THE ROLE OF ADVANCED INTEGRATED FACADES IN THE DESIGN OF SUSTAINABLE BUILDINGS

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1 BACKGROUND

Sustainability issues have been the focus of building design for decades. Major international agreements like the Kyoto protocol have pointed out the importance of reducing energy consumption related CO_2 emissions. It has become obvious that buildings consume a large amount of energy worldwide and thus bear the greatest potential for energy savings.

The OECD project on sustainable buildings for the future identified five objectives for sustainable buildings (John 2005):

- Resource efficiency
- Energy efficiency (including greenhouse gas emissions reduction)
- Pollution prevention (including indoor air quality and noise abatement)
- Harmonization with environment
- Integrated and systemic approaches

Different countries have launched different programs to support the development of sustainable buildings. In Hong Kong, the Chief Executive made clear in his 1999 Policy Address that Hong Kong follows the framework for sustainable development (HKSusDev 2004). The Sustainable Development Department of Hong Kong is working on formulating a Hong Kong specific strategy. The warm and humid climate in Hong Kong demands a specific focus on the appropriate facade design. At the moment, existing regulations give maximum values for thermal heat transfer through the building envelope (EMSD 2006). Comfort criteria are not taken into consideration.

The U.S. Department of Energy has a clear "roadmap" to the Building Envelope design within the next 15 years that is closely linked to other roadmaps that incorporate visions for 2020 on lighting and HVAC systems. The building envelope ought to be (DOE 2004):

- Affordable
- Durable
- Energy-positive
- Environmental
- Healthy and comfortable
- Intelligent

In Europe the Commission of the European Union has published a Directive on Energy performance in buildings (EPBD) with the task for all member states to transfer the directive into national regulations. This directive implies whole building performance evaluation rather than code compliance of components. This gives space for applying integrated building concepts where components can fulfill more than one function, e.g., windows can be integrated with the ventilation system.

1.1 Energy and buildings

Nordic countries like Norway are facing two major challenges. First, new building regulations aim to reduce emissions related to energy consumption in buildings (TEK 2007). In heating dominated climates like Norway this implies more stringent building envelope requirements to reduce heat losses during the heating period. Insulation and air tightness of the building envelope ensures this but can lead as a result to overheating problems during the summer period. Consequently, cooling equipment may be needed that uses additional energy, especially in buildings with high internal loads like commercial buildings.

It can be seen from Figure 1 that the new building regulations in Norway put more stringent reduction of energy consumption into practice. Office

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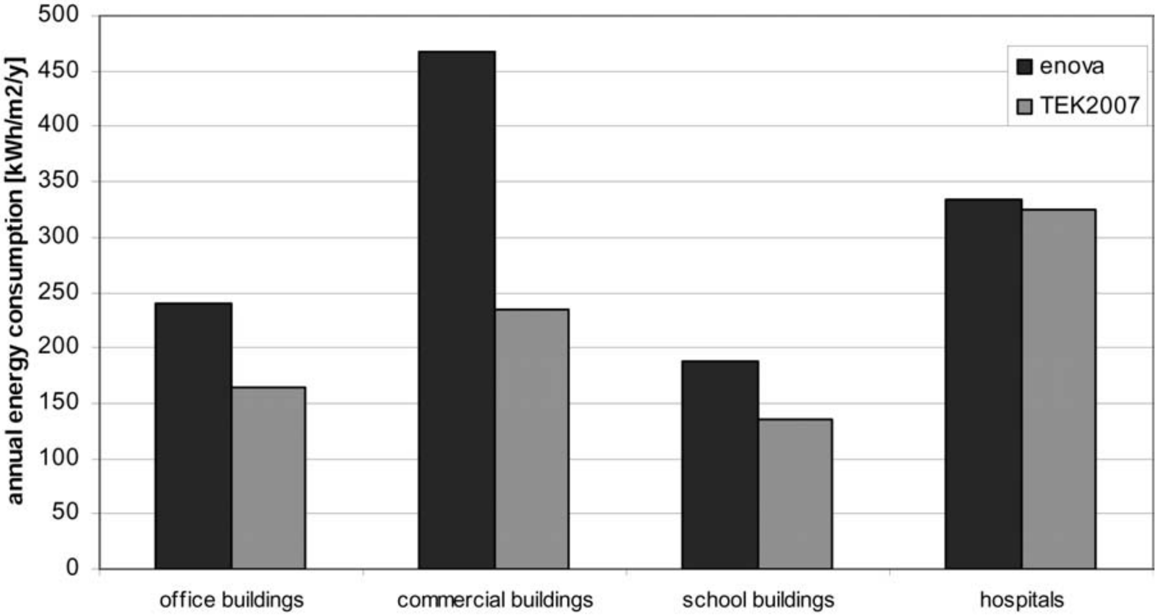
FIGURE 1. Energy frame of different building types according to new technical regulations (TEK2007), compared to measurements of total energy consumption of selected existing buildings (enova).



buildings require 30% reduction, commercial buildings 50%, schools 28%, and hospitals 3% respectively. The reference consumption is based on a survey regularly conducted by the Norwegian state energy agency, Enova (2006).

The second challenge is that climate change predictions for Norway forecast an increase in mean temperature and precipitation. This has the potential to increase the overheating problems in future summer periods and might even extend it to autumn and spring seasons. This may lead in Norway to hot and, especially in western parts, humid summer periods.

1.2 Sustainable building envelope

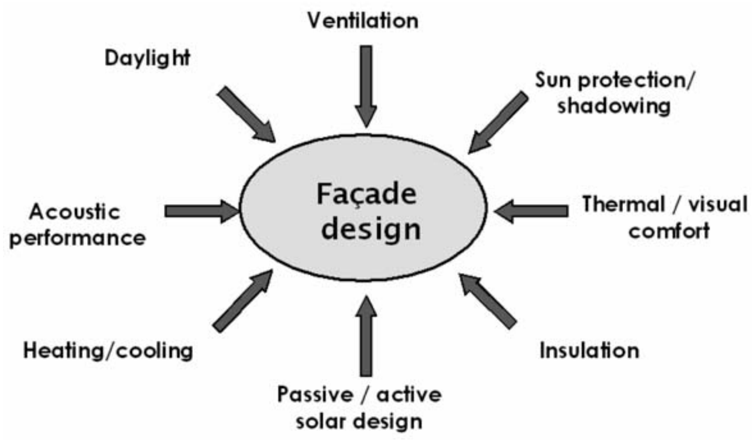
The building envelope includes all the building components that separate the indoors from the outdoors. The envelope of the building consists of the exterior walls, the roof, floors, windows, and doors. In addition to giving the wall the desired appearance, the envelope must withstand the stresses to which it is exposed and must protect the enclosed space against the local climate, ideally moderating the outdoor climate (Annex44 2006a). Designs for exterior walls for buildings have seldom been developed in a systematic and rational way (John 2005).

An intelligent facade (IF) is 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" (Wigginton and Harris 2002). This has also been termed a "climate responsive facade" (Annex44 2006b).

A number of strategies may be used to achieve energy-saving goals, such as natural ventilation, night-time cooling, maximizing the use of natural light, and solar assisted air-conditioning. The implementation and optimization of these strategies produce a complex interaction between facade and building. Advanced Integrated Facades (AIF) gathers all the concepts and establishes a tight connection with building energy and control systems.

Summarizing, an AIF is, from architectural and technical points of view, in tune with the physical and climatic conditions of a particular location. It is a building envelope that exhibits adaptive character-

FIGURE 2. Integrated facade concept.



istics; it has a dynamic behavior providing the basic functions of weather proofing, security and privacy, and of conditioning energy flows in their various forms, in order to minimize energy consumption. Being tightly connected to the building energy and control systems, an AIF has to contribute to environmental sustainability and make the building a structure with climatic sensitivity. Figure 2 illustrates a possible concept of integrated facade design where several building elements and systems are integrated into the facade design.

1.3 Advanced facade design

An analysis of different AIF systems has been conducted. If the advantages of advanced integrated facades can be proved, this technology has a great future. Advanced integrated facades can help to improve the energy performance of buildings and improve the comfort of occupants. A key factor is to understand how different climates influence the performance of the climate responsive element in the building.

