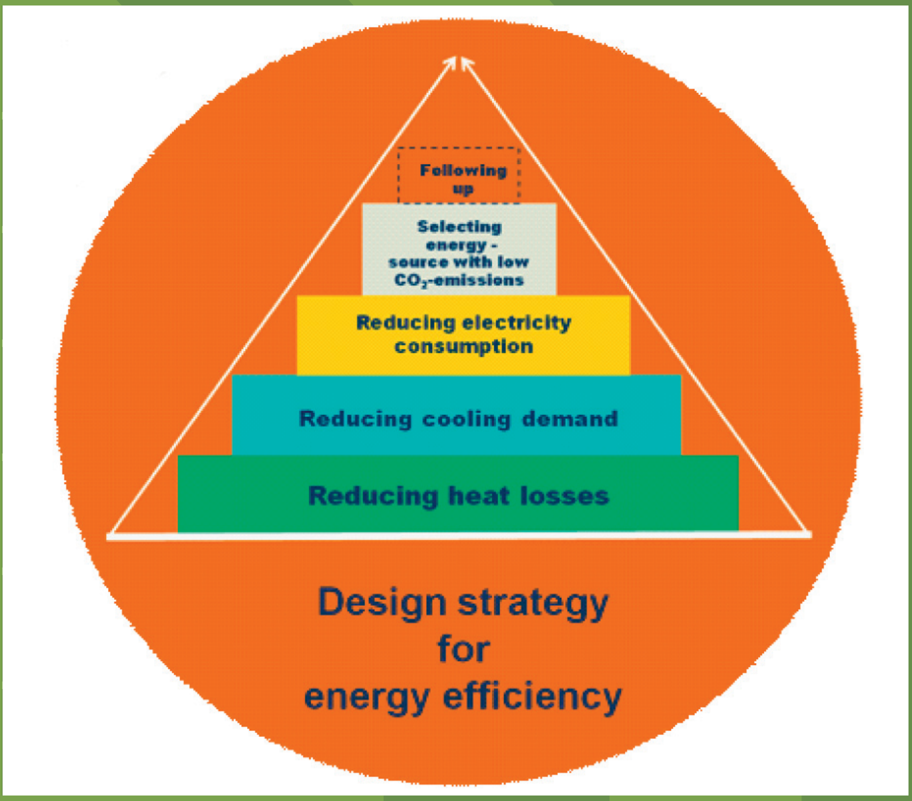
SINTEF Building and Infrastructure

MATTHIAS HAASE, KARIN BUVIK, TOR HELGE DOKKA AND INGER ANDRESEN

Guidelines for energy efficiency concepts in office buildings in Norway

Project report 56 2010



SINTEF

SINTEF Building and Infrastructure

Matthias Haase, Karin Buvik, Tor Helge Dokka and Inger Andresen

Guidelines for energy efficiency concepts in office buildings in Norway

Project report 56 – 2010

Project report no 56

Matthias Haase, Karin Buvik, Tor Helge Dokka and
Inger Andresen

Guidelines for energy efficiency concepts in office buildings in Norway

Keywords:
Architecture, energy efficiency, building design
(Arkitektur, byggekunst, enøk)

Project no. B2175004

ISSN 1504-6958
ISBN 978-82-536-1153-2 (pdf)
ISBN 978-82-536-1154-9 (printed)

Cover, illustration:
Illustration of the design strategy

50 copies printed by AIT AS e-dit
Content: 100 g munken polar
Cover: 240 g trucard

Address: Forskningsveien 3 B
POBox 124 Blindern
N-0314 OSLO
Tel: +47 22 96 55 55
Fax: +47 22 69 94 38 and 22 96 55 08

www.sintef.no/byggforsk

MILJØMERKET
241 Trykksak 379

Preface

This report presents guidelines for energy efficiency concepts in office buildings in Norway. The report gives an overall view of and explains the important tasks and factors that must be attended when planning and designing for energy efficiency in office buildings. A design strategy in several steps is proposed, described and explained.

The report is also a summary report of the work carried out in *Work Package 2 Design guidelines for sustainable energy-efficient building envelopes* in the Strategic Research Project *Climate Adapted Buildings (CAB).*

Documentation of the fulfillment of ambitious energy performance criteria and/or the requirements of the building code for a building is normally done by simulations. The design of 12 different new energy-efficient office buildings in Norway with different energy concepts has been studied in the project with a number of different simulation tools. This research has shown the need for a clear simulation and reporting strategy as the variations and differences in the input and output of the simulated results are considerable. In particular, the prediction of energy consumption and summer overheating conditions vary over a large range. References to further readings are given.

Future energy use in buildings dependency on predicted external climate change is also shortly attended in the report. A predicted increase in cooling degree days makes the awareness of overheating conditions and thermal comfort criteria during summer months even more important. References to further readings are given.

In order to identify the most important design parameters in relation to energy performance a sensitivity analysis has been evaluated and applied to determine a robustness factor. The work is briefly introduced in the report and further readings are given.

The project is financed by the Norwegian Research Council and is organized at SINTEF Building and Infrastructure. The authors gratefully acknowledge the Research Council of Norway. A special thanks to our colleague Noralf Bakken for helping collecting information about the office buildings and the office building owners for sharing the information.

Trondheim, August 2010

Berit Time
Project leader
SINTEF Building and Infrastructure

TABLE OF CONTENTS

Appendix

1 INTRODUCTION

This work is part of the CAB project whose principal objectives are to develop more energy-efficient building envelope assemblies and new methods for the design of building envelopes in harsh climates, resulting in more accurate and geographically dependent design guidelines. Today, the term climate adapted buildings (CAB) and building structures is the common designation given to structures which are planned, designed and performed to withstand various types of external climatic impact – including precipitation, snow deposition, wind, temperature and exposure to the sun. The term may also be widened to include a more proactive role of the building envelope, i.e. envelopes that are able to maintain an optimum indoor environment with a minimum of resource use (energy, materials, and labour) during the building's lifetime. Very little research has been attributed to the exploration of how to design envelopes that meet the increasing demands of minimum resource use in combination with varied and harsh climatic exposure.

The strategic project financed by the Norwegian Research Council was organized at SINTEF Building and Infrastructure as separated into two work packages.

WP 1 Methods for climate adapted design

This work package was divided into the following main activities:

A. **Characterization of selected building materials and building envelope assemblies in terms of reliability in different climates**. This part of the WP includes field investigations and laboratory testing, combined with case studies of building defects. The main purpose is to reveal which material parameters that govern variations in decay rates in different climates.

B. **Methods for assessment and classification of climate parameters and their appurtenant impact on building envelope performance**. The work includes analyses of climate change scenarios and climate data from the Norwegian Meteorological Institute's Climate archive.

C. **Development of GIS-based climate indices and national climate maps as a tool for risk assessment of climatic impacts**. Geographic information system (GIS)-based climate indices allowing for quantitative assessment of building envelope performance or decay potential may be a significant component in the development of risk mapping and adaptation measures to meet the future risks of climate change in different parts of the world.

WP 2 Design guidelines for sustainable energy-efficient building envelopes

This work package was divided into the following main activities:

A. **Specification of representative case studies and related performance criteria**.
The first part of the work package prepared the basis for the analyses which were then carried out. The work included specification of a set of performance criteria for climate-adapted energy-efficient envelopes, as well a set of representative building types within different climate zones. The case studies included realized and planned buildings with advanced envelopes as well as theoretical designs. This work was based on results from the INTFAS project which included a state-of-the-art review of energy-efficient intelligent facades, a generic set of performance criteria for designing such facades, and a generic design method for such facades.

B. **Sensitivity analysis of case studies**.
The focus of this subtask was to assess the performance sensitivity of the selected cases to variations in physical design parameters, climatic conditions, and user scenarios. The work

included computer simulations of energy and indoor environmental performance coupled with uncertainty analyses to determine the total uncertainty in model predictions due to imprecisely known input variables. Sensitivity analyses to determine the contribution of the individual input variables to the total uncertainty in model predictions was also carried out.

C. **Strategies for designing robust solutions**.
Based on the findings in A and B of WP 2, a set of strategies for designing robust energy-efficient envelope solutions for different kinds of buildings in different types of climates were developed. The design strategies and guidelines include specifications of technically feasible improvement potentials for sustainable energy-efficient building envelopes.

This report is the result of part C of WP2 and was based on work done in part A and B where focus was put on office buildings. The reason for this was the notion that quite a lot of work was already dedicated towards residential buildings but less work has been done on commercial buildings. Another project was launched in 2008 with focus on Low Energy Commercial Buildings (LECO), which will run until 2010. Many of the issues discovered in the CAB project were actually followed up in LECO. This had to do with the focus of CAB on the building envelope and excluding i.e. ventilation issues.

More efficient use of energy in the built environment is essential to reach political goals within Norway and the European Union concerning reliable energy supply and reductions of emissions of greenhouse gases. The built environment affects nature through energy use, emissions and use of raw materials. The total energy use in buildings accounts for about 40% of the total energy use in the country, excluding the energy sectors. The construction industry may thus make significant contributions to environmental improvement through energy efficiency and utilization of renewable energy.

In the entire building sector, there are many aspects that affect CO_2 accounts, such as development patterns, land use and energy supply. In this report the focus is put on the individual building, how design affects energy use and related CO_2 emissions.

2 DEFINTIONS

2.1 Energy use

Net energy demand

Theoretical calculation of a building's energy needs includes the effect of passive energy sources. The calculation includes user-specific components such as light and equipment, and ventilation. Active energy supply systems are excluded. [1]

Delivered energy

The total amount of energy that must be supplied to a building to meet energy needs. Delivery via the building's specific energy supply system is included. "Delivered Energy" can be translated as "purchased energy" [1].

Energy target figures

A building's energy performance, set as a quantitative value. Most commonly used today are specific target values, where the amount of energy is divided by the area that is heated, typically kWh/m^2 [heated area].

Target figures for a building’s energy performance are well established, and make it possible to compare different building categories, changes over time within the same category, and comparisons between different countries. Critics of this tradition point out that the system does exclude area efficient construction and user-specific factors [2].

2.2 Area use

When using comparable target figures often specific energy values are used and may be expressed as kWh/m^2. In the Norwegian regulations area use is related to heated floor space, where the area is calculated as the internal area measured within the surrounding walls [3].

3 TECHNICAL REQUIREMENTS

The increasing awareness of environmental challenges linked to energy production, together with a growing energy demand in the building sector, has obliged the government to impose regulations with more stringent requirements for energy use in buildings. The Norwegian building regulation (TEK07) is a tool to improve the technical standard of all new buildings - and in principle also existing buildings after major rebuilding - that will reduce energy consumption by approx. 25% in relation to the previous building regulations [www.be.no]. The requirements will be revised every five years and will be related to technological development.

According to climate conciliation of the Norwegian Parliament in January 2008, the government will consider imposing of passive house level for all new buildings by 2020. Norway is facing the introduction of energy labeling for buildings. The energy labeling scheme will reveal the building's energy-related performance. All buildings for permanent residence must have an energy certificate that is available for new construction, sale or rental of the building from 1. July 2010.

3.1 Technical requirements TEK07

The calculation method has been revised in Norway in 2007 [1]. In addition, building regulations were revised [2] introducing two ways to fulfill the energy requirements for a building.

- Energy measure method (Energitiltak)
- Total net energy demand method (Energirammer)

Energy efficiency performance method

The energy measure method (Energitiltak) sets requirements for certain building elements and installations. The “measures” are listed in Table 1. For code compliance these requirements have to be fulfilled and documented.

Table 3.1: Energy measures for commercial buildings from TEK07.

	TEK 2007 - Commercial building
Glass and door area [a]	20 %
U-value external wall (W/m^2K)	0.18
U-value roof (W/m^2K)	0.13
U-value floor on ground (W/m^2K)	0.15
U-value windows and doors [b] (W/m^2K)	1.20
U-value glazed walls and roofs (W/m^2K)	same as for windows
normalized thermal bridge value (W/m^2)	0.06
air tightness [c] (ach)	1.5
heat recovery [d] (%)	70
specific fan power (SFP) ($kW/(m^3/s)$)	2.0/1.0 [e]
local cooling	shall be avoided [f]
temperature control	night set-back to 19°C

[a] maximum percentage of the buildings heated floor area as defined in NS3031
[b] incl. frames
[c] air changes per hour at 50Pa pressure
[d] annual mean temperature efficiency
[e] SFP day/night
[f] automatic solar shading devices or other measures should be used to fulfill the thermal comfort requirements without use of local cooling equipment

Total net energy demand method

Alternatively, if the total net energy demand for the building, calculated according to the methodology established in the new Norwegian Standard NS3031 (2007), is within the energy frame for the building's category, the regulations are also satisfied. Here, a holistic approach was chosen, accounting for all building energy needs. The frame for aggregate net energy demand for office buildings is in TEK 2007 165 kWh/m^2 (heated area) per year.

3.2 Norwegian Standard NS3031

NS3031 provides national rules for the calculation of the buildings total energy demand in an energy budget. It provides rules for calculating the heat losses used by the redistribution between different energy measures given in TEK07. NS3031 is limited to a detailed description of the monthly calculation method, but also provides guidelines for basic hourly calculations in accordance with EN 13790. So it is useful for the application of computer tool, or spreadsheet for monthly calculations. In addition, NS3031 gives rules for reporting and rules / methods for the calculation of net energy, the need for delivered energy and primary energy, CO_2 emissions, energy costs and heat losses. Factors for primary energy, CO_2 and costs are not provided [1].

4 DESCRIPTION OF LOW ENERGY BUILDING CONCEPTS

In different countries a process towards energy efficiency is under way with the set-up of demonstration buildings to show good examples of how to build and operate energy-efficient and environmental friendly buildings. The main design strategy consists of firstly reducing energy requirements as much as possible and then, as far as practicable, covering the remaining demand with locally produced renewable energy. In Norway, this strategy is known under the name Kyoto pyramid [Norwegian State Housing Bank], but the actual consideration of the principle can be traced back to the 1970s, when an awareness of the world's limited supply of resources was first formed.

4.1 Low energy building

The Norwegian State Housing Bank's original definition of low-energy housing in Norway is a total net energy per year at maximum 100 kWh / m², with a typical heating demand per year of approx. 30 kWh / m², calculated in the standard climate (Oslo). This has until now been used for all building categories.

There is now a Norwegian standard for low energy buildings (NS 3700) where heating demand per year is set to the maximum of 30 kWh / m², calculated in the climate at the construction site. The standard includes several additional requirements, as well as adjustments for cold climates and heated floor area. A standard for commercial buildings has not yet been established but a recent report from SINTEF Building and Infrastructure describes a set of requirements for all other building types [4].

Low-energy buildings can be built using currently available / established technologies, but with less heat losses than technical regulation requires. In addition, a mechanical ventilation system with heat recovery is generally used. Additional requirements regarding the energy source make it difficult to use direct electrical heating alone.

4.2 «Passive building»

The term passive house refers to the concept of providing heating demand without an active heating system using an insulated and airtight building envelope. Moreover, such buildings are equipped with ventilation systems with low pressure drops in air duct routes and highly efficient heat recovery from exhaust air. Adopting these strategies, energy use may come down to 1/4 of the normal standard. Some of these buildings are also equipped with solar energy systems and / or heat pumps, which satisfy part of the energy demand.

Passive houses have been particularly widespread in Germany and Austria. In Norway, interest in passive houses is growing and several new construction projects are planned [5].

A Norwegian standard for passive houses has been introduced [6]. The purpose is to give the term passive a clear Norwegian significance. The standard sets the maximum for heating to 15 kWh / m² year for sites where the annual mean temperature is at least 5 ° C. A somewhat higher heating demand is allowed for single-family homes below 250 m^2 and houses in the colder regions of the country. There is a minimum requirement of renewable energy. The principle is that all heating needs can be met by a highly simplified water based heating system.

Table 4.1: minimum requirements for different concepts

Building components / Air tightness			Minimum requirements		
		TEK 07	Low energy[1]		Passive[1]
			Class 1	Class 2	
Exterior walls, U-value (W/m^{2}K)	$\leq$	0.22	0.18	0.22	0.15
Roof, U-value (W/m^{2}K)	$\leq$	0.18	0.13	0.18	0.13
Exposed floor, U-value (W/m^{2}K)	$\leq$	0.18	0.15	0.18	0.15
Windows, Doors, U-value (W/m^{2}K)	$\leq$	1.6	1.2	1.6	0.80
Thermal bridges (W/m^{2}K)	$\leq$	-	0.04	-	0.03
Air tightness, air changes per hour at 50 Pa pressure difference (h^{-1})	$\leq$	3.0	1.0	3.0	0.6
Heat exchanger in ventilation system (%)	$\geq$	-	70	-	80
Specific fan power (SFP) for ventilation fans kW/(m^3/s)	$\leq$	-	2.0	-	1.5

[1] Proposed standards for low energy and passive building from Standard Norway [6].

4.3 «Zero energy building»

Some ambitious projects use the term "zero-energy buildings," "zero-emission-building", "carbon neutral buildings," "self-sufficient buildings" or "building in equilibrium (equilibrium building)". The terms lack a unified exact definition, and the selection will be even larger if one chooses to categorize according to whether the building is connected and provides energy exchange between a supply system (grid) or not [7].

An important distinction which also must be made is whether only the building's total operating time (lifetime) is considered, or whether the building construction phase + operating period + disposal are included [7].

Often we see that equal meaning is placed on the terms "zero-energy buildings" and "zero-emission-building". However, this is not always correct. A "zero-energy building" could be a building that contributes to CO2 emissions. Alternatively, a "zero-emission-building" could in turn be designed with an amount of net delivered energy distributed over the years.

4.4 «Plus-energy-building»

A research center called Zero Emission Buildings (ZEB) was established in February 2009 at NTNU/SINTEF. The main objective of the ZEB is to develop products and solutions for existing and new buildings, residential as well as commercial buildings, which will guide the market breakthrough for buildings with zero greenhouse gas emissions related to production, operation and disposal. This means that the building must be a net supplier of energy with relatively low emission factor related to the delivery of energy goods. ZEB opens the way for so-called "plus-energy buildings, i.e. buildings that produce more energy than they use. This can be calculated over the building's total operating time, or as in ZEB; considered in the building's total life-cycle. Most demonstration buildings we see today are housing, in particular new constructions [8]. The buildings are designed for active and passive use of thermal solar energy, and are equipped with solar cells that provide electrical power connected to the electricity utility. Utility grid access is a prerequisite for these buildings. On an annual basis, the calculated energy needs equals the amount of renewable energy that is fed into the electrical network. In Norway, such buildings are not yet realized.

