation Centre
Annex 6: Energy Systems and Design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

Annex 8: Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
Annex 13: Energy Management in Hospitals (*)
Annex 14: Condensation and Energy (*)
Annex 15: Energy Efficiency in Schools (*)
Annex 16: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilation Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time HEVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low-exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings
Annex 45: Energy Efficient Electric Lighting for Buildings
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings
Annex 48: Heat Pumping and Reversible Air Conditioning

Annex 49: Low Exergy Systems for High Performance Built Environments and Communities
Annex 50: Prefabricated Systems for Low Energy / High Comfort Building Renewal
Annex 51: Energy Efficient Communities
Annex 52: Towards Net Zero Energy Solar Buildings (NZEBs)
Annex 53: Total Energy Use in Buildings: Analysis & Evaluation Methods
Annex 54: Analysis of Micro-Generation & Related Energy Technologies in Buildings
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance & Cost (RAP-RETRO)

Working Group Energy Efficiency in Educational Buildings (*)
Working Group Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group Annex 36 Extension: The Energy Concept Adviser (*)
Working Group Energy Efficient Communities

(*) - Completed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Dimensioning of components
System
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