Work that has been done in Europe indicates that an advanced integrated facade that is designed for cold winter conditions might result in a performance during hot summer conditions that is not optimal (Gratia and De Herde 2004a; Gratia and De Herde 2004b; Hensen 2002; Haase et al. 2004b; Oesterle et al. 2001; Pasquay 2004; Stec and Paassen 2005). The key aspect in the design of an advanced integrated facade is the integration of weather conditions in the design process. The key issue is to explore the building concept and to make use of the AIF concept in order to achieve:

- reduction of heating energy consumption
- reduction/avoidance of cooling energy consumption
- reduction of ventilation energy consumption/ natural ventilation
- reduction of electricity consumption/daylighting

Analysis of the characteristics of existing buildings with AIF revealed that half of them have been built with natural ventilated external air curtain (Haase et al. 2004a). Thus, the application of combined wind-driven and buoyancy-driven ventilation on the one hand by analyzing naturally ventilated AIF with external air curtain should be a focus. Then, there were buildings that applied a mechanically ventilated AIF with internal air curtain. Here, the enhanced ventilation by applying balanced stack ventilation, solar-assisted ventilation, and fan-assisted natural ventilation should be the aim of improvements to the system.

In the above mentioned work, the objectives were to find out if the overall environmental impact of an office building in a hot and humid climate can be significantly reduced through the optimization of an advanced integrated facade system by controlling the exhaust airflow using a climate sensitive regulator. It was demonstrated that:

- Energy conservation strategies help to reduce (peak) cooling load.
- It is possible to optimize the design of an advanced integrated facade system. The amount of energy resulting in cooling loads through a building's envelope can be reduced by designing

a ventilated airflow window that is optimized in respect to heat transfer.

- While a reduction of radiation is met by using solar shading devices, conduction through the airflow window can be significantly reduced by making use of the ventilated air gap.

Additional benefits of using an advanced integrated facade system could be quantified. A detailed study using CFD has been used to determine thermal comfort and a detailed daylight analysis showed the visual comfort improvements (Haase and Amato 2006). The importance of a careful facade design

TABLE 1. Typical design considerations at each design stage (Annex44).

Step 1	**Conservation**	**Heat Avoidance**	**Daylighting**	**Source Control**
Basic Design	1. Surface to volume ratio 2. Zoning 3. Insulation 4. Infiltration	1. Facade 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, lightwells 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 facade 2. Interior finishes 3. Daylight control strategy 4. ...	1. Building integrated ducts 2. Overflow between rooms 3. Control strategy 4. ...
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 3. ...	1. Application of renewable energy 2. Floor/wall cooling 3. ...	1. LED 2. ...	1. Efficient air distribution 2. Low pressure ductwork, filtration and heat recovery 3. Low pressure fan 4. ...
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

that ensures a reduction in cooling load in office buildings has been examined and it became obvious that advanced integrated facades provide the potential to significantly reduce energy consumption.

2 PLANNING AND DESIGN

In order to be able to plan a suitable facade solution for a project it is important to have an approach that allows to account for all design considerations and to come up with the best solution. A new energy triangle approach for sustainable building envelope design has been proposed, see Figure 3. Following the three steps of this approach can help to develop new building designs that have the potential to contribute to sustainable development. The approach analyzes the potential for improving thermal comfort, which conserves the use of energy by applying different passive cooling strategies.

In order to optimize the building envelope design a three-step approach is proposed that is related to the work of Lysen (Lysen 1996). The energy triangle approach is based on the following considerations. First, it is necessary to analyse the energy that is consumed in order to be able to estimate the potential savings.

Second, it is indispensable to apply energy efficiency (EE) which tries to reduce the energy consumption by using energy in the most efficient way. Third, the remaining energy needs should be produced by means of renewable energy (RE) sources. The approach is illustrated in Figure 3 and illustrates the three dimensions.

At the end of this approach the building energy consumption of fossil fuels is reduced towards zero.

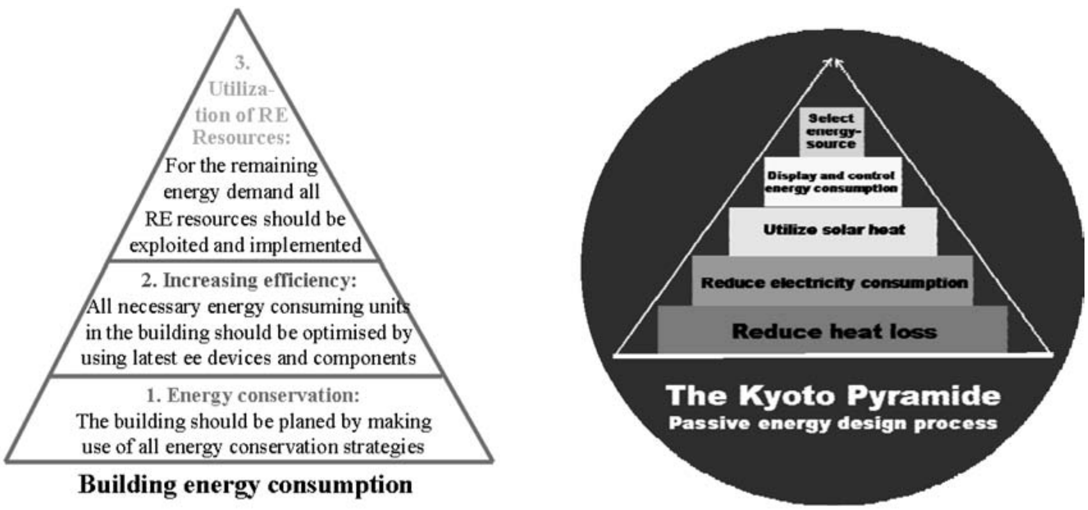
A similar approach has been proposed by Dokka and Hermstad (2006), called the Kyoto Pyramid, see Figure 3. The pyramid consists of 5 steps in the passive energy design process (with modification for other building types in parentheses):

1. Reduce energy demand (and manage and modulate solar gains)
   1.1 Reduce heat loss
   1.2 Reduce electricity consumption
2. Utilize solar energy (utilize daylight)
3. Display and control energy consumption
4. Select energy source

Different measures for improving the energy performance for office buildings according to these steps have been discussed in (Haase and Andresen 2008a).

There is a need for analyzing weather data and the potential for different sustainable design strategies. Altering some of the assumptions (e.g., amount

FIGURE 3. Energy triangle for sustainable building design (Amato and Haase 2005) and Kyoto pyramid (Dokka and Hermstad 2006).



of glazing) may improve the results. The attempt to reduce energy consumption must be aligned with efforts to improve thermal comfort during the warmest months to reduce cooling capacities. A climate responsive building envelope design should assist the design strategies and try to exploit climatic conditions. Different climates need different strategies to ensure thermal comfort by passive means.

A weather data analysis shows significant differences in warm and cold climates (Haase and Amato 2008; Haase and Andresen 2008b). For building design different climates should be considered. In order to evaluate sustainable building design strategies, a detailed analysis is essential.

For example, natural ventilation (NV) has good potential in tropical and temperate climates but not in subtropical climates. This is based on the limiting effect of NV, particularly in humid climates. Especially in Hong Kong it seems to be very difficult to apply NV, and thus the design strategy of climate responsive building envelopes should take this into consideration.

Ensuring acceptable thermal comfort by natural ventilation, several other conditions need to be taken into account, e.g., outdoor air quality, outdoor noise, local wind pattern, urban structure, indoor pollutant sources, internal air-paths and distribution, etc. In most climates, any effort to ensure thermal comfort by passive means would reduce the active control requirements. One exclusion is the warm-humid climate, since a design that maximizes cross-ventilation is not suitable for air conditioning (Szokolay 1987). Accordingly, design solutions must be found for the building envelope that allow NV and air conditioning in a hybrid mode. One possible design element could be an advanced integrated facade. If properly designed, it could not only support the passive heating strategy in the cold period of the year, but also enhance NV in the building (Ding et al. 2005).

2.1 Performance

The use of energy in the building must be analyzed by looking at heating, cooling, lighting, auxiliary systems (fans and pumps) and equipment. Then it is possible to evaluate the importance of the facade and window design.