In some foreign demonstration buildings a combined heat and power generator (CHP) is operated with gas or biofuel. The generator produces electrical energy and heat. Such buildings can manage to achieve "zero emissions" because the national delivery of electric energy is based on fossil fuels and the delivery of power to the electricity grid from local combined heat power is credited. How this should be considered for Norway when these buildings are eventually realized, has not yet been clarified. Still, the energy balance can be set up, and greenhouse gas emissions values can be attributed to the energy use to set up an emission budget.

5 PLANNING AND DESIGNING FOR ENERGY EFFICINCY

5.1 Team work

Usually there are several considerations to attend to in a building project. The planning team should provide suitable facilities with high comfort levels for the users bearing in mind the long-term economy of operation, maintenance and adaptability. Several factors, such as functionality, area efficiency, energy demand, technical systems, materials, etc., influence the environmental load of a building. When planning a complex building, people with different competences and skills are needed to find a suitable, holistic solution. A synergy effect of various actors' skills is achieved when the planning process is successful.

An interdisciplinary planning process is essentially based on the idea of optimized teamwork, which should start in the pre-project stage to make a clear definition of goals. Furthermore, there should be a qualified design process management, and tools for analyses and assessments should be applied, taking into account a variety of options from the very start. The knowledge of different specialists should be introduced at an early stage.

There are incidences where a building owner is told that a design team has experience in sustainability and environmental matters. However, upon getting to know them further, it is uncovered that this is more of a wish to get involved rather than real credible experience. The problem with the lack of knowledge is that when the pressures of the project come to bear, the designers subconsciously fall back on previous experience which pushes good environmental design to the side, resulting in only a few token measures. Therefore, it is essential to spend time, as a client, in choosing a good design team that really does have credible experience in sustainable design. This will mean demanding thorough references and checking out claims with regard to experience.

New concepts and new technology applications are challenging for building owners, architects and consultants. If the design team lacks knowledge of environmental issues or if the performance goals are especially challenging, an external process facilitator should be added to the team. The facilitator will have the task to raise performance issues throughout the process and bring specialized knowledge to the design team [9].

5.2 Goal setting

It is essential to consider sustainability and energy efficiency at the start of the design phase, to establish the key targets. Ambitions and intentions should be stated in the building program, containing a finite number of clear and manageable high level objectives. Objectives regarding building suitability, energy demand and building materials should be emphasized and put into specific terms. Energy targets should be related to functions rather than technologies. If goals are not set at an early stage, they tend to either be forgotten or be pushed out due to pressures from budget or schedule of work [9-10].

5.3 Following-up the environmental ambitions

In general, when broad and qualitative objectives are set at the beginning of a planning period, caution should be taken to fulfill the objectives. Professionals with different competences as well as users should be involved in the conceptual phase, and the building's environmental footprint should be assessed through out the planning process. Sufficient time for planning is often a crucial factor [9].

5.4 Early intervention

The professional knowledge of architects and engineers is to be combined in the design phase, co-optimizing a wide number of parameters. In this phase the designers should repeatedly estimate how different building lay-outs, structures and envelope designs, influence the indoor climate and energy use for heating, cooling, ventilation and lighting. This is an important issue to deal with when goals are ambitious.

Previously, environmental simulation of building performance was only done by engineers at the end of the design process. Any weak points in the performance of the design could then be ‘fixed’ by adding heating, cooling, shades, vents, fans, panels, etc.
However, at the end of the design process it is too late. The decisions made early on in the design process have the largest impact. In addition, environmental issues are becoming more important, the complexity of the building design is increasing, and simulation tools are becoming more architect friendly.

Fundamental to the development of concept design tools is the notion that environmental design principles are most effective when considered during the earliest most conceptual stages of the building design process.

The conceptual stage of design occurs at the very beginning, when the brief is still being analyzed and decisions regarding geometry, materials and siting are still to be made.

This is also the stage most ignored by traditional building analysis and simulation software, primarily because reliable quantifiable data describing the building simply does not exist. The architect’s role requires building a fundamental understanding of the architectural consequences.

Calculation feedback is needed for very early stage conceptual design (particularily of visual nature) as well as final design validation. Designers must start generating vital performance-related design information before the building form has even been developed. It must be possible to start a detailed climatic analysis to calculate the potential effectiveness of various passive design techniques or to optimize the use of available solar, light and wind resources. It must further be possible to test these ideas on some simple sketch models before gradually developing up the final design. This would give the designer the possibility to evaluate his design and adjust it to the situation.

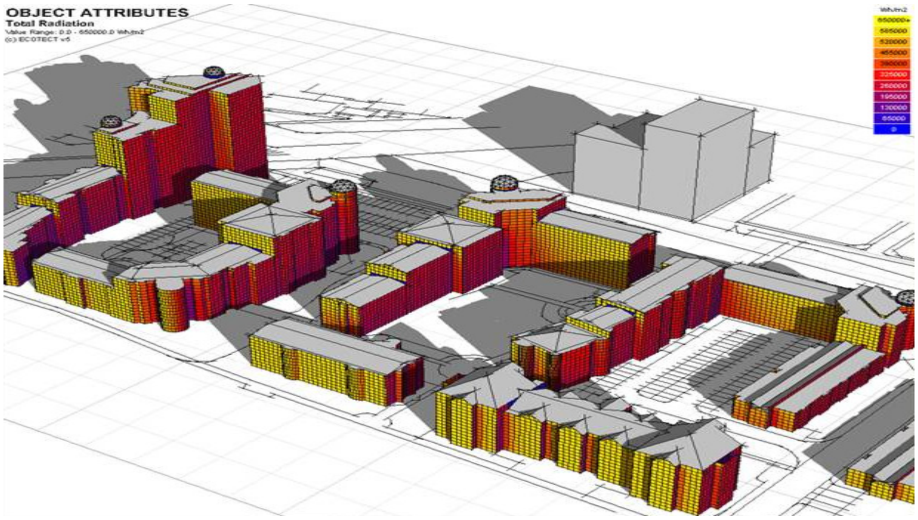


Figure 5.1: Output example from ecotect showing shading and solar radiaiton information for a group of buildings [11]

The architect should be able to:

- Evaluate energetic consequences of design
- Analyze the microclimate
- Establish an environmental programme
- Develop a building energy concept

A qualified team of experts should then

- Quantify architectural concept by
  - Performing heating and cooling load calculations
  - Calculating monthly heat loads and hourly temperature graphs
  - Generating full life cycles of material costs and environmental impact
- Quantify some aspects of architectural quality by
  - Displaying and animating complex shadows and reflections
  - Generating interactive sun-path diagrams for instant overshadowing analysis
  - Calculating the incident solar radiation and its percentage shading
  - Working out daylight factors and artificial lighting levels spatially and at any point
  - Etc.

Therefore, in the design of energy efficient buildings it will be very beneficial to be able to identify the most important design parameters in order to develop more efficient alternative design proposals and/or reach optimized design solutions. Communication between architects and engineers will become more common and important.

The European Union has taken a strong leadership role in promoting energy efficiency in buildings. This is highlighted by the Directive on the Energy Performance of Buildings, which is designed to promote the improvement of energy performance of buildings in member states. One of the benefits of this directive is that it provides an integrated approach to different aspects of buildings energy use, which until now only a few member states were doing, and that all aspects are expressed in simple energy performance indicators. The integrated approach allows flexibility regarding details, giving designers greater choice in meeting minimum standards. In order to achieve a certain degree of harmonization of assessment of buildings for designers and users throughout the EU, a common methodology based on an integrated approach is established and includes the following aspects [12]:

- thermal characteristics of the building;
- heating installations and hot water supply
- ventilation and air-conditioning installations;
- built-in lighting installations;
- position and orientation of buildings, including outdoor climate;
- passive solar systems, solar protection, natural ventilation and natural lighting;
- indoor climatic conditions, including the designed indoor climate;
- active solar systems and other heating and electricity systems based on renewable energy sources;
- district heating and cooling systems

5.5 Evaluation of alternative solutions

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 [13]. Apart from this shift from simulation of phenomena to design decision making, there is 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” [14]. 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 filling 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 a way of embedding any of this data could be found, most analysis engines will only read in a DXF file anyway, which does not recognize this embedded data.

There are also a number of problems with using simulation software:
- It changes the way that the design must be modelled
- It is complex to learn; requires a lot of knowledge
- It favors conventional building types
- Is restricted in the types of geometries that can be modeled
- It can be inaccurate

Many different types of software system 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 behavior simulation (e.g. people flow)

Linking the simulation process to the design process is a very important step but there has not been enough research and development on this aspect. A new framework of applying simulation tools into conceptual design stage has been proposed [15]. 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, and
- the simulation procedure assisting the conceptual design.

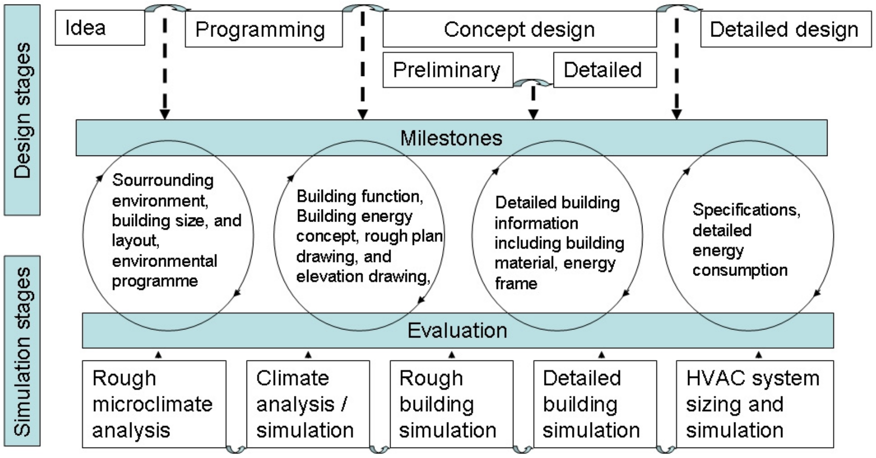


Figure 5.2: Linking design and simulation in the conceptual design stage [12];

What is missing in this programme is a further link to other aspects in conceptual design, e.g. in the building programme (building use defined in design brief), the environmental programme (incl. area and infrastructure, material use, etc.), and architectural quality [16]. 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 [17]. The figure above illustrates how to integrate these issues in the design process [12].

5.6 Balancing different measures

The building design is the first and most important step in developing a sustainable environment. The OECD project on sustainable buildings for the future identified five objectives for sustainable buildings [18]:

- 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.

All these issues must be incorporated into the early design since this provides the largest benefits. The background knowledge that is needed to handle these issues ranges from ecological and environmental to technical/engineering topics.

The architect is not educated to deal with all of these issues. Resource and energy efficiency and pollution prevention are typical fields of engineering application. Harmonization with the environment is multidimensional and most architects are trained to deal with this task. However, there is an integrated and systematic approach to reach a sustainable building that requires architects and engineers to develop an awareness in the early design stage for:

- Energetic consequences of design
- Quantitative evaluation of architectural concept
- Quantitative evaluation of architectural quality
- Qualitative evaluation of energetic concept
- Architectural consequences of energetic concepts

The main task of future architectural research should focus on quantifying architectural qualities and qualifying engineering quantities. This has to begin with the development of communication skills for a common language for architects and engineers.

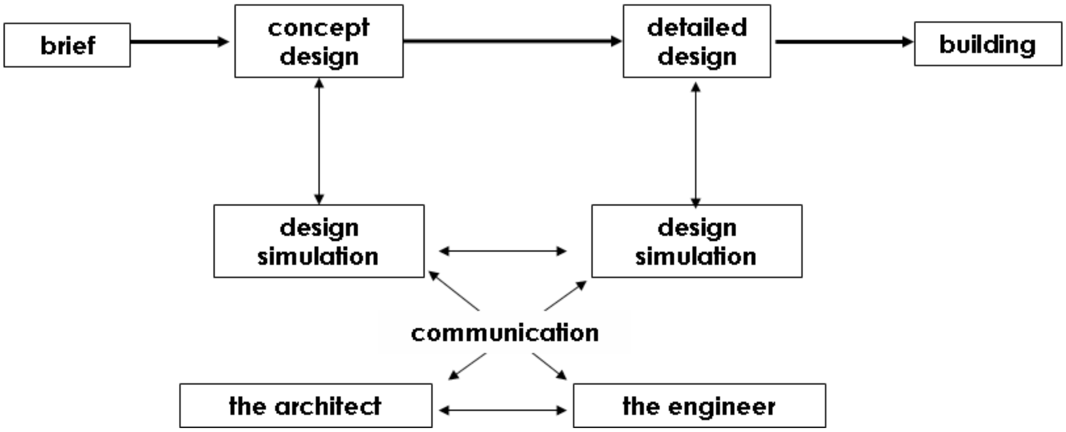


Figure 5.3: Communication between architect and engineer in design phases [12]

A major challenge is balancing goal conflicts. Measures have to be balanced for several goals:

- Exploitation of daylight. This will benefit users' satisfaction and well-being. At the same time, exploitation of daylight will reduce the consumption of electric power for artificial lighting. On the other hand, an extended use of glazing may cause a higher demand for heating and possibly cooling energy.
- Air quality and comfort temperature. This will benefit users' satisfaction and well-being. A high performance ventilation system is thus required and energy consumption for the system should be kept as low as possible.
- Adequate acoustics. This will benefit users' satisfaction and well-being. The desired reverberation time will vary according to functions, and contradictory considerations may have to be taken into account regarding multi functional spaces. The placement of absorbers must be considered in relation to the request for thermal mass [9].

5.7 Tools for environmental evaluation

Different concepts and solutions often have different strengths and weaknesses and there are a number of tools and simulation programs available to analyze and document the environmental properties of each. As of today, however, no tools or systems have successfully consolidated a position as market leader and de facto national standard.

Building certification

Building Certification is a method for documentation of a property, and consists of a comprehensive review of all relevant aspects of the property. Certification typically consists of documentation, registration, and assessment of the following criteria:

- Basic data and documents
- Functional relationships (plan etc.)
- Energy and environmental conditions
- Economic factors
- Technical condition, operation and maintenance

The system is based on a 'spec' database where all relevant functional and environmental requirements of buildings are defined together with its criteria for evaluation of the requirements. Certification is a status analysis at a high level. However, detailed quality documentations may be necessary within certain areas, which are know as property profiles [16]:

- Status Profile (the basis for planning maintenance and upgrading measures)
- Adaptation Profile (flexibility and adaptability to alternative use)
- Eco profile (environmental documentation and classification)
- Life Cycle Profile of housing (accessibility for disabled etc.)

GHG emissions

Norwegian Building Technology and Administration (BE) is in the process of developing a web-based computational tool that makes it possible to calculate the greenhouse gas emissions associated with the planning, construction and operation of buildings. Use of Public Construction and Property greenhouse gas accounting tools will also be one of the criteria for pilot projects within the project «City of the future». [Civitas]

Example for environmental evaluation tools

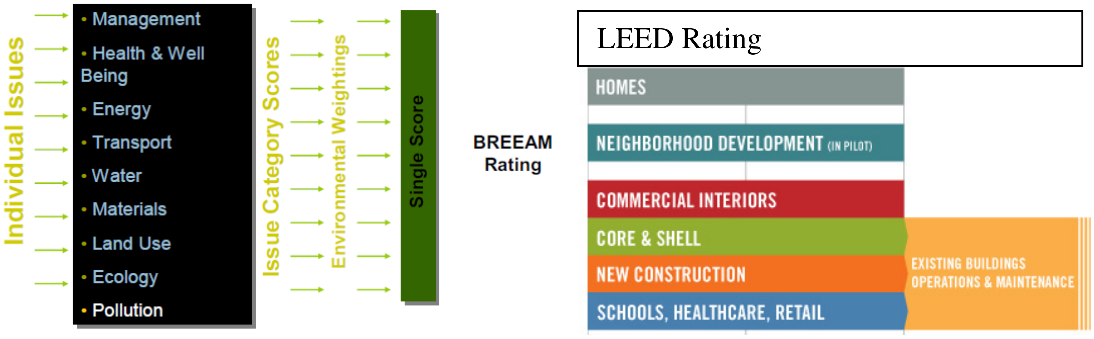


Figure 5.4: BREEAM (left) and LEED (right) evaluation schemes

BREEAM stands for BRE Environmental Assessment Method, which is the British environmental evaluation tool which has been applied in many other countries as well. Its structure is very much like building certification systems but the focus of the criteria is different (picture on the left).
LEED means The Leadership in Energy and Environmental Design, which is an environmental assessment method developed by the Green Building Council. Its structure is similar to BREEAM, the credit system rewards in detail weighted evaluation criteria and results in one sum of credit points for the project.
Parameters are organized in groups: Sustainable Sites, Water Efficiency, Energy & Atmosphere, Materials & Resources, Indoor Environmental Quality, and Innovation & Design Process

Energy labeling of buildings

Norway is facing the introduction of an energy labeling scheme for buildings. The scheme is part of the implementation of the EU building energy directive which will come into force on a voluntarily basis on 1 January 2010 and shall become obligatory from 1 July 2010 for residential buildings and from 1 Jan 2012 for commercial buildings.

The ambition is that the energy labeling of buildings will contribute to increased knowledge and awareness about energy use, and contribute to a more appropriate valuation of residential and professional buildings when they are sold or rented out. The Energy certificate issued is similar to that used from energy labelling of appliances.
Energy labelling is carried out via a Web-based tool developed by the Norwegian Water Resources and Energy Directorate (NVE). The building will have an energy certificate that shows the building's need for delivered energy based on heating solutions, properties of the building and ventilation system. Energy certificate also contains proposals for concrete action that the building owner can implement to reduce energy use, as well as information about how one can find out more about the measures. The energy labeling scheme requires in addition to conduct a regular review of air conditioning system and boilers in order to enhance the most efficient building operation. [Bygningsenergidirektivet.no]

5.8 Sensitivity analysis

In the design of sustainable buildings it is beneficial to identify the most important design parameters in order to develop more efficiently alternative design solutions or reach optimized design solutions.

Introduction

A sensitivity analysis makes it possible to identify the most important parameters in relation to building performance and to focus design and optimization of sustainable buildings on these fewer, but most important parameters. The sensitivity analyses will typically be performed at a reasonably early stage of the building design process, where it is still possible to influence the important parameters.

A reference building was chosen with available monthly measured energy consumption and full hourly simulation with the software SCIAQ Pro was done. Detailed input data and validation with measured data have been reported [19-20]. The parameters listed in Table 5.1 have been studied with input and output variations as summarized in the same Table. Robustness estimation has been applied to calculate two sensitivity coefficients SC1 and SC2.

SC1 and SC2 are sensitivity coefficients that give an indication of each parameter of the sensitivity of the output towards changes in the input. SC1 is often used in comparative energy studies because the calculated coefficients can be used directly for error assessment. SC2 have the advantage that the sensitivity coefficients are dimensionless values expressed in percentage [21].

With the help of the equation below it is possible to determine the robustness RI of the parameter by calculating the amount of change in input parameter (in its specific unit) that will result in a 10% change in output [21].

$$RI = 10\% \times OP_{BC} \times \left\{ \frac{1}{SC1} \right\}$$

with

RI = robustness indicator of parameter

OP_{BC} = output base case (Low energy building with annual energy use of 102kWh/m^2/a)

Table 5.1: Robustness indicator of different parameters [21]

Parameter	**Description**	**RI = (IP value that changes OP 10%)**	
		value	unit
Climate	Annual average temperature	1.62	[°C]
Air tightness of envelope	Air change rate	1.48	[ach at 50 Pa]
U-value	Floor	42.3	[W/m^2/K]
	Roof	0.28	[W/m^2/K]
	Wall	0.33	[W/m^2/K]
Windows/glazing type and size	U-value of window	0.89	[W/m^2/K]
	Window-to-floor-ratio (WFR)	0.12	[-]
Shading and daylighting systems	Shading factor (Fs)	1.63	[-]
Efficiency of heat recovery system	Annual temperature efficiency (μ)	0.12	[-]
Occupancy	Persons/m^2	0.27	[pers./m^2]
Cooling set point temperature	Set point temperature	1.34	[°C]
Heating set-back temperature	Set-back temperature	4.31	[°C]
Lighting load	Specific installed load	6.07	[W/m^2]
Equipment load	Specific installed load	5.91	[W/m^2]

RI gives comparable numbers that are related to the input units. The greater RI the smaller is the influence of its parameter. The values for RI give a clear picture of the robustness of each input parameter. The table above exemplifies that a change of 10% change in annual energy consumption is caused by an annual mean temperature change of 1.62 °C, or an increase of air tightness by factor 1.48 ach (at 50Pa), or an increase of the U-value of the floor by 42.3 $W/m^2/K$, etc. This gives a good indication on the influence of each parameter in reducing annual energy demand in an office building.

Energy calculations

Design of different energy-efficient office buildings in Norway with different energy concepts were studied with a number of different simulation tools [22]. With the help of dynamic computer simulations of energy and indoor environment the impact on energy use and indoor environment was analyzed. A focus was put on a comparison of different simulation tools and their accuracy in predicting the performance in terms of thermal comfort and energy consumption of various cases.

The results show that significant differences in output of the various tools make an objective evaluation difficult. In particular, significant improvements of a standard model description are needed. The importance of a clear simulation and reporting strategy and level of details became obvious. Here, national and international efforts are needed in order to make building regulations more effective and its implementation successful. The results show that significant efforts are needed in order to find a comprehensive way of simulating and reporting input and output differences when using simulation tools. In particular, the prediction of energy consumption and summer overheating conditions vary over a large range, depending on the tool that has been used.

A more accurate determination of sensitive input design parameters is needed that can help to identify those design parameters that have a large influence on the results. A sensitivity analysis of design parameter can help to develop and construct buildings with reduced energy consumption.

The importance of a clear simulation strategy and level of details became obvious. Here, national and international efforts are needed in order to make building regulations more effective and its implementation successful. This strategy for predicting accurately the building performance is an important step towards a more sustainable building stock in Norway.

Also, effective comfort criteria have to be adapted to a changing and enhanced building energy consumption. The design of energy robust, energy efficient, and comfortable buildings depends on building simulation.

Further detailed analyses and simulations are necessary to get more confidence in the simulation results. This further analysis might help to explain the differences in results. A validation with measured data from various case studies is on its way. The large number of uncertain input parameter remains a challenge [22].

Climate and energy

Future energy use in buildings also depends on the external climate and its predicted change. Future climate data for Oslo for 2020, 2050, and 2080 was developed and (summer) thermal comfort was evaluated. This addresses the dual challenge of designing sustainable low-energy buildings while still providing thermal comfort under warmer summer conditions produced by anthropogenic climate change—a key challenge for building designers in the 21st century [23].

Climate conditions independent of building types were studied in order to get an overview of the potential for passive cooling of low energy buildings in Norway. Three sets of future climate data were used as future weather data scenarios (2020, 2050, and 2080) that form the basis for evaluating the future thermal comfort performance of such buildings. These were taken as the basis for future climate change development and compared with respect to summer comfort conditions.

Results show that future climate change predictions will increase cooling degree days. Thus, thermal comfort criteria during summer months will become more important when designing energy efficient buildings. Consequently, it is important to evaluate the impact on thermal comfort from related overheating problems in future summer periods that might start to extend to autumn and spring seasons. A climate responsive building design should assist the design strategies and try to exploit climatic conditions. The cold climate of Norway provides the possibility to exploit different strategies to ensure thermal comfort by passive means.

Designers should be aware of this potential and try to integrate it into their design from early stage. This means a shift in the design paradigm away from focusing on reducing heat losses towards focusing on the integration of passive cooling strategies. It is therefore recommended to take into consideration a four step approach as described in chapter 6 [23].

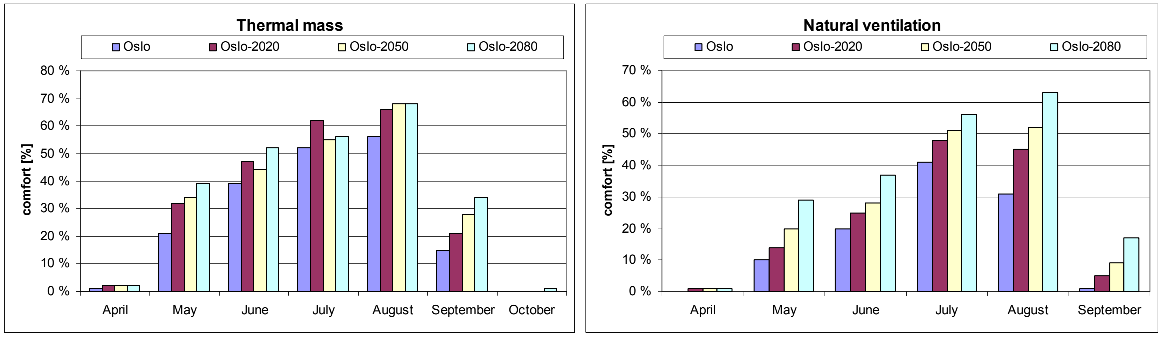


Figure 5.5: Monthly Thermal Comfort potential for the use of Thermal Mass and for the use of Natural Ventilation (for Oslo).

6 DESIGN STRATEGY IN SEVERAL STEPS

In order to reduce energy consumption a three step strategy is recommended, i.e. initially apply energy efficiency measures to reduce heating and cooling demand, and then utilize renewable energy resources, and lastly meet possible remaining demand with an effective energy supply system.

The design strategy is described in detail in the following chapters:

Chapter 6.1 Reducing heat losses

- Building shape, surface to volume ratio
- Building envelope
- Air tightness
- Heat recovery of ventilation air

Chapter 6.2 Reducing Cooling Demand

- Prevent cooling demand
- Modulate temperature levels
- Utilize sinks

Chapter 6.3 Reducing electricity consumption

- Energy efficient lighting and equipment
- Daylight
- Ventilation system

Chapter 6.4 Energy sources and CO_2-emissions

- Electricity
- District heating
- Biofuels
- Heat pumps
- Solar energy

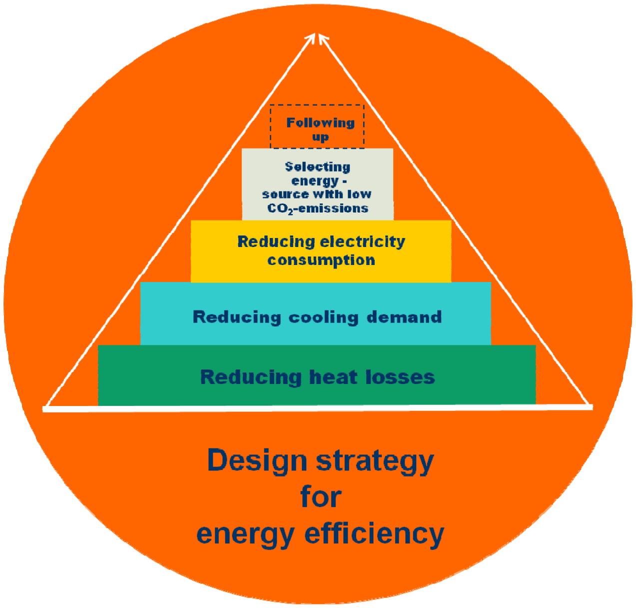


Figure 6.0: Illustration of the design strategy

6.1 Reducing heat losses

Building shape, surface to volume ratio

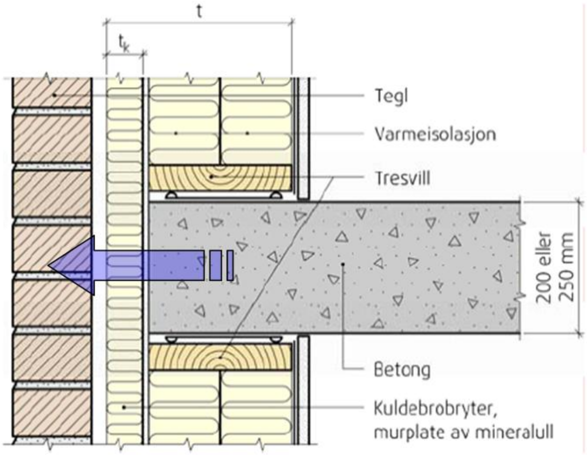
In a cold climate energy conservation in the design phase should focus on reducing heat losses through the building envelope by reducing the surface of the building. A typical value in this respect is the surface to volume ratio. It is defined as the ratio between the building envelope area divided by the total heated volume of the building. Typical values are between 0.1 and 0.3 [24].

Building envelope

Here, thermal insulation levels of walls, floor to ground, and roof are very important. Then thermal bridges in the construction should be minimized. Finally, heat losses from windows should be minimized.

Insulation and thermal bridges

Figure 6.1 below gives construction details how to avoid thermal bridges in the floor.



Kuldebroverdier, Ψ (W/(mK))

t	t_k	Dekketykkelse	
mm	mm	200 mm	250 mm
148	50	0,07	0,10
198	50	0,09	0,11
198	100	0,03	0,05
248	50	0,10	0,12
248	100	0,04	0,06
298	100	0,05	0,07

Figure 6.1: Avoid thermal bridges with external insulation. Values in the table show thermal bridge values for different construction details

Applying traditional techniques and materials in passive houses and zero emission buildings will significantly increase the amount of traditional thermal insulation, e.g. wall thicknesses up to about 400 mm are expected in passive houses. Such large thicknesses may not be desirable due to floor area considerations, efficient material use and need for new construction techniques. Hence, new high performance insulation materials and solutions are being sought. In this respect, vacuum insulation panels (VIPs) are regarded as one of the most promising high performance thermal insulation solutions on the market today. Thermal performance typically are 5 to 10 times better than traditional insulation materials (e.g. mineral wool), leading to substantial slimmer constructions. However, the VIPs have several disadvantages which have to be addressed. The robustness of VIPs in wall constructions is questioned, e.g. puncturing by penetration of nails. Moreover, the VIPs can not be cut or fitted at the construction site. Furthermore, thermal bridging due to the panel envelope and load-bearing elements may have a large effect on the overall thermal performance. Finally, degradation of thermal performance due to moisture and air diffusion through the panel envelope is also a crucial issue for VIPs [25-26].

Heat losses from windows

Glazing is an essential component for energy efficiency, related to both thermal and lighting energy needs. Appropriate choice of glazing requires balancing heat gains and losses as well as daylight issues.

Heat losses through windows should be minimized and heat gains should be modulated by optimizing

- Window size, placement and orientation
- Glazing type
- Frame type
- Also, heat gains should be modulated by the use of separate shading devices

Figure 6.2: Examples for the use of glass in the facade (left: example of less use of glaas; Senter for Marint Miljø og Sikkerhet in Horten, right: example of more use of glass; PriceWaterhouseCooper i Oslo, Photos: Sintef Byggforsk)

Today, high performance windows are available in the market; windows with insulated frames, multiple glazing, low-e coatings, insulating glass spacers and inert gas fills can significantly reduce heat loss compared to window specs available today.

The application of smart windows, such as switchable glazing, spectrally selective glazing and insulating gases (krypton, argon and xenon) are all commercially available. These advanced window technologies can be used in different configurations.

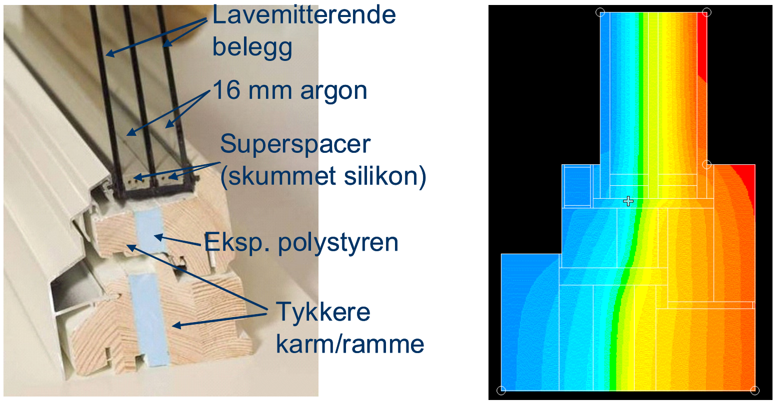


Figure 6.3: NorDan has developed a passive house window with total rated U-value of 0.7 W/m^2 K.

Air tightness

Air-tightness has become particularly important to achieve energy efficient buildings. The air-tightness requirements in the Norwegian technical regulations, TEK 2007 have become stricter, and the government has announced that even more strict requirements will come soon. This has led to a growing demand for construction details devoted towards planning and designing airtight buildings [25, 27].

TABLE 6.1: list of analyzed locations

	laltitude	longitude	annual mean	extreme mean temperature	
			temperature	extreme summe	extreme winter
	[°]	[°]	[°C]	[°C]	[°C]
Stavanger	58.6	5.4	8.4	18.5	-13.5
Trondheim	63.3	10.2	5.1	19.8	-18.5
Oslo	59.6	10.5	6.3	21.5	-20.0
Røros	62.2	11.1	1.0	18.4	-41.6
Karasjok	69.1	25.2	-2.5	18.5	-48.0

Figure 6.4 below shows possible energy savings with stricter air tightness of the envelope for different locations in Norway as listed in Table 6.1. In practice it was shown that it is currently possible to obtain air tightness well below the requirements in Norway by focusing on air tightness [28]. The left figure gives the heating energy demand for different heat recovery efficiencies in the different climates. It can be seen that heating energy demand is reduced with higher heat recovery efficiencies in all climates. The amount of savings is highest in Karasjok and smallest in Stavanger. The right figure illustrates the heating energy demand for different air change rates in the different climates. It can be seen that heating energy demand is reduced with better air tightness in all climates. The amount of savings is highest in Karasjok and smallest in Stavanger.

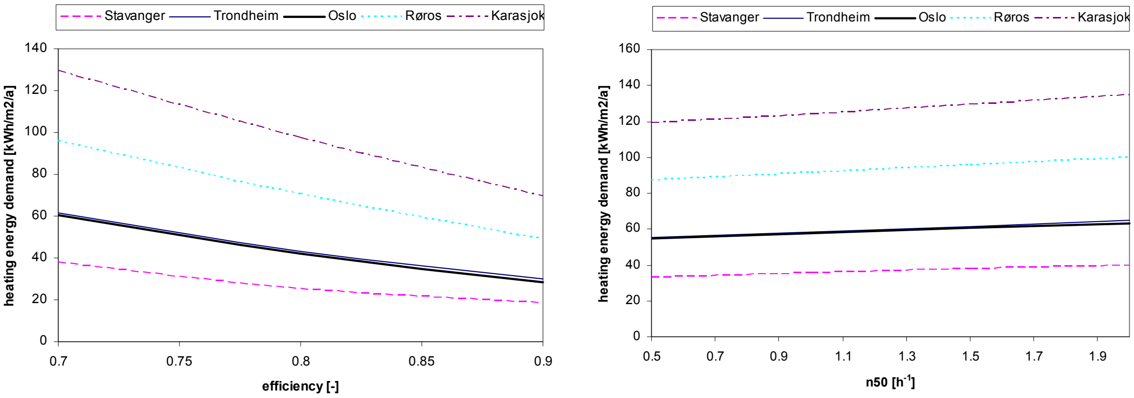


Figure 6.4: heating energy demand for different heat recovery efficiencies and different climates (left) and for different air change rates (given at 50Pa pressure difference, n50) and different climates (right) [28].