The following performance criteria are particularly important:

- Heating demand
- Cooling demand
- Lighting demand
- Energy consumption fans and pumps
- Total energy consumption (thermal and electricity)
- Daylight factors and yearly daylight availability
- Thermal comfort
- Indoor air quality
- Acoustics

Finally, it is important to see how the urban morphology influences wind pressure distributions on facades that can be applied for natural ventilation. The influence of the urban morphology on wind pressure must be determined. It could be shown that in Hong Kong as in many other cities in Asia, their densely packed buildings diminish pressure differences on building facades, and this limits the application of natural ventilation strategies. Also, the Heat Island effect may have a limiting effect (Giridharan et al. 2007).

2.1.1 Computer simulation

For the purposes of discussion, the use of computers can be divided into the following categories:

- numerical analysis
- symbolic manipulation
- visualization
- simulation
- the collection and analysis of data

Numerical analysis refers to the result of well-defined mathematical problems to produce numerical (in contrast to symbolic) solutions.

Over the past two decades, the building simulation discipline has matured into a field that offers unique expertise, with methods and tools for building performance evaluation. It draws its underlying theories from diverse disciplines, mainly from physics, mathematics, material science, biophysics, human behavioral, environmental, and computational sciences.

Computer-based modeling and simulation is becoming more and more significant for the prediction of future energy and environmental performance of buildings and the systems that service them. Modeling and simulation can and should play a vital role in building and systems design, commissioning, management, and operation. Although most practitioners will be aware of the emerging building simulation technologies, few are able to claim expertise in its application. This situation will soon be improved due to developments and activities such as (Hensen et al. 2002b):

- Introduction of performance-based (EU) standards—as opposed to prescriptive standard—in areas such as energy consumption, quality of the indoor environment, etc.
- Establishment of societies dedicated to promotion and the effective deployment of simulation such as the International Building Performance Simulation Association (IBPSA).
- Growth in small-to-medium-sized practices offering simulation-based services.
- Appropriate training, continuing education, and incorporation in the regular curricula of higher educational institutes.
- Development in Graphical User Interface (GUI) technology, giving possibility of more user friendly simulation tools for practitioners

Theoretical challenges are plentiful when recognizing that the physical state of a building is the result of the complex interaction of a very large set of physical components. The integration of these interactions in one behavioral simulation poses major modeling and computational challenges. The ability to deal with the resulting complexity of scale and diversity of component interactions has gained building simulation a uniquely recognized role in the prediction, assessment, and verification of building performance. The building simulation discipline is continuously evolving and maturing, and improvements are continuously taking place in model robustness and fidelity. As a result, the discussion has shifted from the old agenda that focused on software features to a new agenda that focuses on the effectiveness of and team based control over simulation tools in building life cycle processes (Hensen and Nakahara 2001).

A lot of research is devoted to the better description, modeling, and simulation of physical transport flows in buildings such as the flow of energy and matter, as well as radiative transport phenomena such as light and sound. Applications of such studies deal with the simulation of energy conservation and storage systems, dynamic control systems for smart building technologies, optimal performance of heating and cooling devices, visual and acoustic comfort, smoke and fire safety, distribution of airborne contaminants, the growth of molds, and others. It is expected that new developments will radically influence the way that simulation is performed and its outputs used in design evolution and post occupancy decision making (Hensen et al. 2002a). Apart from this shift from simulation of phenomena to design decision making, there are a number of major trends, such as the shift from the need for "raw number crunching" to the need for support of the "process of simulation," and from "tool integration" to the "process of collaboration" (Augenbroe and Hensen 2004).

In this context, most traditional design tools are not particularly useful for analysis at concept stage, for a number of important reasons:

- There is no easy way of imbuing objects in the model with real architectural knowledge.
- CAD models have no concept of spaces and zones; they exist solely as a by-product of the layout of disassociated polygons and prisms.
- Whilst it is possible to assign tokens and indicators to individual objects, it is not possible to apply detailed thermal, lighting, and acoustic material properties.
- Even if you could work out a way of embedding any of this data, most analysis engines will only read in a DXF file anyway, which will completely ignore this embedded data.

There are also a number of problems with using simulation software:

- It changes the way that the design must be modeled.
- It is complex to learn; requires a lot of knowledge.
- It favours conventional building types.
- It is restricted in the types of geometries that can be modeled.
- It can be inaccurate.

Many different types of software systems have been developed to evaluate buildings. For example:

- Environmental impact analysis (e.g., embodied energy within materials)
- Cost analysis (e.g., fabric cost calculation)
- Structural analysis (e.g., structural stability)
- Environmental simulation (e.g., lighting, energy, acoustics)
- User behaviour simulation (e.g., people flow)

Linking the simulation process to the design process is a very important step. There has not been enough research on this aspect. A new framework of applying simulation tools into conceptual design stage has been proposed (Xia et al. 2008). Several issues have been evaluated, including

- the subdivision of the conceptual design stage and their characteristics
- the architects' requirements on the building simulation tools in each sub-stage
- the available information for the building simulation in the different sub-stages
- the simulation procedure assisting the conceptual design

What is missing in this programme is a further link to other aspects in conceptual design, e.g., the building programme (building use defined in design brief), the environmental programme (incl. area and infrastructure, material use, etc.) and the architectural quality (Støa et al. 2006). Here, more architectural research is necessary in order to evaluate architectural consequences of low-energy measures that enable the designer to fully explore the possibilities (Kleiven 2004).

2.1.2 Robustness

In the design of sustainable buildings it is therefore necessary to identify the most important design parameters in order to develop more efficiently alternative design proposals and/or reach optimized design solutions (Heiselberg 2006). This can be achieved by applying sensitivity analysis early in the design process. A sensitivity analysis makes it possible to identify the most important design parameters in relation to building performance and to focus design and optimization of sustainable buildings on these fewer, but most important, parameters (Lam and Hui 1996; Lomas and Eppel 1992; Saltelli et al. 2000). A sensitivity analysis will typically be performed at a reasonably early stage of the building design process, where it is still possible to influence the selection of important parameters. Thus, sensitivity analysis and robustness studies make it possible to identify the most important design parameters for building performance and to focus the building design and optimization on these fewer parameters.

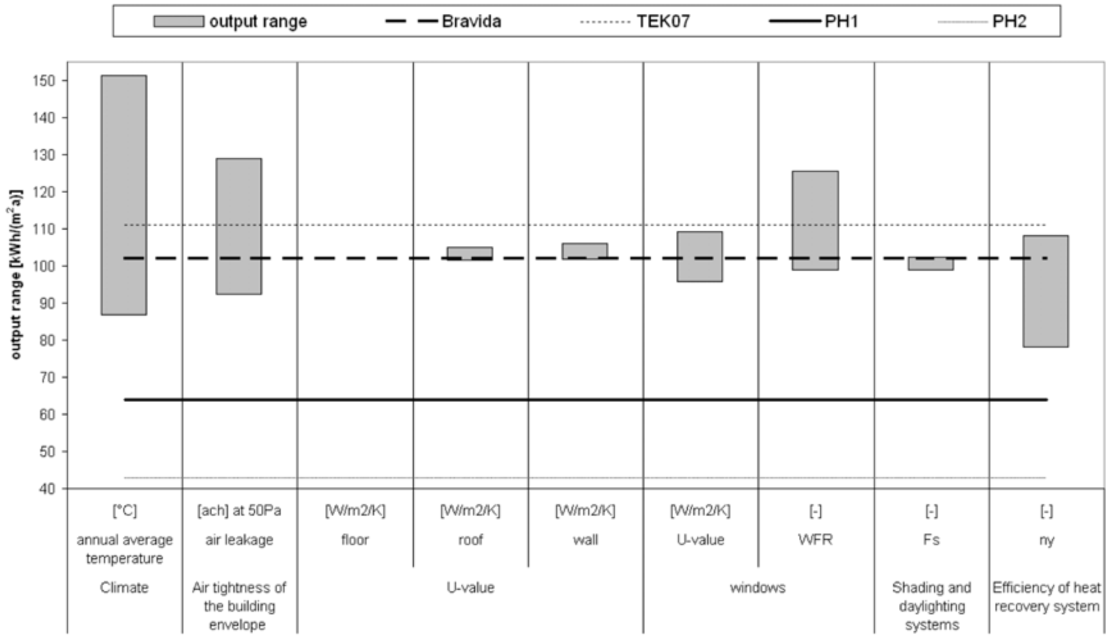
The main barrier for application of sensitivity analysis in building performance assessment is the increase in calculation time and complexity (Heiselberg 2006). Figure 4 shows the results of a recent study carried out at SINTEF (Haase and Andresen 2008a). It illustrates the impact of different design parameters of a typical office building in Norway. For a typical office building design in Norway the sensitivity analysis gives more insight to which extent design parameters influence annual energy consumption (see Figure 4). A robustness factor has been calculated that identifies the robustness of various input parameters. From this analysis, it can be seen, for example, that the change of the U-value of the roof of 0.28 $W/m^2/K$ results in a 10% change in annual energy consumption under south Norwegian climate conditions.

2.2 Integration

In order to achieve major reductions of the energy use in new buildings, development of new construction solutions, new types of building envelopes, and new building materials, is requred. It will also require the development of more holistic building concepts, i.e., sustainable buildings where an integrated design approach is needed to ensure a system optimization and to enable the designer(s) to control the many design parameters that must be considered and integrated.

In this context, Whole Building Concepts are defined as solutions where *reactive building elements* together with service functions are integrated into one system to reach an optimal environmental performance in terms of energy performance, resource consumption, ecological loadings, and indoor environmental quality. *Reactive building elements* are defined as building construction elements that are actively used for transfer of heat, light, water, and air.

FIGURE 4. Robustness of design parameter for a typical office building in Norway.



max input value	7,8	5,714	0,2	0,25	0,3	2	0,3927	1	0,9
min input value	4,7	0,357	0,1	0,15	0,15	0,8	0,0873	0,4	0,55
Bravida Input	6,4	2,14	0,2	0,2	0,2	1,4	0,1309	0,5	0,6
TEK07 Input	5,7	1,50	0,15	0,13	0,18	1,2	0,1745	0,5	0,7
PH1 Input	6,4	0,60	0,15	0,13	0,18	1,2	0,1745	0,5	0,85
PH2 Input	6,4	0,60	0,1	0,1	0,15	0,8	0,1309	1	0,85

This means that construction elements (like floors, walls, roofs, foundation, etc.) are logically and rationally combined and integrated with building service functions such as heating, cooling, ventilation, and energy storage. The development, application, and implementation of reactive building elements are considered to be a necessary step toward further energy efficiency improvements in the built environment (Annex44 2006c).

With the integration of reactive building elements and building services, building design completely changes from design of individual systems to integrated design of "whole building concepts," augmented by "intelligent" systems and equipment. Development of enabling technologies such as sensors, controls, and information systems are needed to allow the integration. Design strategies should allow for optimal use of natural energy strategies (daylighting, natural ventilation, passive cooling, etc.) as well as integration of renewable energy devices (Annex44 2006c).

Obviously, advanced integrated facade design cannot be done by optimizing the building envelope. The best solution has to be integrated into the whole building design and embedded into the energy concept of the building. The local environment and climate determines the best energy concept. But, integration issues exist as follows: Architecture and esthetics, Functionality, Economy: initial and operational, and Flexibility and elasticity.

3 ENERGY CONCEPTS

For typical energy efficient office buildings, the following energy concepts are studied and the role of the building envelope in each of the concepts is described with special focus on:

- Passive solar design
  - Thermal insulation of the building envelope (walls, floor, roof)
  - Windows size/glazing type/shading type
  - Compactness
  - Orientation
- Climate adapted design
  - Balanced ventilation with heat recovery
  - Air tightness of the building envelope
  - Efficiency of heat recovery system
- Active solar design
  - Building integrated photovoltaics (BIPV)
  - Solar thermal collector

In the following, the three different design concepts for reducing the energy demand by applying various passive strategies are introduced. Each concept is illustrated with examples.

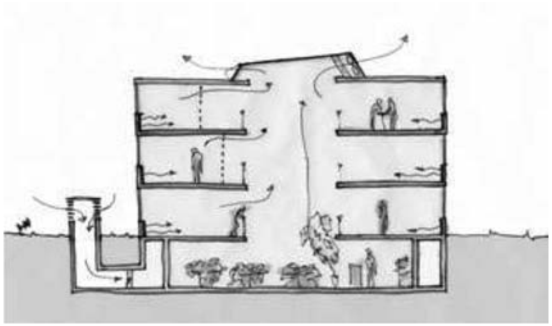
- Passive solar design concept 1: Culvert model with heat gain from earth
- Passive solar design concept 2: Facade solution
- Climate adapted design concept 1: Integrated double facade and culvert model
- Climate adapted design concept 2: Passive house standard for dwellings
- Climate adapted design concept 2b: Modified passive house standard for non-residential buildings
- Active solar design concept: Zero-net-energy building – "Architecture unplugged"

3.1 Passive solar design concept 1: Culvert model with heat gain from earth

3.1.1 Concept:

- Relative compact building form.
- Internal atrium for daylight distribution to the inner zones of the building and to exhaust air in the building integrated ventilation system.
- Concrete culvert for passive pre-treating of supply air, which is integrated into the building foundation.
- Use of short vertical air ducts in the facades of the building for air distribution.
- Comprehensive use of available, well known, and low emitting materials for reducing demand of supply air.
- Building integrated air ducting with overflow from offices to common areas and toilets and further to atrium.

FIGURE 5. Illustration of design concept 1 (Illustrations: Kleiven, T.).



- Heat recovery of exhaust air with optimized battery yield.
- Large cross-sectional areas, reduced ventilation components, and building integrated air ducting result in a system with low pressure drop and small fan energy demand.
- Motion sensor control of lighting, ventilation, cooling, and heating (demand control).
- Thermal mass activation in order to reduce heating demand and eliminate cooling demand/keep satisfactory thermal comfort conditions.
- Optimization of the building's natural regulation potential (free running optimization).
- Specific building envelope requirements (see below).

This concept is applicable for buildings with moderate operation time and moderate internal loads, which are: office buildings, school buildings, kindergartens, cultural buildings, and similar building types.

3.1.2 The role of the building envelope

The building envelope in this concept is important. It is comprised of the following specifications:

- Relative compact building form. This ensures a minimum of building envelope area in relation to the treated floor area.
- Use of high insulating 3 layered glass with integrated Venetian blinds between glass layers.
- Windows divided into two parts, the lower part with normal solar shading that is controlled by solar radiation, and an upper part for daylight

with Venetian blinds that reflect light into the room. Upper part of windows can be opened for natural ventilation, if needed.

- In addition to high insulation levels of windows, walls, roof, and floor, the focus should be put on thermal bridge free detailing.

FIGURE 6. Model of Nydalspynten building (Illustration: Nils Torp Arkitekter AS, in [Dokka and Thyholt 2006]).

3.1.3 Example: Nydalspynten, Oslo, Norway

This project is the planned office building Nydalspynten, located in Nydalen, Oslo, Norway. The building consists of 3 floors and 1 lower ground floor. Approximate 2700 m^2, with 120–130 work places located around a central atrium.