Heat recovery of ventilation air

Air tightness and heat recovery systems are important factors in energy efficient building design in Norway. Also the efficiency of the heat recovery systems is important. A careful design of climate adapted and super-efficient envelope systems can further enhance energy robustness, energy efficiency and comfort of the future building stock in Norway [28]. The heating demand for an office building with standard air tightness of n50=1.5 h^{-1} together with the reduced heating demand for an air tightness of n50=0.6h^{-1} was analyzed. It can be seen that an air tightness of n50=0.6h^{-1} can further reduce heating energy demand (see Figure 6.5).

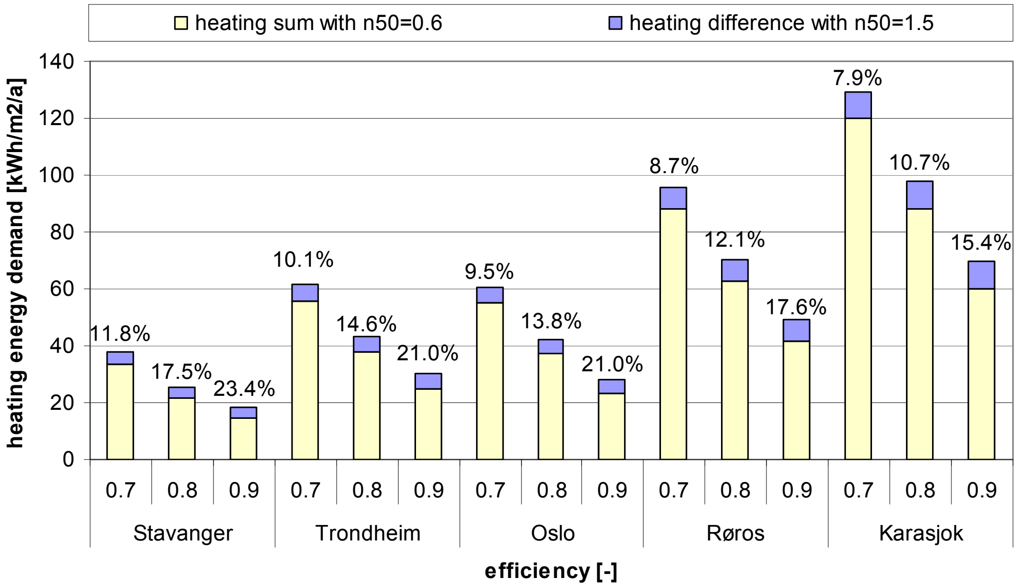


Figure 6.5: Heating energy demand for different heat recovery efficiencies and different climates (percentage give heating reduction of different heat recovery efficiencies compared to standard values given in TEK07) [28].

6.2 Reducing cooling demand

The design of low energy office buildings with high internal loads avoiding mechanical cooling and uncomfortably high room temperatures can be done in three steps;

- Prevent: using solar shading, trying to decrease internal loads
- Modulate: reducing thermal discomfort by increasing thermal mass,
- Utilize: Ventilation strategies like natural ventilation are also possible.

The figure below shows the effectiveness of measures for reducing cooling demand. Here, the results of the three step strategy are shown. It can be seen that a stepwise reduction of energy use results in energy savings of 70% [29].

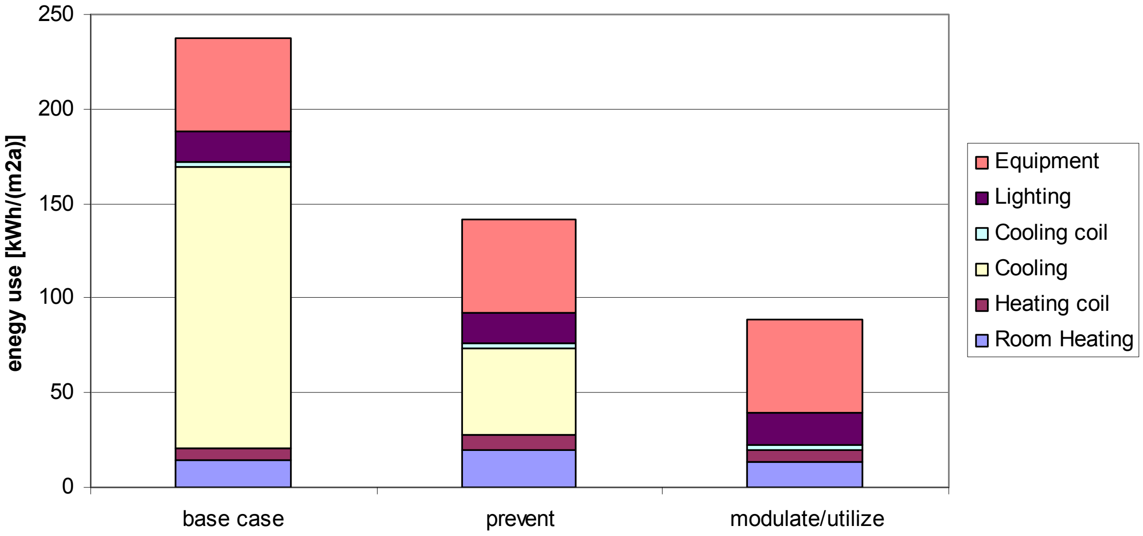


Figure 6.6: Passive cooling as Design Strategy (Example with window's U-value 1.2 W/m^2K) [29]

Prevent cooling demand

The first and most important step to consider in the first phase of the planning is to prevent or minimize the chance of overheating which occurs in the building. The measures to prevent overheating can be summarized by the following considerations:

- Micro-climate and environmental design
- Solar (solar control, window orientation)
- Building design and organization
- Internal load control
- Thermal insulation and solar absorption of opaque structures
- User behavior

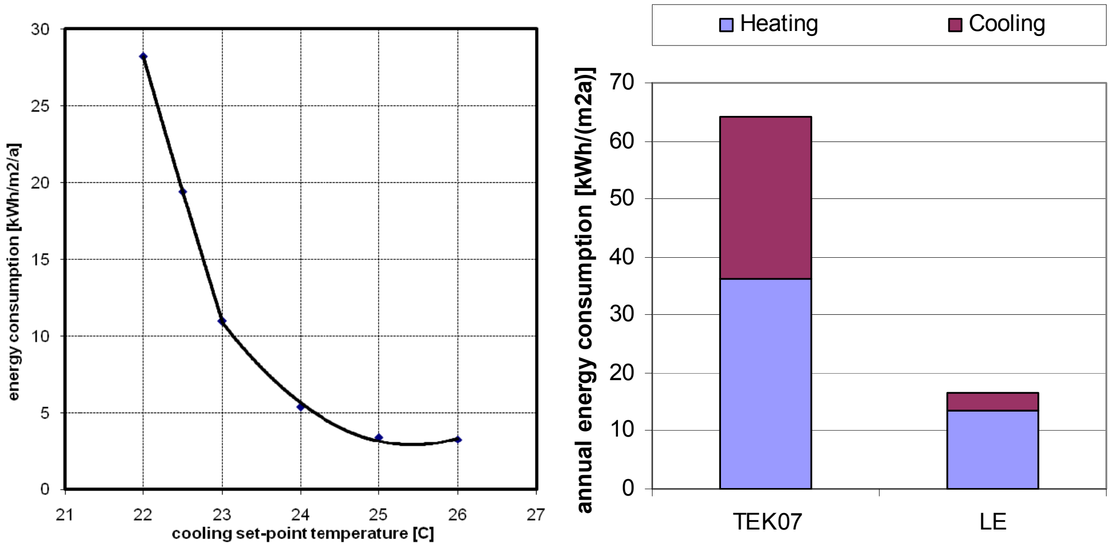


Figure 6.7: Energy demand depending on set-point temperatures (left) [30] and monthly energy consumption for TEK07 and LE model (right) [31].

Figure 6.7 above shows the influence of the indoor set-point temperature on the cooling load. It can be seen that with an increase in cooling load the energy demand is reduced. Here, thermal comfort needs to be checked in order to prevent the building from overheating. This has been done for two construction standards; for TEK07 standard and low energy (LE). It illustrates that LE has reduced energy consumption for heating and cooling compared with TEK07 standard which is due to different cooling set-points. While TEK07 recommends avoiding mechanical cooling it is important to check (summer) temperatures and to ensure that the offices do not overheat.

Solar shading

Solar shading prevents overheating in the warm season in order to avoid energy consumption for comfort cooling. Windows on east or west facades are often the cause of overheating in summer and are difficult to shade without blocking out the sun, because of the low angle of the solar radiation. The problem of glare in non domestic buildings can also be a big problem, particularly in winter, because of the low angle of the sun which comes below any fixed shading device.

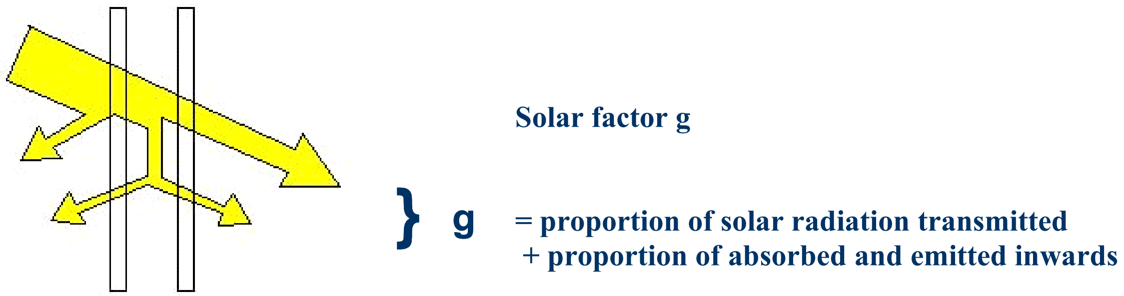


Figure 6.8: Solar factor g definition

Figure 6.9: Example of external shading with automatically controlled venetian blinds on the left (Miljøsenter Blindern) and fixed louvers on the right (Telenor Kokstad); Photos: SINTEF Byggforsk)

Figure 6.10: Schule Weiler i Vorarlberg, Østerrike. University with passive house standard. Windows on east and west orientated facades are divided into two parts. The lower part allows direct view to the outside if the shading system in down. The picture on the upper right shows the bridges to the classrooms. The inner part of the building is daylighted from skylights. The open areas connect the ground floor with the skylights. The lower right picture shows the entrance area with wardrobe. Window areas are oriented towards north and do not need solar shading. Architect Dietrich Untertrivaller. Photos: SINTEF Byggforsk.

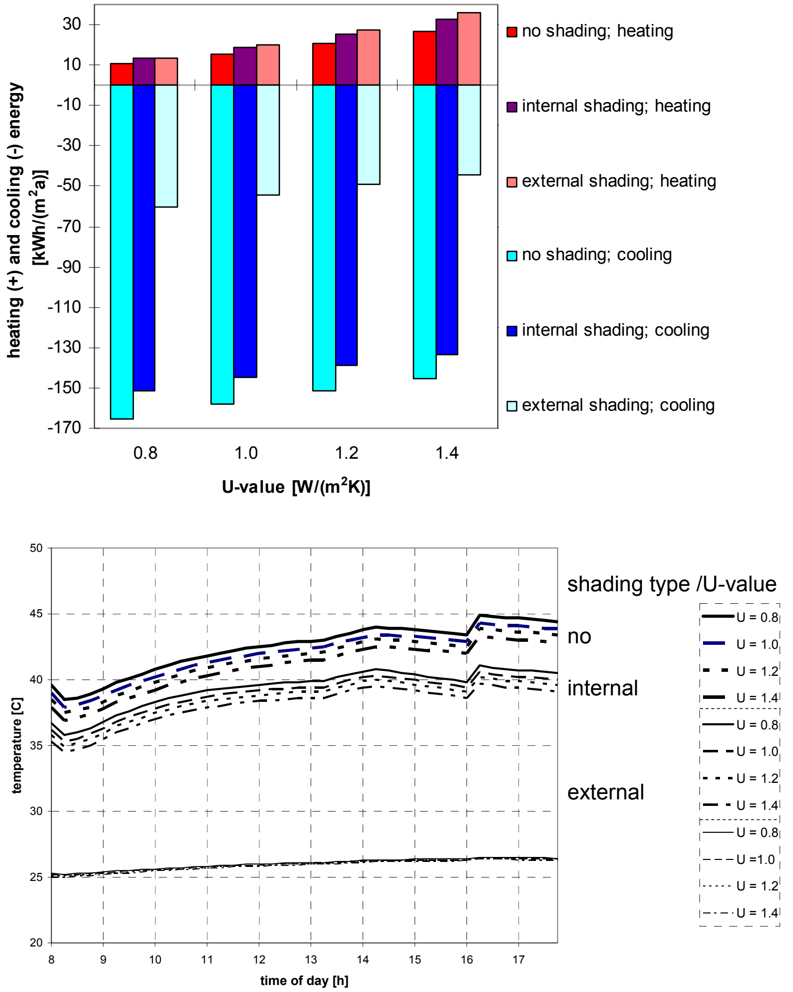


Figure 6.11: Influence of shading position on heating and cooling demand (top) and thermal comfort (bottom) for a fully glazed façade with different U-values [32].

It can be seen from Figure 6.11 (top)that cooling energy consumption is higher than heating energy consumption. A reduction in U-values of the glazing reduces heating energy consumption but increases cooling energy consumption. The influence of the shading system is relatively high. An external shading device can reduce cooling energy consumption significantly at the same time it increases heating energy consumption. A climate responsive building envelope that can dynamically change its g-value has good potential. Extreme summer conditions were simulated for the three different shading and window type options and operative room temperatures are shown in Figure 6.11 (bottom). It can be seen that only external shading can reduce indoor air temperatures (operative temperature) at 26°C while the U-value of the window does not influence the results.

Modulate temperature levels

The second step is to modulate the heat surplus by moving the heat energy in the time domain by utilizing the thermal mass. Excess heat is stored in building materials with high thermal mass, e.g. a concrete wall and then released by outdoor air ventilation at night. So in principle two measures are possible:

- Utilization of thermal mass
- Thermal mass combined with night cooling

Heavy constructions can absorb and store some of the heat penetrating windows. Light constructions are able to store less heat than heavy constructions, and the solar radiation may more easily cause overheating.

Mass exposed to direct solar radiation is most effective. Dark colors absorb more energy than light colors. The thickness of the mass is also of importance. In general, mass thicknesses beyond 10–15 cm have little effect.

Even in the Northern countries, the prevention of overheating in sun-spaces is a challenge. A helpful technique to control overheating and extend warm conditions in the sun-space once the sun is gone, is the use of heavy mass materials in interior walls, floors and ceilings. Thermal mass will absorb solar radiation, smooth out the peaks of solar gain, and slowly radiate heat back into the room when the sun has set. Thermal mass thus helps to even out interior temperature fluctuation by raising or lowering the radiant temperature of the interior.

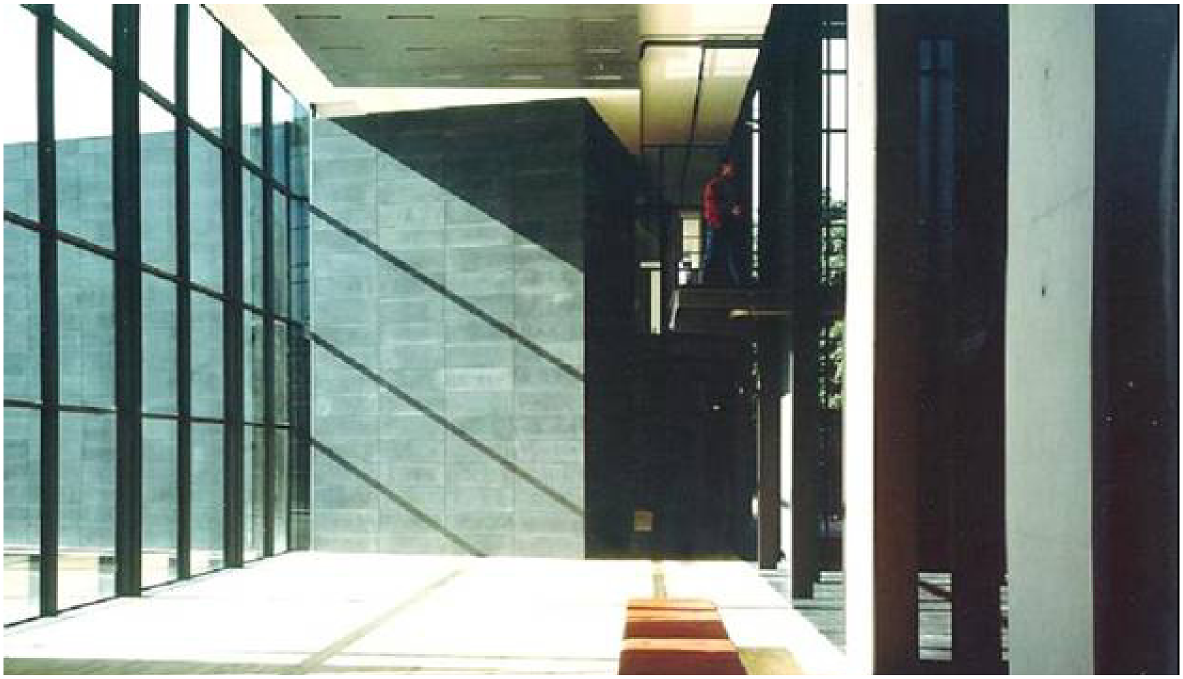


Figure 6.12: Heavy materials, concrete and stone, give thermal mass which even out temperature swings.
Picture from the headquarter for E. Pihl & Søn in Lyngby, Denmark. Office building from 1994. KHR AS Architects. (http://www.khras.dk/Projekter/Kronologisk?g=60)

Thermal mass as energy reservoir

A thermal heavy construction acts as an energy reservoir, with properties depending on:

- Ability to store heat (heat capacity)
- Ability to conduct heat (conductivity)

The reservoir should be designed to correspond with the diurnal temperature fluctuations of the outdoor air

- Mineral wool has a low thermal conductivity and low thermal capacity. This material does not constitute a good thermal reservoir.
- Steel has very high thermal capacity but has a too high heat conductivity. This reservoir is charged and discharged too quickly compared to the diurnal cycle.

- Wood has relatively high thermal capacity, but has low thermal conductivity. The low conductivity causes the reservoir to charge and discharge too slow compared to the diurnal cycle.
- Concrete and bricks have high thermal capacity and moderate heat conductivity. The combination makes the energy reservoir charge and discharge in accordance with the diurnal cycle.

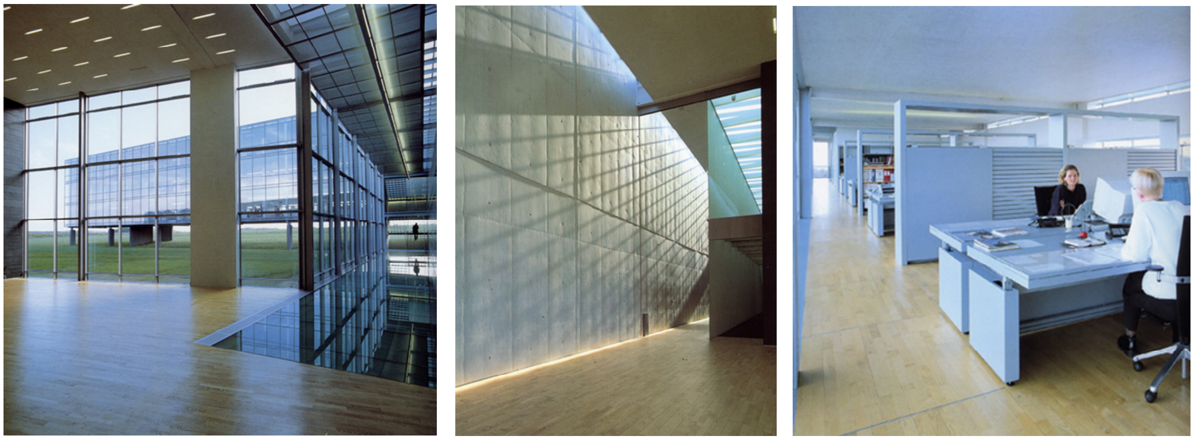


Figure 6.13: Bang & Olufsen's Hovedkvarter, Struer, Danmark. 1998. KHR AS Architects

Potential for utilizing Thermal mass in Norway

There is the possibility for analyzing weather data and the potential for different passive cooling strategies. The results of the weather data analysis show significant thermal comfort improvement potential, especially in the summer months. This can help to design comfortable buildings with climate responsive building components. The use of thermal mass has a good potential in Norway. The results show that in particular in the warmest summer months (July and August) the potential for achieving thermal comfort is around 50%. The design of climate responsive building envelopes should take this into consideration.
A climate responsive building design should assist the design strategies and try to exploit climatic conditions. The cold climate of Norway provides different strategies to ensure thermal comfort by passive means.

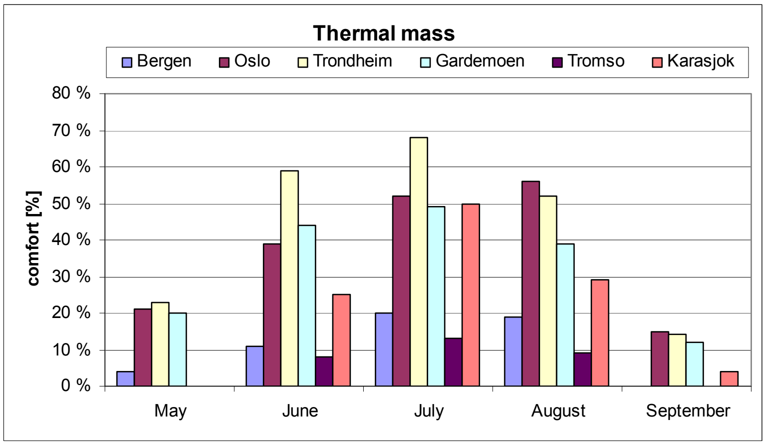


Figure 6.14: Monthly Thermal Comfort Improvement Potential for the use of Thermal Mass in Norway for different locations, [29].

Relation between thermal mass, U-values of windows and thermal comfort

Figure 6.15 below shows in addition to the heating energy use also the hours per year that the operative room temperature exceeds 26°C. Here it can be seen that a reduction in U-value of the windows results in an increase of hours where the operative room temperature exceeds 26°C. Thermal mass can help to decrease the amount of these hours but with a decrease in U-value this effect also decreases.

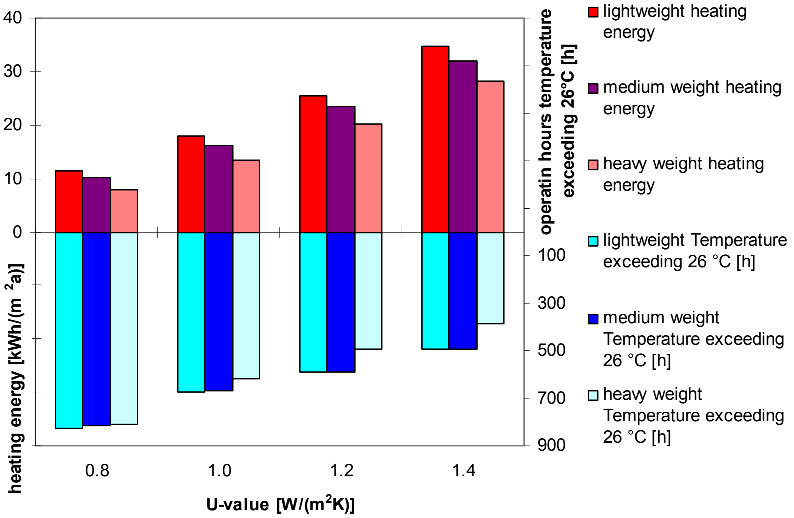


Figure 6.15: Annual Heating Energy use and Thermal Comfort for Different Window and Thermal Mass Types [29]. The shading system was automatically closed at solar radiation above 150W/m2.

Thermal mass challenges

There are a number of challenges when trying to utilize thermal mass in a building. Especially room acoustics have to be planned carefully. Hard surfaces give long reverberation time. A ceiling without acoustic panels reduces the amount of surfaces in the room that can be used for absorbtion. Also, building details have to be planned so that they eliminate or minimize cold bridges. For the surface finishes good craftsmanship is essential.

Utilize sinks

The third step is to use heat sinks to dump the excess heat energy. Passive cooling strategies can help to improve thermal comfort without applying energy consuming cooling machines. Not all building types are suited for completely eliminating the need for cooling, e.g. hospitals and commercial buildings with high internal loads. This strategy goes on to cooling by ventilation (replace the warm air with colder air), exploit geothermal cooling, evaporative cooling, or radiation cooling.

Free cooling

In many building types the use of free cooling with outdoor air can help to get rid of excess heat. Typically, there remains a critical very warm summer period (usually less than two weeks) where it should be discussed whether higher temperatures would be acceptable.

Night cooling

Cooling the building during night is most effective if high internal thermal mass exists that can act as thermal buffer storage during the day. Cooler night air can then help to cool down the building [33]. One possible design element especially in commercial building types could be a double-skin façade. If properly designed it could not only support night cooling the building but also enhance the passive heating strategy in the cold period of the year [34].

Earth cooling

The pre-heating effect of a culvert on the ventilation air has been calculated [35]. The simulation of the concrete culvert showed that it has a considerable pre-cooling effect while the pre-heating effect is rather modest. Heating effect from the culvert will be app. 4 kW (relatively low compared to the needed 70 kW). Energy contribution from the culvert over the year is between 3000 – 6000 kWh (relatively small contribution of the culvert to pre-heating).

To further utilize heat gains the following measures can be applied

- Comfort-ventilation
- Geothermal Cooling
- Evaporative cooling
- Radiant cooling

Natural Ventilation

Natural ventilation in Norwegian climates is a good measure for passive cooling during the summer [17, 36]. In order to be able to make use of the potential the following design parameters can be chosen:

1. Windows and openings
2. Atria, stacks
3. Air distribution

[37]

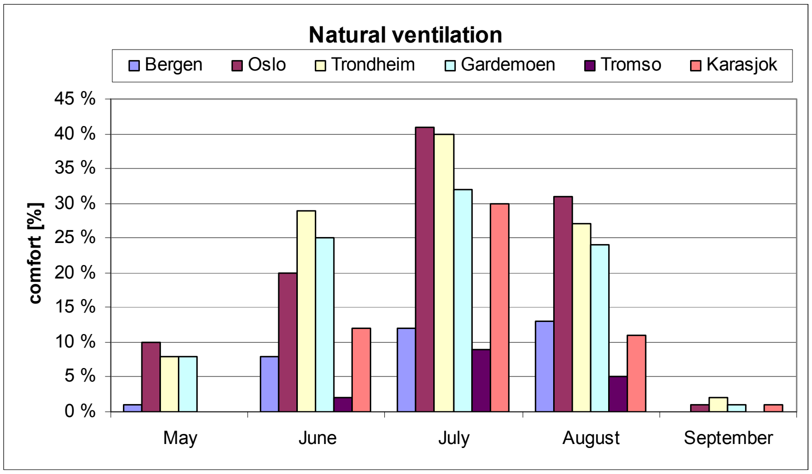


Figure 6.16: Monthly Thermal Comfort Potential for the use of Natural Ventilation in Norway [29].

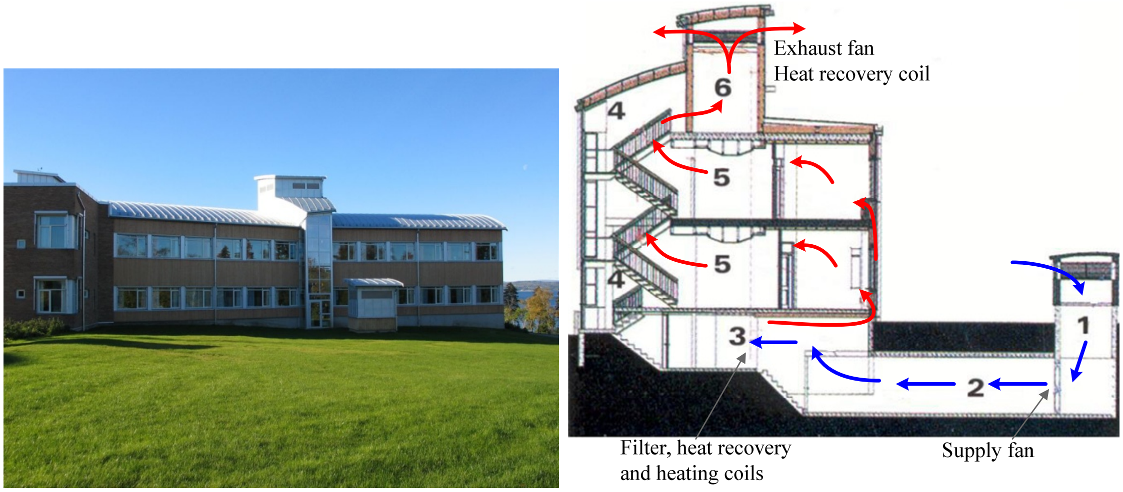


Figure 6.17: Example of exhaust air path including heat exchanger integrated in stairways (School building in Røstad, Norway), Photo: Sintef Byggforsk/NTNU Department for Energy and Process Technology)

6.3 Reducing electricity consumption

Energy efficient lighting and equipment

The use of light in office buildings is defined by two components; the installed power and the operation as illustrated in the Figure 6.18 below. Energy efficient lighting thus can follow two strategies; reducing the installed power and/or reducing the operation of the lighting system. The same is relevant for energy efficient equipment: Equipment energy can be reduced by applying equipment with the latest energy efficient technology in order to reduce not only installed power but also power during operation and outside operation.

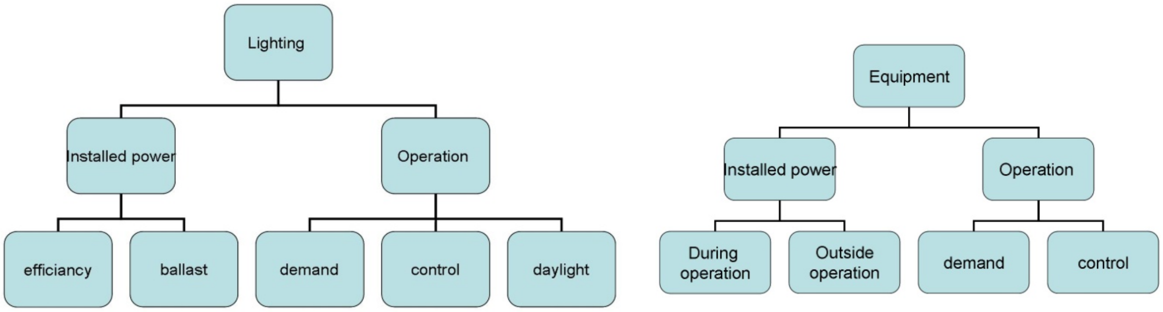


Figure 6.18: Energy efficient lighting and equipment strategies.

Daylight

Strategies that enhance daylight in the building can have two effects. First, direct energy use of the lightings are reduced. Typical energy use for lighting in buildings range between 17 and 56 kWh/(m^2a). Accordingly the potential for savings depends on building type and the following measures provide different possibilities.
1. Room height and shape
2. Zoning
3. Orientation

The second effect is a reduction in internal heat source. This reduces internal heat which is helpful in the summer but might lead to an increase in heating energy use [37].

Daylight Optimization

Special computer simulation can help to optimize daylight in the building. Typically, the following parameters are important:
1. Windows (type and location)
2. Glazing
3. Skylights, lightwells
4. Light shelves

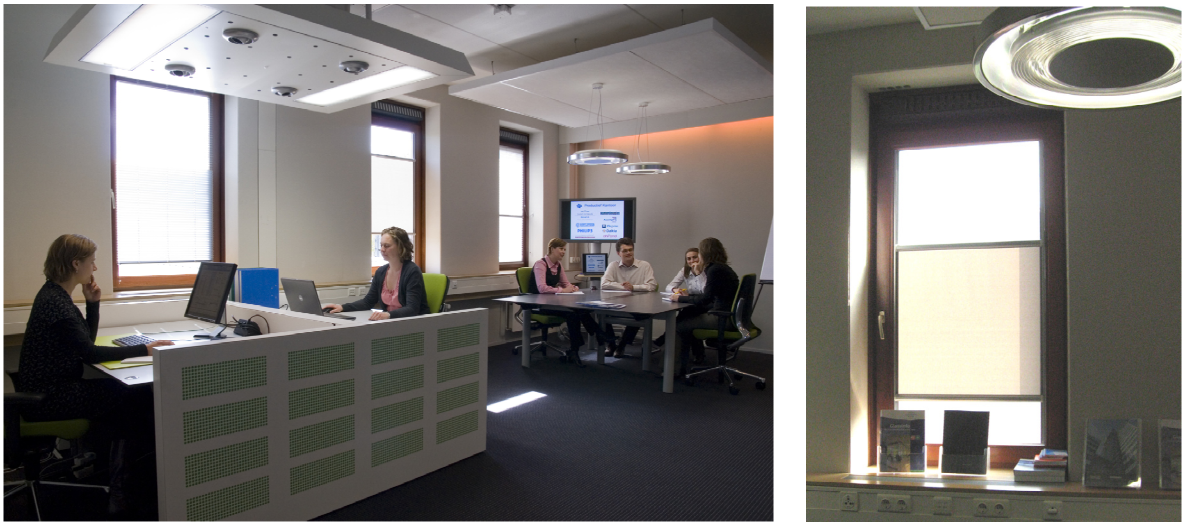


Figure 6.19: Pictures from «The Productive Office» at TNO (Netherlands Organization for Applied Scientific Research) in Delft. Moveable solar shading that covers a small window area prevents direct radiation hitting the person sitting there. Picture on the left: TNO, right: SINTEF Byggforsk.

As a design goal typically a daylight factor is used. New research results show that more dynamic factors provide advantages in determining useful daylight levels. These are daylight autonomy, daylight coefficient, and Useful daylight index (UDI) [38].

Energy efficient ventilation system

Energy use of ventilation systems is defined by two parameters as described in [2]:

- Air changes per hour
- SFP factor

Air changes per hour

The fresh air supply required in order to achieve satisfactory air quality is determined by the expected pollution load. Supply fresh air must therefore be assessed on the following three sources:
A) pollution from persons
B) pollution from materials (pollution from building materials, fixtures and installations)
C) pollution from activities and processes

Fresh-air supply is calculated on the basis of the values (A + B) and C. The two values (A + B) and (C) are compared and the largest value forms the basis for design of ventilation installations. The total exhaust must be balanced with the amount of fresh air supplied. This is normally achieved by the use of mechanical ventilation.

A) Pollution from persons
The amount of pollution a person makes, increases with increasing activity. Supply fresh air due to pollution from individuals must be at least 7 l / s person for people with light activity. With increased activity such as gymnastics and heavy work the fresh air supply should be increased so that the air quality is satisfactory. For premises where there is no information about how many people the premises are planned for, $15m^2$/person should be allowed for as design number (office), i.e. 0.47 l/s per m^2 floor space.

B) Pollution from materials
The amount of outside air that must be applied because of the odor and irritation effects from substances emitted from building materials and fittings, must be at least 1 l/(s.m^2) utility floor

space provided that mainly well-known and well-tested materials were used and are judged to be low emitting. If certified low-emitting materials that do not emit well-known irritant or hazardous substances are used, the outdoor air quantity is reduced to 0.7 l/(s.m²) utility floor space. High emitting products must be used in small scale.
Examples of materials that normally are low emitting include concrete, brick, ceramic tile, high pressure laminates, plasterboard, paper, wallpaper, glass, solid wood, etc. Wood from hardwood emits less material than wood from the conifer. Additives in concrete can lead to increased emission. More information is available from the Danish Techical Institute (http://www.teknologisk.dk/specialister/253), Norwegian Architectural Association (NAL; http://www2.arkitektur.no/page/Miljo/Meny_Miljo/8627/62214.html), and M1 in Finnland (http://www.rts.fi/M1classified.htm).

C) Pollution from activities and processes
Necessary fresh air supply due to activities and processes is calculated specifically from the specified requirements for pollution concentrations. Polluting processes should be encapsulated and provided with exhaust, or placed in special rooms. In rooms where smoking is permitted, it should be applied at least 20 l/s per person, calculated for the dimensions of the room to counteract acute irritation effects [2].