3.1.3.1 Project information

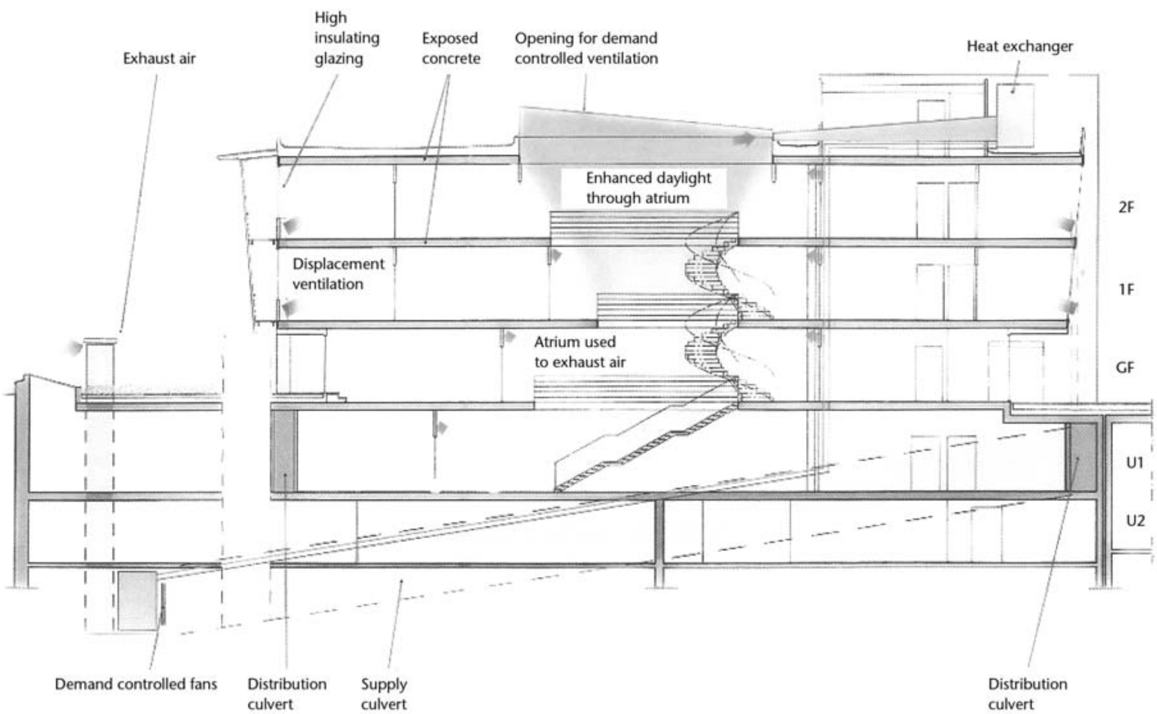
- Location: Nydalspynten, Oslo, Norway
- Completion: Probably 2009
- Architect: Nils Torp, as arkitekter mnal.
- Consultant: SINTEF Building and Infrastucture
- Building owner: Avantor ASA

3.1.3.2 Energy concept

The building applies the following features:

- Use of solid and indoor environment friendly materials.
- Hybrid ventilation and passive cooling (without cooling system).
- Utilization of daylight.
- Passive solar heating in the atrium.

FIGURE 7. Scheme of the energy system.



- Optimal demand control of ventilation, lighting, and heating.
- Super insulated building envelope.
- Solar thermal collectors and boiler plant for bio-pellets.
- Demand controlled lighting, heating, ventilation, and cooling.

3.2 Passive solar design concept 2: Facade solution

3.2.1 Concept

The concept consists of the following points:

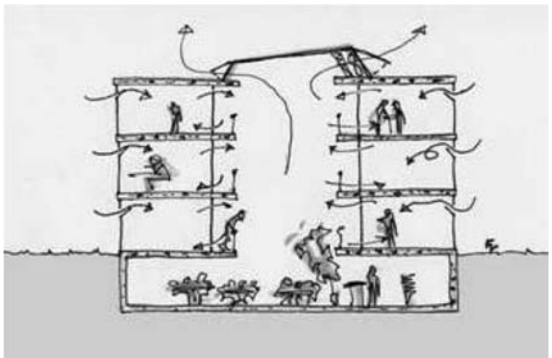
- Specific facade requirements
- Can function as natural or hybrid ventilation
- Can preheat supply air
- Normally no heat recovery but possible with exhaust air heat exchanger
- Large amount of thermal mass
- High ceilings
- Deliberate night ventilation strategy to avoid (mechanical) cooling
- Demand controlled ventilation with CO_2 sensor and humidity sensor

This concept is applicable for the following building types: office buildings, school buildings, hospitals, kindergartens, and cultural buildings.

3.2.2 The role of the building envelope

In this concept the building envelope has to integrate the ventilation strategy. Therefore, the following requrements are important:

FIGURE 8. Illustration of design concept 2 (Illustration: Kleiven, T.).



- Air intake in facade
- Upper parts of windows for daylight in combination with ventilation window

3.2.3 Example: Maela school, Norway

The new Mæla School is situated in the outskirts North of Skien centre, near Oslo on the border between city and fields. The building complex consists of several building volumes that are structurally interwoven with the cultural landscape. The school layout is arranged as bands that are located above and below the rolling landscape—partitioning the vegetation and the building as illustrated in Figure 7.

3.2.3.1 Project information

- Completion: 2007
- Architect: Pir II arkitektkontor AS | Agraff AS (LARK)
- Consultants: SINTEF | Cowi AS (RIBr, RIA)
- Project leader: Aso (Arne Olaussen)
- Building owner: Skien Kommune
- Main contractor: HRL Skien

3.2.3.2 Energy concept

The energy concept of this building applies the following features:

- Hybrid ventilation system, with balanced ventilation with heat recovery in the winter and natural ventilation during summer period.
  - Cross ventilation through automatically controlled daylight windows under the ceiling (opening 4 m above floor)
  - Operable windows in the occupied zone
- Solar shading systems.
  - Automatically controlled external shading of south-west facing facade
  - Blinds integrated in glazing in the south facade
  - Net covered with plants/trees outside the south east facade (in the cooling season)
- Utilization of thermal mass.
- Reduction of share of glazing/translucent insulation in the facades.
- Decentralized air handling units placed in small technical rooms in WC-module.
- Displacement ventilation via units located in front of WC-module.
- Outlet at ceiling level.

FIGURE 9. Mæla school layout of building mass (Illustrations: Interconsult AS, in [Wachenfeldt 2004]).

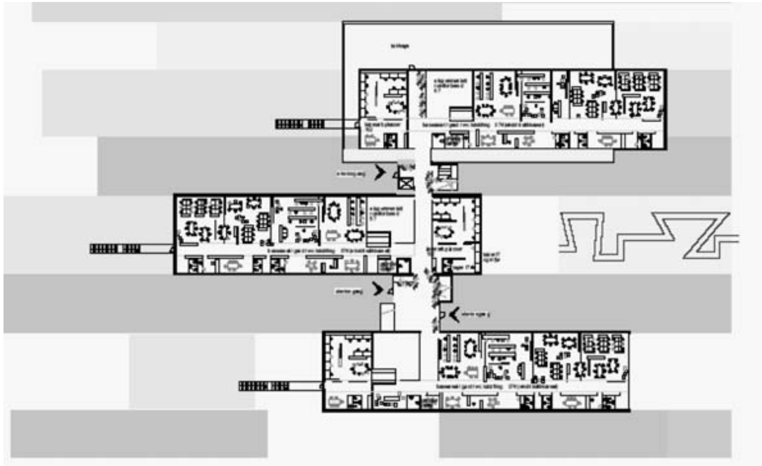


FIGURE 10. Translucent facade.

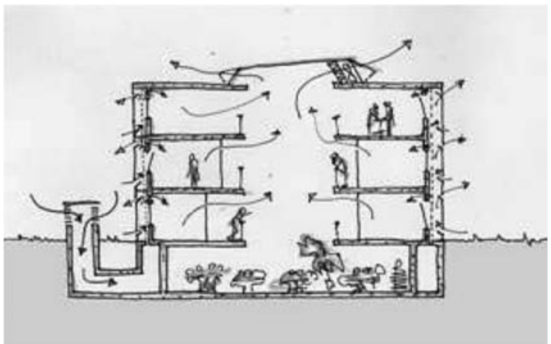
- Mechanical ventilation supply chamber for pre-cooling at night.
- Open-plan with more than 4 m from floor to ceiling.

3.3 Climate adapted design concept 1: Integrated double facade and culvert model

3.3.1 Concept

- Advanced integrated facade with special requirements (see below).
- Can function as natural or hybrid ventilation.
- Can preheat supply air in the winter but should have large openings for high flow rates in the summer (climate responsive control).

FIGURE 11. Illustration of design concept 3 (Illustration: Kleiven, T.).



- Normally no heat recovery but possible with exhaust air heat exchanger.
- Large amount of thermal mass.
- High ceiling.
- Internal atrium for daylight distribution to the inner zones of the building and to exhaust air in the building integrated ventilation system.
- Concrete culvert for passive pre-treating of supply air, which is integrated into the buildings foundation.
- Deliberate night ventilation strategy to avoid (mechanical) cooling.
- Demand controlled ventilation with CO_2 sensor and humidity sensor.

This concept is applicable for the following building types: office buildings, school buildings, hospitals, kindergartens, and cultural buildings.