SFP factor

The normative requirement for Specific Fan Power (SFP) in commercial buildings is 2 kW/(m³/s) during normal ventilation operation. In the planning phase of ventilation system the engineer has rarely full control over all parameters that affect the SFP value. It is therefore recommended that the engineering objective of the SFP is equal to 1.7 kW/(m³/s) during normal operation of ventilation to allow for this. Moreover, the normative requirements for SFP outside of normal ventilation operation, that is, night and weekends, are 1 kW/(m³/s).

Optimum fan and motor selection, favorable designed fan outlet and careful component selection along the canal path with the highest pressure drop, can reduce energy requirements for fan operation significantly. As a rule, it is also feasible to optimize the placement of technical rooms and shafts, and increasing the aggregate size, short pathways of ducts, large ducts, etc. In addition, energy-efficient construction is in general less noisy than traditional plants.

The SFP outside operating hours may be minimized by regulating the speed of the fan so that the amount of air in the plant is reduced. It requires a frequency converter for speed control of the fan. A reduction in air volume by 25% will automatically provide a reduction of the SFP between 50% and 60%. In practice, often air volumes are reduced by 60% to 80% off the running time. This means that a facility that meets the requirements of SFP during normal operation will also satisfy the requirement outside of normal operations by reducing the speed of the fans.

Speed regulation is more expensive and also leads to a loss of energy that must be taken into account, but the variable speed control provides a range of benefits such as:

- the ability to regulate the amount of air to a minimum level, rather than to close the plant completely, reducing the risk of microbial growth and wear and tear on the unit
- ability to regulate the amount of air during periods of special needs (for example, cooling)
- optimal efficiency of the fan motor
- opportunity for demand control

Reducing the amount of air by choking the system (increasing the pressure drop), will at worst only reduce SFP similar to reduction of air quantity, which means that you have to halve the amount of air to half the SFP.

SFP can also be expressed as the ratio between the total pressure drop to be overcome with the help of the fans in the system and fan system efficiency. Fan system efficiency indicates how much of the effect added to the fan motor that actually will be needed to transport the air in the ventilation system. It is therefore important to use fans and fan motors with high efficiency and have the least possible power losses between fan and motor.
Other factors that should be assumed by the engineering and construction:

- dimension channel network for low air speed (maximum 1 Pa per meter)
- designing channel network for low pressure drop, i.e. the plan with the shortest possible routing paths and reduce the number of bends, T-cuts, transitions, etc. to a minimum
- do not use flexi-channels - not even for valve connection
- choose heat exchanger with low pressure drop
- select fans design that gives small system loss
- avoid filter with high pressure drop

Many ventilation systems are designed with significant spare capacity in case the use changes. Fans and fan motor should be designed in relation to the expected operating points (airflow and pressure drop) so they have a high efficiency at normal operating conditions.
Control measures of the SFP should be performed after commissioning, and ventilation system should be provided with a commissioning protocol which includes measured SFP values during normal operation. The requirement applies to the SFP at medium filter pressure drop. It is often appropriate to measure the SFP with the new filter. Then the SFP should be below 1.8 kW/(m^3/s) to fulfill the requirement of 2.0 kW/(m^3/s) at medium pressure. This rule of thumb is based on a maximum pressure drop increase across the filter at 100 Pa before the filter change on both supply air and exhaust side and just one filter on air supply side [2].

For further information on SFP and demand controlled ventilation, please refer to:

- SINTEF Building Research Design Guides - Construction Details 552335: Design of energy efficient ventilation systems
- SINTEF Building Research Design Guides - Construction Details 552323: Demand-controlled ventilation

6.4 Energy sources and related CO_2-emissions

The new regulations led to a new discussion about energy efficiency and CO_2 emissions from buildings [39]. Especially the use of CO_2 factors is still under development (NS3031). The report that specifies criteria for passive house in commercial buildings tries to establish CO_2 factors that link building design and CO_2 emissions [4].

Greenhouse gas emissions related to energy use in a building depends on the particular type of energy and energy source used for the operation of the building in its lifetime. In addition, embodied energy from production and disposal of building materials that can be associated with emissions have to be considered [40].

Electricity

Electricity in Norway has been considered virtually free of CO_2 emissions according to the Statistical office (SSB) [41], but this assessment is likely to be modified. As Norway is part of a larger electricity market, national consumption of electricity cannot only be seen in relation to Norway's own production. In the Nordic countries the current average production of electrical energy accounts for around 100 grams of CO_2-eqv. per kWh. If one looks at the "last" kilowatt-hours produced in this market, i.e. the so-called marginal production is CO_2-eqv. per produced kWh approx. 600 grams [42]. In ‘Statsbygg’ web-based model for calculating greenhouse gas emissions associated with construction and operation of buildings an emission factor equal to 357 grams CO_2-ekv./kWh of electricity is used [43]. This factor is the same as the average factor for the OECD countries in 2004, and therefore consists of a mixture of many different energy commodities. The development of national emission factor for electrical energy is needed.

District heating

District heating production varies, between the different manufacturers, and over time. Today, the incineration of waste, utilization of waste heat from industry, biofuels and the use of heat pumps constitutes just below 70% of all district heating production in Norway [SSB]. Remaining energy products in production are gas, oil and electricity. When assessing the CO_2 emissions of district heating to a specific building, it would be natural to assess the actual ratio of energy of the products of the current district heating provider [44].

Biofuels

Bio-based energy products are considered to have close to zero greenhouse gas emissions. The reason for this consideration is that the quantity of CO_2 emitted during combustion, was bound in the growth period. By seeing these events in context can result in zero emissions. Processing of bio-based raw materials for energy goods, however, requires some energy, thus bio-fuels (wood, tile, race, pellets, briquettes) has been given an emission factor equal to 14 grams CO_2-ekv./kWh thermal energy [44].

Heat pumps

A heat pump uses (usually) electrical energy to transport and utilize heat from a cold to a hot reservoir. The amount of heat that is moved may be considered as renewable and without CO_2 emissions.

A heat pump collects heat from
- Outdoor air
- Sea water
- Ground water
- Rock
- Earth
- Fresh water (river/lake)

[45]. Coefficient of performance (COP) ranges between 2.05 and 2.34 depending on the type of system [1]. CO_2 factors depend on the COP and the CO_2 factor for electricity.

Solar energy

There are two possibilities for utilizing solar energy:
- PV and
- Solar thermal systems.

PV

Photovoltaics (PV) are solid-state, semi-conductor type devices that produce electricity when exposed to light. The photovoltaic effect can be achieved by using many different semiconductor materials, the most commonly used is silicon.

Due to their modular layout, lightweight and simple assembling, there are many possibilities for integration of photovoltaic panels into roof or facade elements. PV panels may replace or assist other necessary functions, such as weather skin or solar shading. In this way, it is possible to identify three main principles for PV integration into buildings:

1. Weather skin: roof and facade integration
2. Solar shading elements
3. Daylighting elements

Solar thermal system

The value chain for active solar heat consists of the collection of solar energy, energy storage, and the distribution of it for space heating and/or production of hot tap water. The main components in a solar heating system are a solar collector, heating storage and heat distribution system. A working system also needs pipes, valves, pumps, expansion vessel and control unit. The latter must be specially adapted for solar energy [46].

Performance effiviencies range between 8.12 and 10.0 depending on the type of system [1]. CO_2 factors depend on the CO_2 factor for electricity used for the pumps. More information can be found in the Appendix.

7 FOLLOWING UP ON THE CONSTRUCTION SITE

7.1 Motivation and control

Objectives, requirements and solutions that are developed during the planning period shall be transferred to the construction process. It must be ensured that the contractor and craftsmen have the necessary knowledge and are motivated to deliver a building with high quality. A seminar for craftsmen, foremen and construction managers before the start of the construction site can be useful. Revision of goals, requirements and solutions can help to create the foundation, understanding, accuracy and care about detail solutions are necessary to achieve high energy and environmental goals. Details of the building to be tested, for example, with pressure testing and thermal photography can create an understanding that craftsmanship is of great importance. Also, information and discussion about the execution of critical points such as thermal bridges, air tightness and integration of technical installations should be included.

Follow-up during the construction phase is also necessary. Architect and consultants should be available to discuss solutions that the contractor selects. A more systematic quality assurance of the construction process will lead to better a construction and less building damage. TA control plan is an important tool in this work: it specifies what is to be controlled, when it will be checked, and how it should be checked. When the worker is informed about what, when and how the work will be quality assured, the control could be perceived positively [10].

Figure 7.1: Site visit at passive house project in Uddevalla, Sweden (top left); Blower door test (top right); Thermograph of window and wall (bottom left), visual control site visit (bottom right) (Photo: SINTEF Byggforsk; draftstop.net; passivhaustagung.de; hartford.gov)

7.2 Commissioning

Checklists can be prepared in detail during the project phase, and often in cooperation between the project leader and the facility manager.

Before the commissioning, the following work should be done:

- Commissioning and function control of the ventilation system
- Commissioning and function control of the heating plants
- Testing of the management and visualization systems

Construction Technical Review, air tightness measurement and thermal photography should be done at an earlier stage. Pressure testing is a requirement for the passive house, but recommended also for Low-energy buildings.

A recent review and adjustment of energy calculations with "as built" values should be done in order to document design parameter. In particular, it is important if the estimated energy consumption will be compared with actual consumption [10].

8 FOLLOWING UP IN THE OPERATION PHASE

8.1 Smart energy information technologies

Demand control of heating, ventilation, lighting and equipment. See chapter 6.3.

Demand controlled ventilation

A review of 157 classrooms in Oslo showed that at normal operation of the air handling system for 11 hours demand control system with motion sensors can reduce energy demand by 25 kWh/(m^2a) while the use of demand control system with CO2 sensors can reduce energy demand by 31 kWh/(m^2a) compared to a Constant Air Volume (CAV) –system [47].

Demand controlled lighting

Savings of the lighting system range between 40 – 60% of the reference energy use for lighting (in TEK07 this is 25 kWh/(m^2a)).

8.2 Feedback on consumption

A feedback of energy consumption to the user can help to raise awareness and effective implementation of energy saving measures [48].

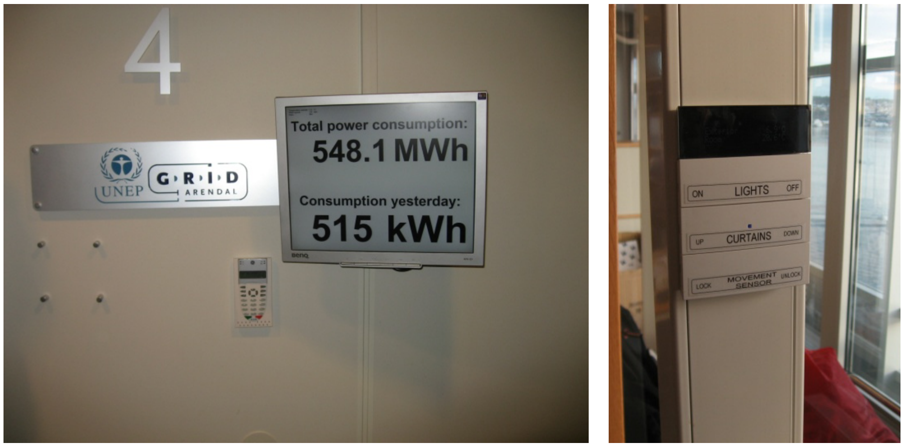


Figure 8.1: Display of energy consumption in staircase and individual control in office (FN bygg, Photo: SINTEF Byggforsk)

8.3 Energy tracking system - ETS

A user manual should be prepared that includes operation and maintenance of the building and technical facilities, but also how the building was planned to be used to achieve the intended energy use. There are a range of products for energy registration and follow-up on the market which are tailored towards the use in commercial buildings.

8.4 Classification

The classification tools mentioned in the previous chapter Tools for Environmental evaluation can also be used as verification of the completed building, eventually should a classification be considered before further energy saving measures are to be implemented.

8.5 Reporting, monitoring and evaluating

Reports on building performance (measurements and user evaluations) and lessons learnt from process, concepts and applied technologies can help to improve energy efficiency in office buildings [49].

Contractors and design teams should revisit their buildings and make a post construction report. This should be made a contractual matter at an early stage.

The post construction report should make visible the various dilemmas faced in the design and building process. Even when the building owner from the starting point is determined to choose environmentally friendly solutions, it might turn out that it is not an easy task in practice. The report should include a description of how the objectives of the project have been met, fulfillments and short-comings, including adequate indicators and relevant performance requirements (compared with the national average).

The post construction report should have 12 months continuous of actual energy performance figures compared with the design target figures. This will help to encourage the design team to properly train the building users in operating the low energy technologies, again a matter often overlooked. The fees for post construction monitoring should be negotiated at the same time as the design fees; otherwise they are likely to be quite high [9].

A lot of reports point out the benefits of a continuous commissioning process that should be applied in the maintenance contracts [50].

9 REFERENCES

1. NS3031, *Calculation of energy performance of buildings – Method and data*. 2007, Standard Norge.
2. TEK, *Energi – Temaveiledning*, StatensBygningstekniskeEtat, Editor. 2007, Norsk Byggtjenestes Forlag.
3. NS3940, *Area and volumes of buildings*. 2007, Standard Norge.
4. Dokka, T.H., et al., *Kriterier for passivhus- og lavenergibygg – Yrkesbygg*. 2009, SINTEF Building and Infrastructure: Oslo.
5. Andresen, I., et al. *Passive House Projects in Norway – an Overview*. in *11th international Passive House conference*. 2007. Brengenz.
6. NS3700, *Criteria for low energy and passive houses - Residential buildings*. 2010, Standard Norge.
7. Wigenstad, T., et al., *Energimerking av næringsbygg*. 2005, SINTEF Building and Infrastructure: Trondheim.
8. Task40/Annex51. *Towards Net Zero Energy Solar Buildings*. 2009 [cited 2006 23 October 2006]; Available from: http://www.civil.aau.dk/Annex44/.
9. Buvik, K. and A.G. Hestnes, *Interdisciplinary approach to sustainable building – Experiences from working with a Norwegian demonstration building on retrofitting.* Nordic Journal of Architectural Research, 2008. **08**(1).
10. Andresen, I. and A.G. Hestnes, *Integrert energi design*. 2008, Norwegian University of Science and Technology: Trondheim.
11. *ECOTECT*. [cited 2010 11 Jan]; Available from: http://www.squ1.com.
12. Haase, M. and A. Amato. *The importance of communication in concept design simulation*. in *EAAE/ARCC conference*. 2008. Copenhagen, Denmark: EAAE/ARCC.
13. Hensen, J.L.M., R. Lamberts, and C.O.R. Negrao, *Building performance simulation at the start of the 3rd millennium.* Building and Environment, 2002. **37**(8-9): p. 765-767.
14. Augenbroe, G. and J. Hensen, *Simulation for better building design.* Building and Environment, 2004. **39**(8): p. 875-877.
15. Xia, C., Y. Zhu, and B. Lin, *Building Simulation as Assistance in the Conceptual Design.* Building Simulation Journal, 2008. **2008**(1): p. 46–52.
16. Støa, E., D. Kittang, and I. Andresen. *Verktøy for miljøprogrammering for tiltak i byer og tettsteder*. 2006 [cited 2008 24.04.2008]; Available from: http://www.miljoprogrammering.no/hjelp/rapport.pdf.
17. Kleiven, T., *Natural ventilation*, in *Architecture*. 2004, NTNU: Trondheim.
18. John, G., *Sustainable building solutions: a review of lessons from the natural world.* Building and Environment, 2005. **40**: p. 319-328.
19. Dokka, K.A. and T.H. Dokka, *Validation of SIMIEN*. 2008.
20. Haase, M. and I. Andresen. *Key issues in energy-efficient building envelopes of Norwegian office buildings*. in *8th Nordic Symposium on Building Physics*. 2008. Copenhagen, Denmark.
21. Haase, M., et al. *Sensitivity analysis in the design of climate adapted building envelopes in Norway*. in *ANZAScA conference*. 2008. Newcastle, Australia.
22. Haase, M., et al. *Simulation of energy-efficient office buildings in Norway*. in *Building simulation conference (BS09)*. 2009. Strathclyde.
23. Haase, M., et al., *Building for climate change – meeting the design challenges of the 21st century.* Nordic Journal of Architectural Research - special edition for COP 15 - Copenhagen, 2009.
24. Voss, K., et al., *Buerogebaeude mit Zukunft*. 2006, Karlsruhe: Solarpraxis.
25. Time, B. *Adaption of buildings to a changing climate in Norway – resent and future research work*. in *Passivhus Norden*. 2009. Gothenburg.

26. Grynning, S., et al., *Vakuumisolasjonspaneler for bruk i bygninger – Egenskaper, krav og muligheter*. 2009, SINTEF Byggforsk: Trondheim.
27. Relander, T.O., J.V. Thue, and A. Gustavsen. *Air tightness performance of different sealing methods for windows in wood-frame buildings*. in *8th Nordic Symposium on Building Physics*. 2008. Copenhagen, Denmark.
28. Haase, M., et al. *The role of air tightness and heat recovery in the ventilation system of energy-efficient office buildings in Norway*. in *Buildair / AIVC conference*. 2009. Berlin.
29. Haase, M. and I. Andresen, *The Role of Passive Cooling Strategies for Norway.* International Journal of Climate Change: Impacts and Responses, 2009. **1**(2): p. 63-74.
30. Haase, M., et al. *Energy-efficient buildings in Norway – from low energy standards to net zero energy buildings*. in *Eurosun*. 2008. Lisbon, Portugal: ISES.
31. Haase, M., et al. *Design and future of energy-efficient office buildings in Norway*. in *Building simulation conference (BS09)*. 2009. Strathclyde.
32. Haase, M. and I. Andresen. *Adapting office building envelopes in Nordic countries*. in *International congress e-nova*. 2008. Pinkafeld, Austria.
33. Artmann, N., H. Manz, and P. Heiselberg, *Climatic potential for passive cooling of buildings by night-time ventilation in Europe.* Applied Energy, 2007. **84**(2): p. 187-201.
34. Saelens, D., *Energy performance assessment of single storey multiple-skin facades*, in *Department of Civil Engineering*. 2002, KATHOLIEKE UNIVERSITEIT LEUVEN: Leuven.
35. Dokka, T.H. and M. Thyholt, *Passiv klimatisering*, in *SINTEF Byggforsk*. 2006, SINTEF Byggforsk: Trondheim.
36. Haase, M. and I. Andresen. *The potential for passive cooling strategies in Norway*. in *International congress e-nova* 2008. Pinkafeld, Austria.
37. Haase, M., I. Andresen, and T.H. Dokka. *Guidelines for sustainable building envelopes*. in *International conference on sustainable development (ISDRC)*. 2009. Utrecht.
38. Reinhart, C. and S. Selkowitz, *Daylighting--Light, form, and people.* Energy and Buildings, 2006. **38**(7): p. 715-717.
39. Buvik, K., M. Haase, and M. Thyholt, *CO2-effekt av energitiltak i bygninger.* Architektur N, 2009. **06**(09): p. 42-47.
40. Mysen, M., et al., *Forslag til Byggenæringens Miljøfond og Tiltaksmodellen*. 2010, SINTEF Byggforsk: Oslo.
41. StatisticsNorway (2006) *Energy consumption in Norway*. Electricity statistics.
42. NVE. *Norwegian water and energy department*. Available from: www.nve.no.
43. Civitas. *Klimagassregnskap for utbygningsprosjekter*. 2009; Available from: http://www.statsbygg.no/FoUprosjekter/Klimagassregnskap/.
44. prNS3700, *Criteria for low energy and passive houses - Residential buildings*. 2009, Standard Norge.
45. HeatPumpCentre, I. *Heat Pump Technology*. 2009; Available from: http://www.heatpumpcentre.org/.
46. Andresen, I., *Planlegging av solvarmeanlegg for lavenergiboliger og passivhus*, S. Byggforsk, Editor. 2008, SINTEF Byggforsk: Oslo.
47. Mysen, M., et al., *Occupancy density and benefits of demand-controlled ventilation in Norwegian primary schools.* Energy and Buildings, 2005. **37**(12): p. 1234-1240.
48. Mathisen, H.M., R. Høseggen, and S.O. Hanssen. *Measurement and simulation of energy use in an office building with hybrid ventilation*. in *Nordic Building Physics conference*. 2005. Reykjavik, Iceland.
49. Grini, C., et al., *LECO – Energibruk i fem kontorbygg i Norge*. 2009, SINTEF Byggforsk.
50. Djuric, N. and V. Novakovic, *Review of possibilities and necessities for building lifetime commissioning.* Renewable and Sustainable Energy Reviews, 2009. **13**(2): p. 486-492.

51. Poirazis, H., *Double-skin facades for office buildings*. 2004, Division of Energy and Building Design, Department of Construction and Architecture, Lund Institute of Technology, Lund University: Lund. p. 196.
52. Lieb, R.D.a.O., E. *'Das Duesseldorfer Stadttor' Exercising an integrated approach to double façade planning*. in *International Conference on Building Envelope Systems and Technology*. 1997. Ottawa, Canada: Bath: CWCT Services Ltd., University of Bath.
53. Pasquay, T., *Natural ventilation in high-rise buildings with double facades, saving or waste of energy.* Energy and Buildings, 2004. **36**(4): p. 381-389.
54. Loncour, X., et al. *Ventilated double facades*. [pdf file] 2004 October 2004 [cited 2006 Oct 2006]; Available from: http://www.bbri.be/activefacades/new/download/Ventilated%20Doubles%20Facades%20-%20Classification%20&%20illustrations.dvf2%20-%20final.pdf.
55. Oesterle, E., et al., *Double-skin facades : integrated planning : building physics, construction, aerophysics, air-conditioning, economic viability*, ed. E. Oesterle. 2001, Munich: Prestel. 207 p.
56. Balocco, C., *A simple model to study ventilated facades energy performance.* Energy and Buildings, 2002. **34**(5): p. 469-475.
57. Annex44. *State of the Art report*. Integrating responsive building elements in buildings 2006 [cited 2006 23 October 2006]; Available from: http://www.civil.aau.dk/Annex44/.
58. Saelens, D., J. Carmeliet, and H. Hens, *Energy performance assessment of multiple skin facades.* International Journal of HVAC&Research, 2003. **9**(2): p. 167-186.
59. von Grabe, J., *A prediction tool for the temperature field of double facades.* Energy and Buildings, 2002. **34**(9): p. 891-899.
60. Annex44. *State of the Art report of responsive building elements*. Integrating responsive building elements in buildings 2006 [cited 2006 23 October 2006]; Available from: http://www.civil.aau.dk/Annex44/.
61. Andresen, I., et al., *Energy-Efficient Intelligent Facades. A state-of-the-Art*, SINTEF, Editor. 2005, SINTEF Building and Infrastructure: Trondheim.
62. Saelens, D., S. Roels, and H. Hens, *The inlet temperature as a boundary condition for multiple-skin facade modelling.* Energy and Buildings, 2004. **36**(8): p. 825-835.
63. Stec, W.J. and A.H.C.v. Paassen, *Symbiosis of the double skin facade with the HVAC system.* Energy and Buildings, 2005. **37**(5): p. 461-469.
64. Haase, M., F. Marquez da Silva, and A. Amato. *Model validation of double-skin façade simulation*. in *Sustainable Building conference 2007 (SB07)*. 2007. Hong Kong SAR.
65. Haase, M. and I. Andresen. *Adapting office building envelopes in Nordic countries*. in *International congress e-nova* 2008. Pinkafeld, Austria.
66. Haase, M., M. Thyholt, and T. Wigenstad. *Energy-efficient building refurbishment in Norway*. in *CISBAT - From nano to urban scale*. 2009. Lausanne.
67. Haase, M. and A. Amato, *Performance evaluation of three different façade models for sustainable office buildings.* Journal of Green Building, 2006. **1**(2).
68. Haase, M., F. Marques da Silva, and A. Amato, *Simulation of ventilated facades in hot and humid climates.* Energy and Buildings, 2009. **41**(4): p. 361-373.
69. TRNSYS. *Trnsys16 user manual*. [User manual] 2004 Oct 2006 [cited 2005 Jan 2005]; Available from: http://sel.me.wisc.edu/trnsys/.
70. NS-ISO7730, *Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria*. 2005, Standard Norge.

Appendix

Double-skin façades

General introduction

The double skin is a system involving the addition of a second, glazed skin installed at a distance from the main façade. The intermediate space that is created provides additional insulation and can be heated by solar radiation, thus improving energy performance.

In the summer, the double façade can reduce solar gains as the heat load against the internal skin can be reduced by the ventilated cavity. Shading systems placed within the cavity are protected from the weather. A natural stack effect occurs in a solar heated cavity, as absorbed solar radiation in the glass, the structure and blinds is released. In the winter, the double façade will act as a buffer zone between the building and the outside; reducing heat losses and improving U-values.

Figure A.1: Exempel av dobbel fasade (FN bygg in Arendal, Norway; Photo: SINTEF Byggforsk, sketch on the right Skanska Norge)

Amenity and comfort may be claimed to be the primary function of a double-skin façade. Secondary function is energy savings (buffer effect, preheating). Attention must be given to the needs for solar shading and ventilation for summer periods. Adapting to the climate might be possible with a double-skin façade system by controlling the air flow in the cavity according to the external climatic conditions. A lot of developments in façade design has thus focused on controlled ventilated double-skin facades [34, 51].

The term double skin façades (DSF) refers to an arrangement with a glazed skin in front of the main glazed façade, forming a cavity in between. Solar control devices are placed within the cavity, where they are protected from weather and air pollution [51-55].

Allowing air to flow in the cavity gives advantages in thermal performance which is the reason why DSF are designated as ventilated façades. Further advantages rise from the extra skin introducing control over the wind pressure on the inner façade, thus - at least for some of the possible DSF configurations - makes natural ventilation possible even in high-rise buildings, “powered” both by the wind and the stack effect generated within the cavity. This stack effect is due to the “solar collector” behaviour of the cavity, enhanced by the re-radiation from the shading devices. Heat is then removed by the ascending air flow [56].

A DSF can also act as a thermal buffer between outdoor and indoor environment, contributing to keeping the innermost façade less hot in summer and less cold in winter, meaning that spaces closer to the windows can be better utilized as a result of the increased thermal comfort conditions [57-59].

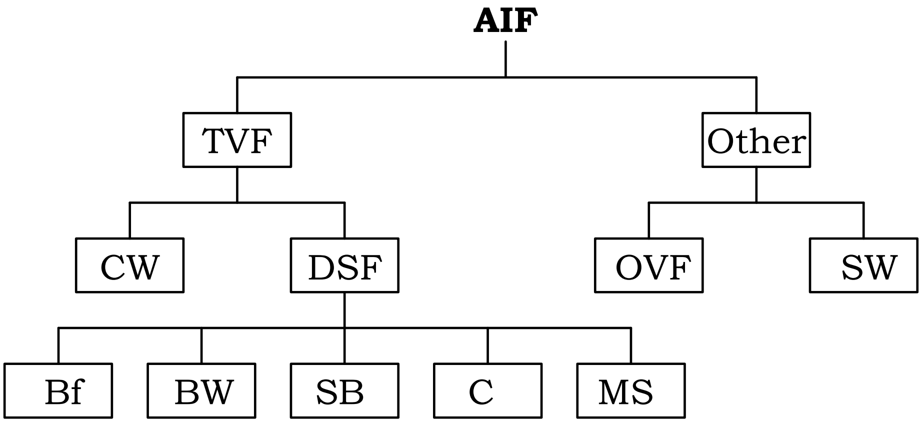


Figure A.2: Classification of double-skin facades [60], Advanced intelligent façade (AIF), transparent ventilated façade (TVF), climate wall (CW), double-skin façade (DSF), buffer façade (Bf), boc window façade (BW), shaft-box window façade (SB), corridor façade (C), multi-storey façade (MS), opaque ventilated façade (OVF), swing window façade SW).

The air flow driving force within the cavity defines the type of ventilation. Types to be considered are [51, 57]:

- Natural Ventilation (NV), the driving force being the wind induced pressure distribution or the stack effect.
- Mechanical Ventilation (MV), the driving force being supplied by a fan.
- Hybrid Ventilation (HV), using both of the previous as a function of ventilation needs and outdoor conditions.

Figure below shows the possible airflow paths in double-skin facades. The air flow path is a very important issue being strongly associated to the integration of the double-skin facade into the building energy and control systems. Possible arrangements are:

- Exhaust air: the DSF acts removing indoor air (Fig.A.3.IV).
- Supply air: the DSF acts supplying air to the indoor environment (Fig. A.3.III).
- Static air buffer: the DSF acts as both of the previous depending on outdoor/indoor conditions and local control devices.
- External air curtain: the DSF cavity is ventilated by outdoor air with no connection to the indoor air (Fig. A.3.I).
- Internal air curtain: the AIF cavity is ventilated by indoor air with no connection to outdoor air (Fig. A.3.II).

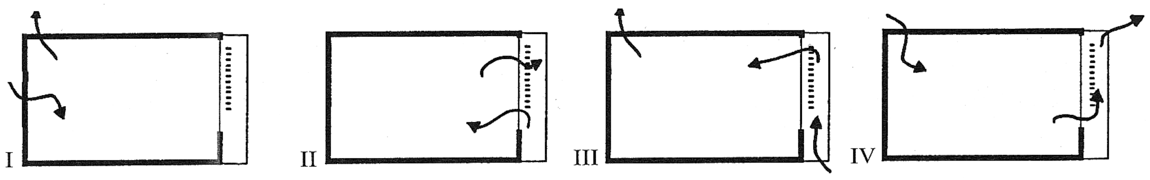


Figure A.3: Ventilation principles for use in double skin facades. I: Buffer zone, closed. II: Buffer zone, open. III: Air intake through facade. IV: Air exhaust through facade [61].

Figure A.4: Double facade with fixed opening below and controlled opening at the top (left) and solar shading in the cavity (UN-grid building in Arendal, Photos: SINTEF Byggforsk)

It was found that U- and g-values are dynamic with such a façade configuration. It is possible to change the airflow in the façade by controlling dampers in the façade [62-63]. This provides the possibility to adjust the performance of the façade according to external weather conditions. Usually detailed dynamic building simulation is applied in order to optimize the construction and control strategies of a double-skin façade [58, 64]. However, little work has been done to estimate the potential of energy performance of a DSF. This is mainly due to the large variety of possible façade and control configurations [65].

Example of refurbishment with the use of a double-skin façade

Energy efficient refurbishment of the existing building stock has to be focused. Here, appropriate solutions have to be identified and possible technologies have to be developed that integrate into the building. One possibility might be an advanced façade system. A lot of developments in façade design has focused on ventilated double façade systems for new buildings [34, 51]. However, there exists very little work on exploring the possibility of energy efficient refurbishment by applying a ventilated double façade system to an existing building.
With the help of dynamic computer simulations of energy and indoor environment for a case building in Norway the impact of an additional ventilated glass facade on energy demand and indoor environment was analyzed [66]. A focus was put on a comparison of energy demand and thermal comfort levels of various cases. Main parameters to study were:

- different construction standards (air tightness, thermal bridges, and facade design) and their energy demand implications
- simulation robustness in dependence of different assumptions (thermal bridges in and air tightness of the existing building)
- airflow control strategies and their energy demand implications
- comfort criteria and energy issues (thermal vs. visual comfort vs. heating cooling demand)

A model of the existing building with an extra glass layer on the outside has been developed. Dynamic thermal building simulation has been coupled with airflow network in order to simulate the airflow through the ventilated double-skin façade.

Thermal model

Three different models were developed using TRNSYS and TRNFLOW [67-69]:

- base case model
- ventilated double-skin façade with insulated glass
- ventilated double-skin façade with single laminated glass

Two different rooms were taken to compare the results; an office room in the 3rd and a hotel room in the 5th floor. The model description is detailed in Table1.

Table A.1: Description of simulation model.

Climatic data	Trondheim (meteonorm file)
3. floor	office room: 5.3m x 6 m (internal gains: equipment 11W/m^2, 2 persons (2 x 75 W), lights 8W/m^2, operation 12 hours/5 days/52 weeks)
5. floor	hotel room: 5.3m x 6 m (internal gains: equipment 1W/m^2, 2 persons (2 x 75 W), lights 8W/m^2, 16 hours/7 days/ 52 weeks)
Ventilation system	2 fans per room (120 m^3/s, balanced ventilation), 17 °C supply air temperature
Walls	External walls with U-value = 0.6 W/(m^2 K)
Shading:	Automatically controlled venation blinds in cavity (no shading in base case)

Table A.2: Description of airflow and leakage.

specifications		**Base case**	**Double façade system**	
		Existing fasade	**dfs (1)**	**dfs (2)**
Window properties	Glass layers	Insulating glass (4/16/4), air filled	Additional insulating glass (4/16/4), lowE, Krypton filling	Additional single glass 10 mm
	U-value	2.6 W/(m^{2}K)	1.1 W/(m^{2}K)	5,46 W/(m^{2}K)
	g-value	0.76	0.60	0.77
Air leakage, m=Cm x (p)^n	Leakage between	room and outside	room and dfs (1)	Same as dfs (1)
	Cm	0.0128 kg/s @ 1Pa (based on 0.6h^{-1})	Same as base case	Same as dfs (1)
	n	0.65	Same as base case	Same as dfs (1)
Other leakage, m=Cm x (p)^n	Leakage between	-	dfs (1) and outside	Same as dfs (1)
	Cm	-	0.0021 kg/s at1Pa (based on 0.1h^{-1})	Same as dfs (1)
	n	-	0.65	Same as dfs (1)

Airflow model
Airflow modeling was coupled to the thermal model (see Figure 1). Here, the dsf consists of 16 different zones that were linked using the specifications in Table 2.

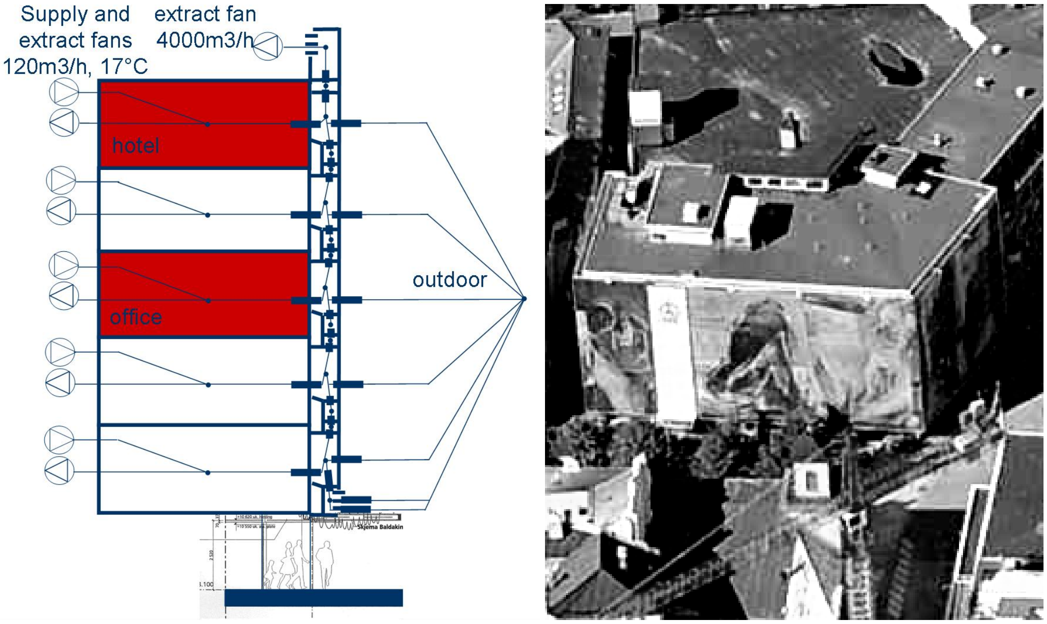


Figure A.5: Model and airflow description and real building with textile facade.