3.3.2 The role of the building envelope

In this concept the building envelope has to integrate the ventilation strategy. Therefore, the following requirements need to be fulfilled:

- Air intake through advanced integrated facade
- Upper parts of advanced integrated facade for daylight in combination with ventilation openings

3.3.3 Example: Post tower, Bonn, Germany

This 40 storey building is a representative administration building designed as the new headquarters of the Deutsche Post AG. It is a fully glazed office tower with a low-rise podium building situated in Bonn, near the river Rhine with a mild German climate.

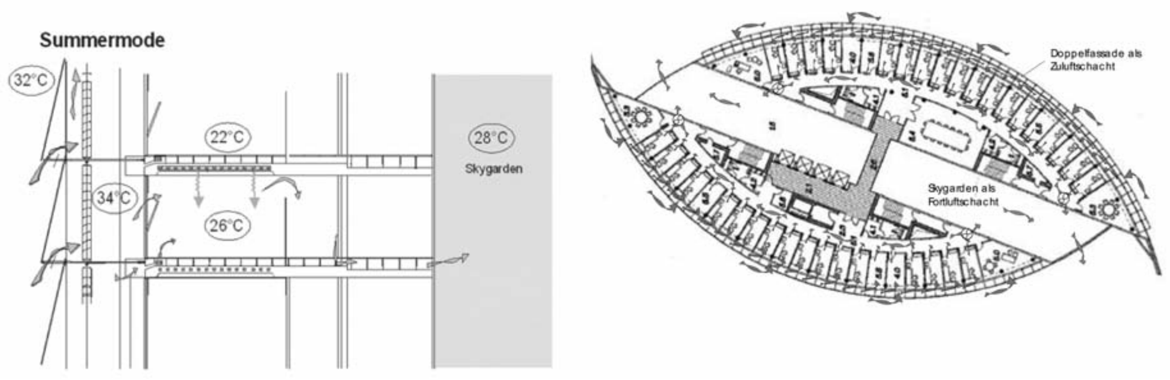
3.3.3.1 Project information

- Architect: Jahn&Murphy
- Completion: 12/2002
- Area: 107.000 m^2
- Location: Bonn, Germany
- Structure: Werner Sobek Ingenieure, Stuttgart
- Energy Concept: Transsolar, Stuttgart
- MEP Consultant: Brandi Consult, Berlin

From the early planning stages there was a high demand on flexibility, increased workplace quality with natural lighting and ventilation.

FIGURE 12. Post tower with advanced integrated facade for natural ventilation (2003; Fenn 2003).

FIGURE 13. Natural ventilation strategy in section and floor plan (Reuss and Schuler 2003).



As a consequence, manually operable windows and limited individual control over heating and ventilation were realized. The objective of the planning phase was to reduce operating costs for heating, cooling, and ventilation by taking advantage of natural energy with low total annual energy consumption. The measurements from 2003 show 90 kWh/m^2 annual energy consumption (Reuss and Schuler 2003).

3.3.3.2 Energy concept

The energy concept of this building explores the following features:

- Advanced integrated facade with reflective solar protection.
- Building component activation of the massive ceilings.
- Cooling via groundwater wells.
- Allow individual window ventilation to the advanced integrated facade.
- Condition supply air to the offices via decentralized supply air units integrated into the facade.
- Utilization of waste heat by directing exhaust air through the atria.

3.4 Climate adapted design concept 2: Passive house standard for dwellings

3.4.1 Concept:

- Specific building envelope requirements (see below).
- Balanced ventilation system.
- Heat recovery of exhaust air with optimized battery yield.
- Total 15 kWh/m^2/yr heating consumption.

This concept is applicable for the following building types: residential buildings, nursing homes, and similar buildings.

3.4.2 The role of the building envelope

In this concept the building envelope has to be built to support the balanced ventilation system. Therefore, the following requirements must be fulfilled:

- Relative compact building form.
- Very air tight construction.
- High insulation of windows, walls, and roof (and floor).

FIGURE 14. Illustration of design concept 4 (Illustrations: Kleiven, T.).

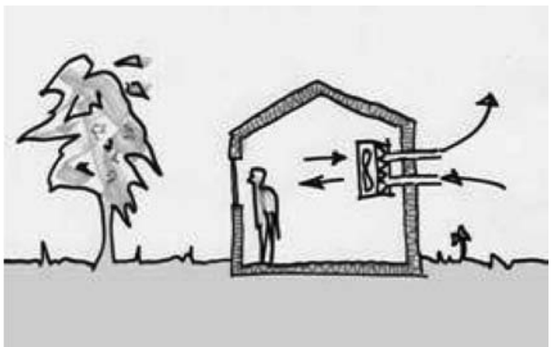


FIGURE 15. Overview of project (Illustration: ABO Arkitekter/MIR, in [Dokka and Helland 2008]).

3.4.3 Example: Row houses at Fyllingsdalen, Bergen, Norway

The 28 passive house apartments were planned as a part of a large low energy dwelling complex "Løvåshagen" with a total of 80 apartments. The construction started in summer 2007. The average size of the apartments is 80 m^2. Bergen has a relatively mild and moist coastal climate, with a yearly mean ambient temperature of 7.8°C and design winter temperature of –10°.

3.4.4 Project information

- Location: Fyllingsdalen, Bergen
- Completion: Autumn 2008
- Architect: ABO Arkitekter
- Consultant: SINTEF Building and Infrastructure
- Developer: ByBo AS

3.4.5 Energy concept

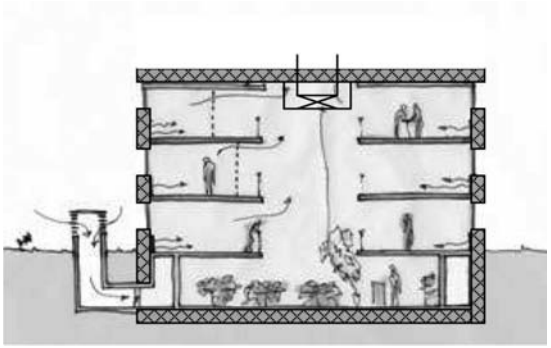
Floor slabs are in-situ concrete and exterior walls are wood frame with 35–40 cm of mineral wool. Windows have a U-value of 0.8 W/(m^2K) (N-Tech from Nor-Dan). Slab on ground has 35 cm of rigid foam insulation. Thermal bridges are minimized to < 0.02 W/mK. Air tightness is planned to reach the requirement of n_{50} = 0.6 ACH. Each apartment has a mechanical ventilation system with 80% heat recovery (rotary wheel, placed in the bathrooms). The apartments have a simplified water based heating system with floor heating in the bathroom and one radiator (800–1000W) in the living room. Each apartment also has its own solar heating system delivering about 19 kWh/m^2/yr. Auxiliary heating energy is supplied by electricity. Space heating demand is estimated to 15 kWh/m^2/yr and the total end energy use is estimated to 70 kWh/m^2/yr. The developer has estimated the total extra investment cost of the energy concept to about 1000 NOK/m^2 (ca. 125 Euro/m^2) which corresponds to about 5–6% above typical construction cost (Andresen et al. 2007).

3.5 Climate adapted design concept 2b: Modified passive house standard for non-residential buildings

3.5.1 Concept:

- Specific building envelope requirements (see below).
- Balanced ventilation system, low specific fan power (SFP).
- Heat recovery of exhaust air with optimized battery yield.
- Total 15 kWh/m^2/y heating consumption.
- Passive cooling measures like active use of thermal mass, natural ventilation/night ventilation, solar shading, earth cooling, and minimized internal loads to eliminate mechanical cooling.
- Daylight controls.

FIGURE 16. Illustration of design concept 5 (Illustration: adapted from Kleiven, T.).



This concept is applicable for the following building types: office buildings, school buildings, hospitals, kindergartens, and cultural buildings.

3.5.2 The role of the building envelope

In this concept the building envelope has to be built to support the balanced ventilation system. Therefore, the following requirements must be fulfilled:

- Relative compact building form.
- Very air tight construction.
- High insulation of windows, walls, and roof (and floor).
- Efficient solar shading.
- Openings that allow natural ventilation/night ventilation.