In order to evaluate the winter and summer performance the following parameters were examined:

- Temperature (inside window surface)
- Energy (power)
- Thermal comfort (with values as described in Table 3; according to ISO 7730 [70])

Table A.3: Values for thermal comfort calculations.

Parameter	**values**
Clothing [Clo]	1
Metabolic rate [MET]	1
Activity [W/m^2]	0
Air speed [m/s]	0.1

The results show that significant efforts are needed in order to establish ventilated double-skin facades in Norwegian buildings as high energy efficient solutions. In particular, significant improvements of construction details regarding insulation levels and air tightness of the envelope are needed. The best solution provides a heating energy demand reduction of 40%, but the importance of a clear ventilation strategy and level of details became obvious. Also, condensation problems have to be addressed.

The design of energy robust, energy efficient, and comfortable buildings depends on building simulation. The strategy developed for improving building performance with an additional ventilated glass layer can be a sustainable solution for more buildings in the Norwegian building stock.

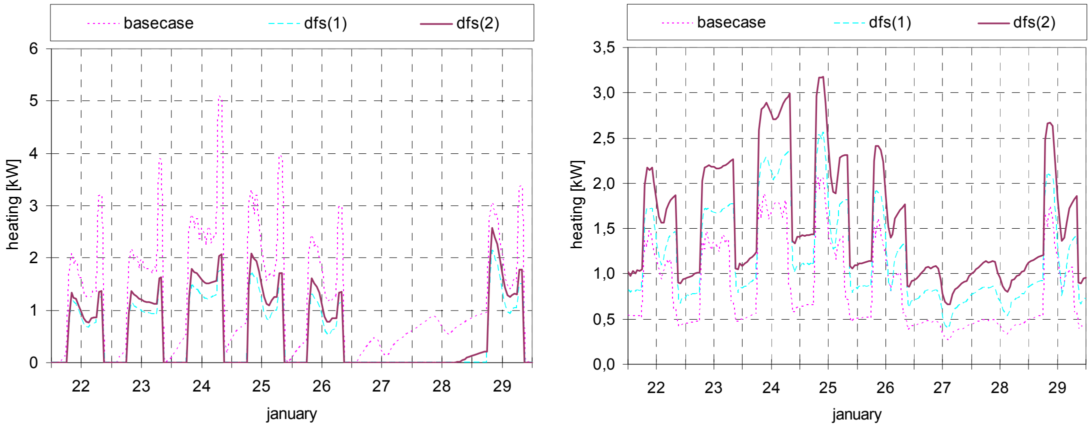


Figure A.6: Power distribution for office (left) and hotel room (right) for different façade solutions. It presents the power needed for the office and the hotel room for a typical winter week. It can be seen that power distribution in the office (left) is reduced for both dsf types (1 and 2) with slightly more reduction for dfs (1). The power distribution in the hotel room (right) shows an increase for both dsf types (1 and 2) with higher increase for dsf (2).

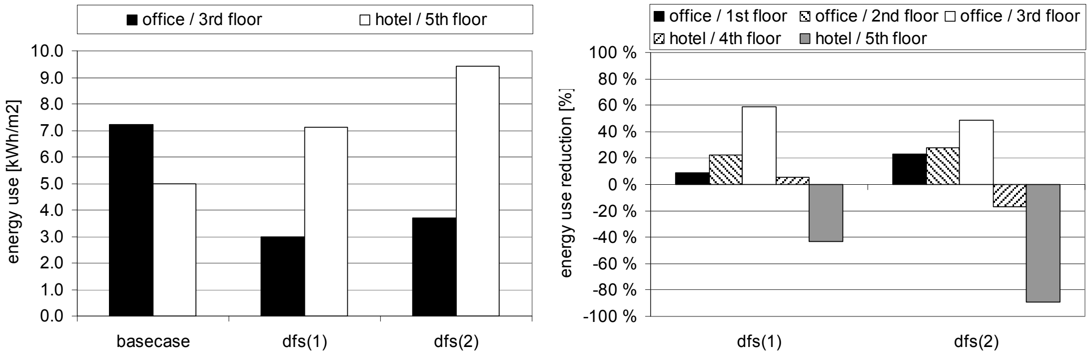


Figure A.7: Summed net energy demand for heating in office and hotel room (left) and percentage energy demand for heating compared to base case in all rooms (right). Figure 4 shows the net energy demand results for both rooms (left) and a reduction in energy demand in percentage compared to base case for all rooms (right). It can be seen that energy demand in the different rooms vary. Energy demand for heating in the office room (3rd floor) is reduced by 59% while energy demand in the hotel room (5th floor) is increased by 89%.

Thermal comfort
Figure 8 presents thermal comfort of the office and hotel room for a typical summer week.

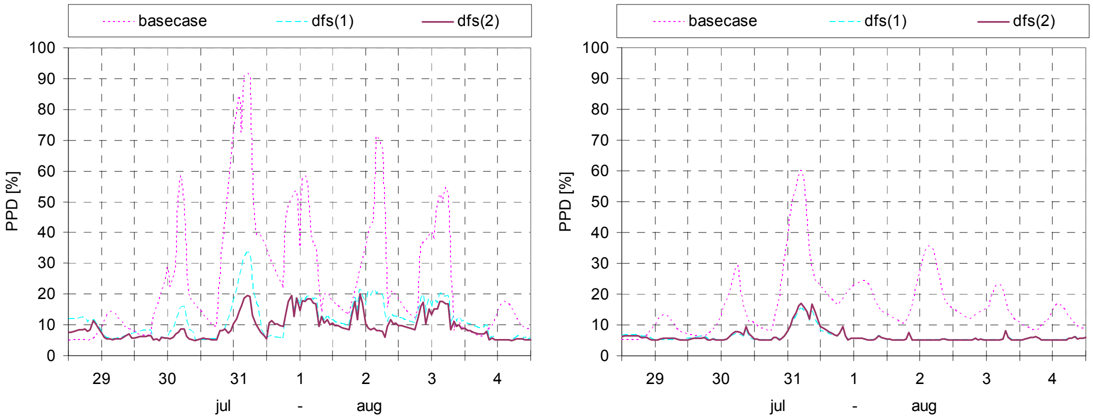


Figure A.8: Thermal comfort for a typical summer week in office (left) and hotel room (right).

The results show that energy efficient refurbishment of an existing façade with double façade system is possible. Temperatures on the inside of the windows as well as thermal comfort are improved with both types of dfs (1 and 2). Energy savings seem to depend on the vertical airflow within the dfs and range between 59% and -89% for the different rooms.
The construction of a dsf in combination with high air leakages in the old façade results in airflows between rooms and dsf cavity. The amount of airflow increases because of the dfs which leads to an increase in energy demand for heating. Especially the hotel room in the 5th floor needs between 43% and 89% more heating (with an additional insulated glass layer (dfs 1) and single glass layer (dfs 2) respectively).

The solution (1) with insulated glass seems to perform better with respect to glass temperatures, thermal comfort, and energy savings than solution (2).
More work is needed in order to optimize the construction of a ventilated dfs in respect to operational energy savings. One possibility could be to reduce air leakages in the old façade construction.
Condensation of humid cold air on the outside and inside of the dfs layer could lead to unwanted effects and should therefore be evaluated [66].

Solar energy utilization

There are two possibilities for the appliaction of solar energy systems in buildings:

- Solar thermal system and
- PV.

Solar thermal system

The value chain for active solar heat consists of the collection of solar energy, energy storage, and the distribution of it for space heating and/or production of hot tap water. The main components in a solar heating system are a solar collector, heating storage and heat distribution system. A working system also needs pipes, valves, pumps, an expansion vessel and control unit. The latter must be specially adapted for solar energy [46].

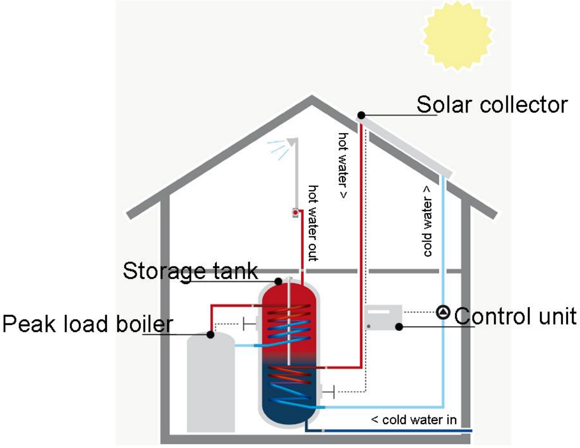


Figure A.9: Solar thermal system, adapted from [46].

Solar energy collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium. The major component of any solar system is the solar collector. This is a device which absorbs the incoming solar radiation, converts it into heat, and transfers this heat to a fluid (usually air, water, or oil) flowing through the collector. The solar energy thus collected is carried from the circulating fluid either directly to the hot water or space conditioning equipment or to a thermal energy storage tank from which can be drawn for use at night and/or cloudy days.

There are basically two types of solar collectors: non-concentrating or stationary and concentrating. A non-concentrating collector has the same area for intercepting and for absorbing solar radiation, whereas a sun-tracking concentrating solar collector usually has concave reflecting surfaces to intercept and focus the sun's beam radiation to a smaller receiving area, thereby increasing the radiation flux. A large number of solar collectors are available in the market [46].

The collector is the heart of the solar system, which is where solar radiation is converted to heat. There are several different types of stationary solar collectors, for example flat plate solar collectors (FPC), vacuum tube-collectors (ETC), and compound parabolic solar collectors (CPC). FPC is the one that traditionally has been used mostly in buildings. Gradually, ETC have a larger share of the market.

Figure A.10: Solar thermal system at south facing facade (left) and on the roof (right) (Bravida office building, Photo: SINTEF Byggforsk)

Figure A.11: FPC integrated into the facade (FN Bygg, Photos: SINTEF Byggforsk), ETC can alsobe used as facade elements, f.e. as railings in balconies.

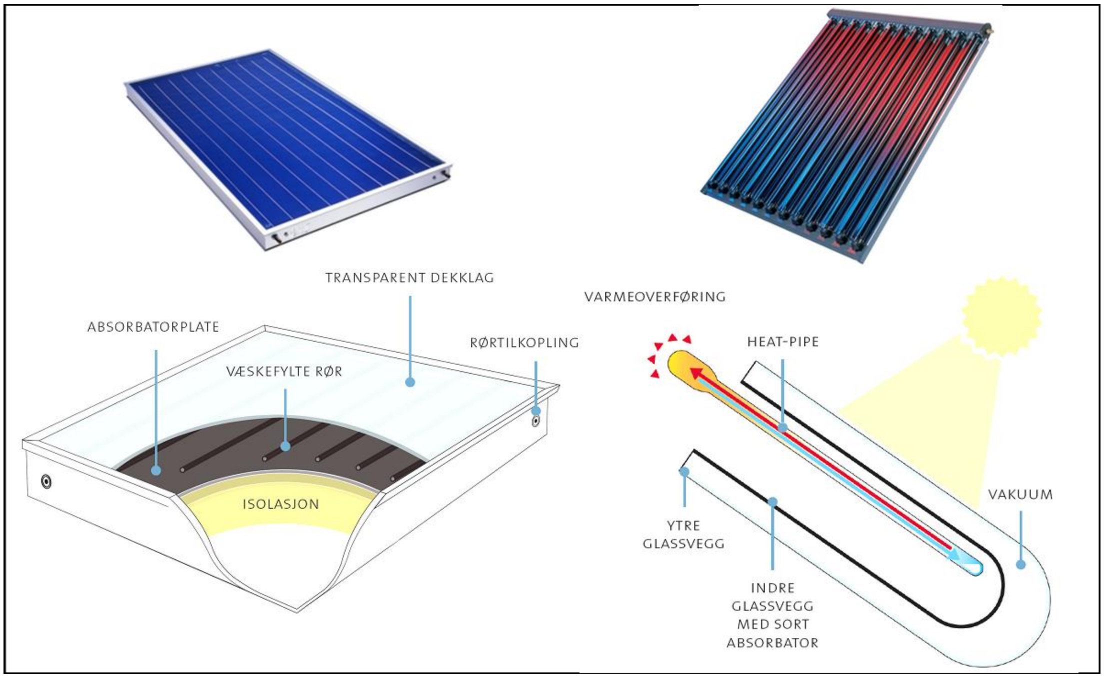


Figure A.12: Two most used solar absorbers – Flat plate collector (FPC) on the left and evacuated tube collector (ETC) on the right, adapted from [46]

Building integrated PV systems
Due to their modular layout, lightweight and simple assembling, there are many possibilities for integration of photovoltaic panels into roof or facade elements. PV panels may replace or assist other necessary functions, such as weather skin or solar shading. In this way, it is possible to identify three main principles for PV integration into buildings:
Weather skin: roof and facade integration
Solar shading elements
Daylighting elements

General modules are optimized for efficiency and put on roof or as façade cladding. They are not developed for building integration.
Special products developed for building integration are optimized for structural integration and placed in roof or glazing. Products are often not complete systems.
BIPV products that are structurally and architecturally integrated with roof, glazing, or façade cladding have already high standard and high costs.
Special project developments focus on structural and architectural integration with roof, glazing, or façade cladding has already high level of architectural integration.

Advantages

- Electricity produced by PV can be used on the spot, stored in batteries, or sold to the electricity distribution network.
- Mature technology with increasing demand worldwide.
- No noise, no moving parts, no emissions on-site.
- On site production as:
    - stand-alone system (not connected to public el. grid)
    - grid-connected system (exchanging el. with public grid)
- PV may replace traditional building elements, e.g. roof or facade cladding
- Wide range of off-the-shelf PV products in various shapes, colours, costs and efficiencies to match different demands

Types of commercially available PV cells:

- Monocrystalline PV cells (~ 15% efficiency)
- Polycrystalline PV cells (~ 13% efficiency)
- Amorphous thin film PV (~ 7% efficiency)

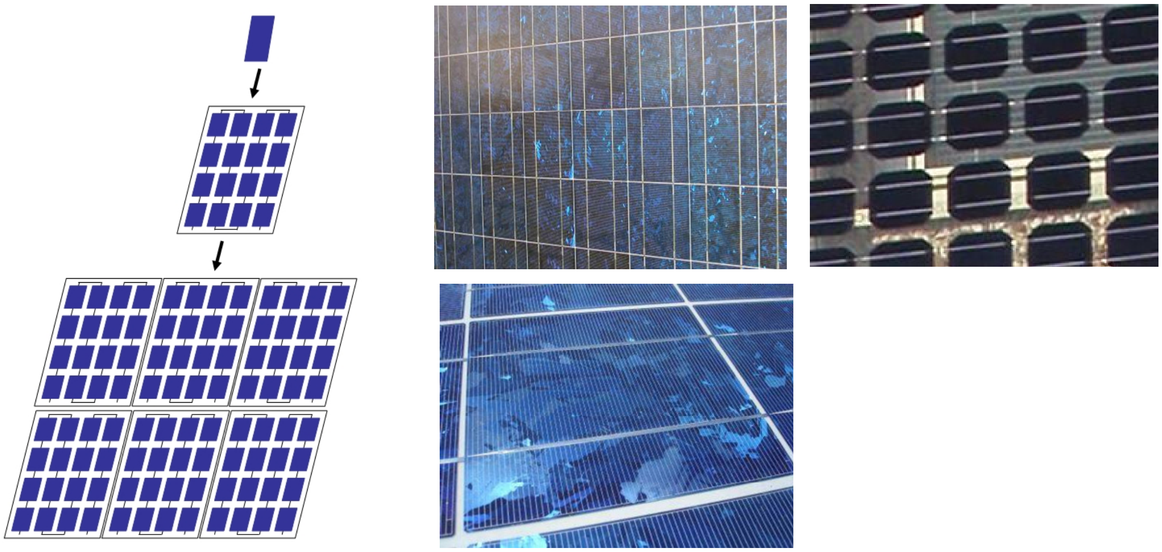


Figure A.13: Photovoltaic systems. Cell, Module, Array, and different types of PV cells. A range of sizes, transparency & colour are available.

Orientation of PV modules

Optimal angle with regard to solar irradiation:

- Vertical: tilted (measured from the Horizontal) appr. Little less than degrees of laltitude, depends on local climate (especially cloud cover or ratio between direct and diffuse radiation)
- Horizontal: due South (+/- 45o if better fit with building design)
- Avoid shading by surrounding vegetation or buildings
- In a serially connected PV module, the cell with the lowest output determines the efficiency of the whole module
- Shading of one single PV cell therefore reduces the efficiency of the entire module

Before retrofitting After retrofitting.

Figure A.14: New skin layer of glazing and PV. BP Solar Skin, NTNU, Trondheim, Norway, 63 °N. Renewal design: SINTEF/NTNU

Due to increasing façade performance expectations the envelope has become a more complex and multifunctional element of a building. New technological developments allow radical changes to the design of façades and roofs. During building envelope design awareness is needed that the use of PV needs to be integrated in order to fulfill building envelope performance expectations, e.g. today PV can be used in the building envelope to provide:

- Weather protection

- Heat insulation
- Sun protection
- Noise protection
- Modulation of daylight and
- Security

Figure A.15: SINTEF researcher Inger Andresen in front of the renovated façade at NTNU and a scetch of working principle The intermediate space acts as a buffer zone that creates opportunities for improving energy performance. The BP Solar Skin has multiple functions: it is a new building skin which produces electricity, provides extra insulation and air tightness to the building envelope, provides a stack effect for ventilation air, gives daylight and view out and gives a more aesthetic façade than the old one.

The SINTEF Group is the largest independent research organization in Scandinavia. Our vision is «Technology for a better society». Our goal is to contribute to wealth creation and to the sound and sustainable development of society. We generate new knowledge and solutions for our customers, based on research and development in technology, the natural sciences, medicine and the social sciences.

SINTEF Building and Infrastructure is the third largest building research institute in Europe. Our objective is to promote environmentally friendly, cost-effective products and solutions within the built environment.

SINTEF Building and Infrastructure is Norway's leading provider of research-based knowledge to the construction sector. Through our activity in research and development, we have established a unique platform for disseminating knowledge throughout a large part of the construction industry.

Technology for a better society

www.sintef.no