3.5.3 Example Wagner, Marburg, Germany

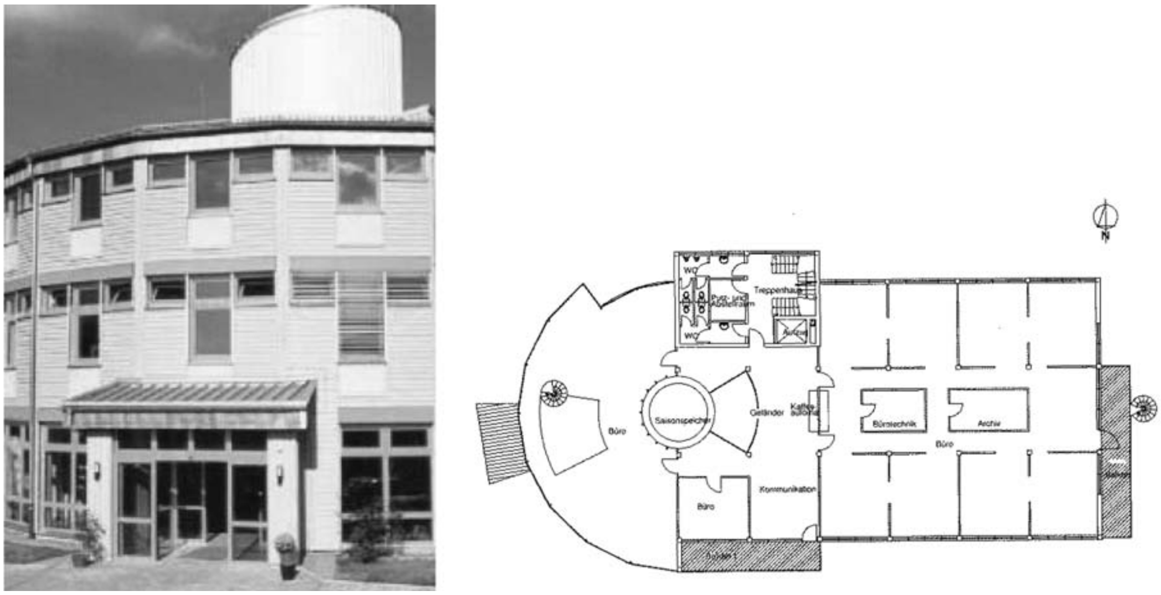
After the concept of passive houses in numerous residential buildings had been tested and proved its worth, in 1998 Wagner & Co. built for the first time a multi-office building as a passive house. For the growing company a building was planned with about 40 office jobs, exhibition rooms, a transition area, and seminar rooms with canteen.

Wagner & Co., as a manufacturer of solar technology and rain water systems, wanted to realize with the new company building a consistent overall approach to correspond and demonstrate ways of saving energy for heating, ventilation, and power requirements as far as technically possible and also to exemplify its own products.

3.5.3.1 Project information

- Completion: 1997
- Architect: Christian Stamm, Schweinsberg
- Consultant: Passivhaus-Institut
- Building owner: Wagner & Co.

FIGURE 17. Wagner & Co. building view and plan. (www.solarbau.de).



The building contains office working space with open-plan offices on the first floor and single offices on the ground floor. The building also contains zones with special requirements. On the ground floor there is a big reception zone as well as a workshop. On the second floor there are a kitchen in combination with a canteen and two seminar rooms together with an open area for communication.

The building with a gross floor area of 2180 m^2 has a well insulated building envelope, consisting of up to 40 cm of mineral wool. Even under the foundations there is a layer of 24 cm foam to insulate the building against the ground. To make the envelope air tight, a PE-foil runs all around the building and is carefully adhered to the window frames. The windows themselves are realized as triple glazed windows with krypton filling (U-value = 0.85 W/m^2K).

All in all the walls achieve an average U-value of 0.15 W/m^2K, whereas the floor and the ceiling have a U-value of 0.12 W/m^2K. The tightness of the building requires an active ventilation system: The fresh air passes an earth-to-air heat exchanger ground heat exchanger (4 × 32 m pipes of concrete, Ø = 0.5 m, distance: 0.15 m, depth: 1.5 m), and a highly efficient heat recovery unit (4 cross flow heat exchangers with a dry efficiency of up to 90 %).

During the heating period the air can be warmed up in the central pre-heater (water-air heat exchanger with a rated capacity of 42 kW). Then the air is distributed to the nine thermal zones in the building passing additional decentralized re-heaters (water-air heat exchangers with rated capacities of 2–6 kW), to reach the zonal rated value for the temperature. The return air is exhausted in the sanitary rooms and passes the heat recovery unit before leaving the building. The energy to heat up the air in the pre-heater as well as in the nine re-heaters is delivered by an active solar heating system. It consists of 64 m^2 of collectors (solar roof, 28° tilted, south-orientated), charging a seasonal storage with a volume of 87 m^3. A cogeneration system (12.5 kWtherm, 5.5 kWel) acts as a backup system.

The measured values for a space heating demand for the period 99/00 was 12 kWh/m^2a and electric power consumption for the whole building was 37 kWh/m^2a (Spieler et al. 2000).

3.6 Active solar design concept: Zero-net-energy building—"Architecture unplugged"

3.6.1 Concept:

- Very compact building form.
- Very air tight construction.
- Optimized window size with daylight and heat loss optimization (efficient solar shading).
- Very high insulation level of windows, walls, and roof (and floor).
- Balanced ventilation system with extremely high heat recovery rate (> 90 %).

FIGURE 18. Energy concept of Wagner & Co. building (Spieler et al. 2000).

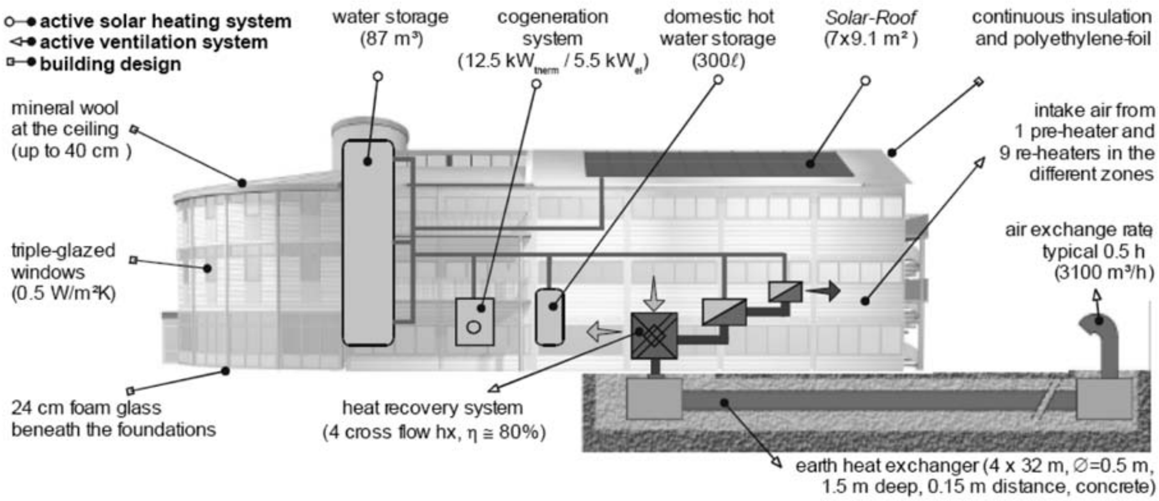
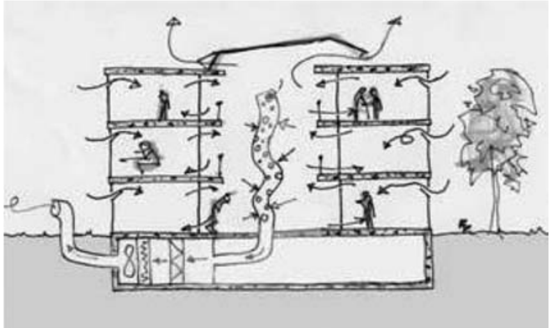


FIGURE 19. Illustration of design concept 6 (Illustrations: Kleiven, T.).



- Utilization of free cooling and natural ventilation when applicable (summer).
- Total energy consumption balanced with (on-site) renewable energy production.
- Very low internal loads, and low wattage equipment, lighting, fans, and pumps.
- Renewable energy production on roof and facade integrated (both heat and electricity).
- Seasonal heat storage system.

This concept is applicable for the following building types: most buildings.

3.6.2 Example

An example is not yet available. Several newly planned buildings in Norway and other countries are focusing on this concept and will try to reach this goal. Two new research programs of the International Energy Agency, Annex 52 within the Energy Conservation in Buildings and Communities and Task 40 within the Solar-Heating and Cooling programme, has been launched in October 2008 that will focus on Net Zero Energy Buildings (http://www.iea-shc.org/task40/index.html).

4 CONCLUSIONS

A general introduction to Building Exterior has been given. It has been emphasized that sustainable building design solutions require a detailed analysis of the local climate. Energy-efficient solutions should not be copied to different climates since they will not perform as good as planned.

Advanced intelligent facade solutions require detailed analysis of benefits of exterior facade products that yield superior sustainable performance. The analysis should be performed in the early design phase of a project and should be constantly evaluated and updated throughout the design process. Performance goals should be established early in the process and be fulfilled by an integrated design team.

The development of superior single products will be an important step towards sustainable building solutions. But it turned out that whole building concepts are coming on the market and will probably become more and more dominant in the design phase. This implies a whole set of design parameters to be optimized. The optimization should be done with dynamic whole building simulation software and requires skilled people.

4.1 Climate and design

- The use of energy in buildings must be analyzed by looking at different locations representing different climatic zones.
- Predicted climate change will have large consequences for future energy consumption. The design solutions of new buildings should take this into account.
- Scenarios of the future development of energy consumption should take this into account.
- Solutions for the hot summer/warm winter climatic zones and other locations focus on different weather extremes and the solutions should thus look different.

A new energy triangle approach for sustainable building design has been proposed.

- Following the three steps of this approach can help to develop new building designs that have the potential to contribute to sustainable development in Asia.
- The approach requires analysis of the potential for improving thermal comfort that conserves the use of energy by applying different passive cooling strategies.
- It has been shown that natural ventilation has different potential for different months of the year. At the same time it is apparent that the building design strategy defines the utilization of renewable energy in the facade. The amount of

available solar radiation on unobstructed facades is large and could further be utilized to cool the indoor environment.
- Hong Kong can help to act as a model for modern urban densely packed high-rise environments. As tall buildings of 40 floors and above are becoming more prevalent in Asia, a greater focus on designing them in an ecologically responsive way needs to be adopted. This includes the importance of a careful facade design that ensures optimized energy conservation but also the utilization of solar radiation to meet the energy needs in the building.
- Solutions in colder climates will look different. Here, the compactness of the building form is an important factor.
- The requirements for the facade depend on the climatic situation.

The results of the weather data analysis show significant differences in warm-humid climates.

- For building design purposes two different warm-humid climates should be considered; a very humid and a dry climate. In order to evaluate sustainable building design strategies, a detailed analysis is essential.
- Analyzing weather data and studying the potential for different sustainable design strategies is the first step toward sustainable building design. Altering some early design decisions (e.g., amount and type of glazing) may result in significant energy savings.
- A climate responsive building envelope design strategy should assist the design and try to exploit local climatic conditions. The different warm-humid climates that have been identified need different strategies to ensure thermal comfort by passive means.
- Natural ventilation has a potential for energy savings in tropical and temperate climates but not in subtropical climates. Especially in Hong Kong it seems to be very difficult to apply NV. The design of climate responsive building envelopes should take this into consideration.
- When ensuring acceptable thermal comfort by natural ventilation, several other conditions need to be taken into account, e.g., outdoor air quality, outdoor noise, local wind pattern, urban structure, indoor pollutant sources, internal airpaths and distribution, and others.
- In most climates any effort to ensure thermal comfort by passive means would reduce the active control requirements. One exclusion is the warm-humid climate, since a design that maximizes cross-ventilation is normally not suitable for air conditioning. Accordingly, design solutions have been found for the building envelope that allow NV and air conditioning in a hybrid mode.
- If an AIF is properly designed it could not only support the passive heating strategy in the cold period of the year, but also enhance NV in the building.

4.2 Advanced intelligent facades

It is possible to design an energy efficient AIF system.

- The amount of heat gain through a building's envelope can be reduced significantly by designing an AIF that is optimized with respect to heat transfer.
- The AIF with external air curtain (EAC) uses natural ventilation in the cavity to counter any heat gain. Wind pressure on the building envelope was taken into consideration. This system provides the possibility to reduce annual cooling loads as well as peak cooling loads of an office. The results showed that the best outcome was achieved for the EAC with climatic control, especially for the reduction of cooling loads in the hot summer period.
- A climate responsive building envelope can significantly reduce the energy consumption of an office building in warm and humid climates.
- A solar chimney might be applied to the airflow window to allow the extraction of air in an energy efficient and natural manner. The chimney could be used to ventilate the advanced integrated facade system and also help to reduce the impacts of wind on building envelope openings.

With this optimized system the overall environmental impact of an office building in a hot and humid climate can be significantly reduced.

- Especially in warm-humid climates there is a growing demand for energy conscious high-rise construction. Advanced integrated facades can help to improve the energy performance of buildings and improve the comfort levels within the building.
- A key factor is to understand the different climates and how they influence the performance of the climate responsive element in the building.
- For a better integration more information is necessary to be made available to architects, building designers, and investors.

The key barriers for implementing advanced integrated facades are:

- Fire regulations that restrict airflow between floors of a building
- Higher initial and maintenance costs
- If connected to the HVAC system, the whole planning and construction process has to be changed
- A negative image resulting from earlier discussions around advanced integrated facades

4.3 Design parameters

The advanced integrated facade design helps to reduce the peak cooling loads in the summer months. It can also help to reduce heating loads in the winter.

4.3.1 Facade materials and design

There is a strong tendency toward fully glazed facades with high transparency and narrow building plan in order to enhance an office working environment as natural daylight is increasingly acknowledged as a design parameter. There is also an increasing trend for existing buildings to refurbish the exterior. The AIF can provide the means to accomplish these difficult tasks.

4.3.2 Building design (orientation and floor plan)

The importance of the orientation of office buildings in HK is well known and understood. Many design guides explain that east and west elevations receive the major amount of solar radiation. At the same time these orientations are more difficult to shade properly due to the low sun angles.

The use of an AIF provides a very good opportunity for those difficult orientations. The performance of an AIF on East, SE, SW, and West orientations show lower annual cooling load compared to other orientations. In case of AIF with a cavity that linked to the inside, regulating the airflow through the cavity is very important to increase the efficiency.

4.3.3 Building services (link to HVAC)

An increase in airflow through the cavity in an AIF (and through the room and the building) can increase the efficiency of the facade system with respect to annual heating and cooling load reduction. If the return air is kept small enough to be directed through the exhaust, the effectiveness of the AIF is decreased. If the exhaust airflow is increased and directed through the AIF and a solar chimney, the effectiveness of the AIF is increased.

4.4 Simulation and optimization

The usefulness of computer simulation for evaluating advanced facades was discussed. It was shown that it plays a vital role in assessing sustainable building design.

4.4.1 Detailed building envelope simulation

Heat transfer processes through the building envelope were analyzed, followed by an overview of computer simulation for modeling of AIF. The simulation methodology was introduced and a new model for dynamic building simulation has been developed. It consists of an airflow simulation through the AIF coupled with the energy balance method of dynamic building simulation.

A validation of the simulation model with measured data is important to demonstrate that the model is sufficiently accurate for simulating AIF. Measured temperature profiles of a naturally ventilated facade must be simulated within minimal difference. The surface temperature of the interior pane should especially agree well with measurements. A validated energy concept model can help to better understand the implications of the complex behaviour of AIFs.

4.4.2 Robustness

Detailed energy efficiency calculations coupled with comfort calculations can be made in order to evaluate different facade options. Thus, such simulations can be used to quantify building performance of different energy concepts and single measures and can play an important role in advancing the building simulation discipline and in applying energy efficient building envelopes in the future.

4.4.3 Optimization

The optimization of a ventilated AIF can be achieved by integrating the AIF system into the building. Building shape, form, and orientation are parameters that have an influence on the performance of a facade system.

The AIF system provides opportunities to reduce cooling loads and thus to minimize the HVAC system. It is therefore essential for an optimized AIF to be planned in an early design stage. This ensures that AIFs will not remain solely an aesthetic facade option.

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