Energy-efficient office buildings with low internal heat gains
Simulations and design guidelines

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1. Introduction

1.1 Background

One of the greatest environmental challenges in the world today is the ever-increasing emissions of greenhouse gases (GHGs) from human activities and the influence these are believed to have on climate change and global warming. CO_2 is the most important anthropogenic GHG since it has been released in great quantities in more than 150 years of industrial activity. The major source for CO_2 emissions is the burning of fossil fuels in production of electricity and heat (Johansson, Nylander et al. 2007). In order to stabilize the concentration of GHGs in the atmosphere at a harmless level, the United Nations Framework Convention on Climate Change (UNFCCC) was established and the Kyoto Protocol was adopted in Kyoto, Japan in 1997. In the protocol, industrialized countries (currently 191 states) agreed on collectively reducing the amount of GHG emissions by 5.2% against 1990 levels over the period 2008-2012 (UNFCCC 2012).

1.1.1 European directive on energy performance of buildings

The Kyoto Protocol was an important starting point for the energy saving initiatives taken within the European Union. In 2007, the European Union made a commitment to, by the year 2020, reduce its own GHG emissions by 20% (in relation to 1990 levels), increase the share of renewable energy to 20% and reduce the total primary energy use by 20% (Europa 2012). Since buildings account for approximately 40% of the total energy consumption within the Union, the building sector plays a key role in achieving the climate policy. The reduction of energy consumption and the use of energy from renewable sources in the building sector are important measures needed to reduce the Union’s energy dependency and GHG emissions.

Thus, the European Parliament and the Council of the European Union promoted the Directive on Energy Performance of Buildings (EPBD) in 2002, with a recast formally adopted in 2010, as a legal framework for all member states in order improve the energy performance in buildings (European_Parliament 2010).

The EPBD requires that all member states shall:

- Apply a methodology for calculating the energy performance in buildings in accordance with the general framework.
- Take the necessary measurement to ensure that both new and renovated buildings meet the minimum energy performance requirements.
- Ensure that by 31 December 2020, all new buildings are nearly zero-energy buildings.
- Establish a system of certification of the energy performance of buildings.
- Establish a regular inspection of heating and air-conditioning systems in buildings.
- Ensure that independent control systems for energy performance certificates and building inspections are established.

It is each member states responsibility to set national minimum standards on energy performance in buildings. This makes it possible to take into account differences in outdoor climatic and local conditions as well as indoor climate requirements and cost-effectiveness. To comply with the EPBD, member states need to implement the directive in national building codes by 2013 at the latest (European_Parliament 2010).

1.1.2 Zero-energy buildings

According to the European Directive on Energy Performance of Buildings (EPBD), "*a nearly zero-energy building is a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby*" (European_Parliament 2010).

The nearly zero-energy building standard still has to be defined in detail on both European and national level. However, this is not an easy task since many parameters must be regarded. The concept has been described in literature with a wide range of terms and definitions, according to a review and overview carried out by Marszal, Heiselberg et al. (2011). First, the main issue must be to agree on the unit that is measured (and must be "zero") in the balance. The unit can for instance be primary energy, end-use energy, exergy, CO_2 emissions or energy cost. The most frequent unit so far is primary energy. The next thing to discuss is if the period of time for the energy balance is the entire life cycle, a year, a season or a month. Furthermore, the options for renewable on-site and off-site energy supply, as well as the connection options to the energy grid must be discussed. The authors also discuss whether all energy types should be included in the balance or not. A building's energy performance is often judged by the consumption of auxiliary energy only. The user related energy is mostly neglected since it is difficult to predict and since there is a lack of reasonable data. This approach ought to be changed though the authors consider. There is a great potential for reducing overall energy by motivating energy efficient behaviour. Furthermore, the user related energy becomes a more and more important part of the total energy use as the auxiliary energy constantly improves (Marszal, Heiselberg et al. 2011). Since the overall objective of the EPBD is to reduce the CO_2 emissions and the primary energy use in European buildings, the most logical approach should be to include the user related energy. User related energy is electricity and most electricity has high primary energy use and emits a large amount of greenhouse gases in production.

1.1.3 Swedish directive on energy performance of buildings

The Swedish government has not established the national directive on energy performance of buildings that is supposed to comply with the European Directive. The building code BBR 2012 is therefore the current regulation.

In the Swedish building code today, the energy performance is determined on the delivered (end-use) energy for heating, domestic hot water, cooling and auxiliary energy. The user related energy is not regulated at all. Primary energy is not estimated and there exist no national primary energy conversion factors which annoys many in the industry. However, for the last decade, an important aim of the Swedish energy policy has been to reduce the dependency of electricity in general and in particular the electricity used for heating in the building sector (Johansson, Nylander et al. 2007). This was clear when the building code was supplemented with much stricter guidelines for buildings with electricity supplied heating. Electric-heated buildings are now allowed to consume only half the energy compared to buildings with other sources than electricity.

Until the new directives are established, the only incitement for building low-energy or nearly zero-energy has been commercial or local interests. There are different volontary energy classification concepts such as passive house, GreenBuilding, Breeam, Leed and Miljöbyggnad. Just recently, in January 2012, the Swedish Centre for Zero-energy buildings published a new non-residential definition of zero-energy buildings, passive houses and mini-energy buildings (SCNH 2012).

1.1.4 Energy performance of office buildings in Sweden

The energy consumption in office buildings is generally high compared to other building types. The most recent statistics for Sweden show that the total delivered energy (end-use energy) to existing office buildings was around 210 kWh/m²yr in 2005. The statistics come from the "Step by step STIL" survey, an inventory of 123 existing office and administration buildings of different age carried out on behalf of the Swedish Energy Agency (Energimyndigheten 2007). The main objective of the survey was to identify the electricity use in office buildings. Out of the total average energy use, almost half is electricity (108 kWh/m²yr) and out of the total electricity use, half (57 kWh/m²yr) is user related electricity for lighting and office equipment. The average lighting energy was 23 kWh/m²yr in the studied office buildings. However, the lighting energy ranged between different buildings, from 7 to 53 kWh/m²yr for the lowest and the highest case. This spread can be explained by differences in number of lighting fixtures per m^2, type of fixtures, control systems and operation of the buildings. The result indicates however that there is a great saving potential regarding lighting energy in office buildings. Daylight can be utilized in a greater extent and modern efficient fixtures can be installed. Furthermore, all the user related electricity can be completely shut off outside office operation. The user related electricity contributes to large internal heat gains which must be cooled a great part of the year.

Regarding new office buildings, designed and constructed after the "Step by step STIL" survey, the energy performance has been improved. Particularly the heating demand has been reduced because of more well-insulated and airtight building envelopes. This improvement is likely a result of the new energy regulations established in 2006 combined with the GreenBuilding introduction. However, the electricity for lighting and equipment has not been improved since the user related energy is not regulated in the building code or in the GreenBuilding criterion. Since the user related electricity has not been reduced, and this electricity affects the internal heat gains, the cooling energy is still unnecessary high in Swedish office buildings, given the high latitude and rather cold climate.

Thus, there is a great saving potential in office buildings, both in reducing the electricity for lighting and equipment and cooling and ventilation energy. In Germany, a number of passive and low-energy office buildings has been constructed and evaluated. Also, research on energy efficiency potential for a passive office building has been carried out with dynamic simulations by Knissel (200X). These German experiences are clearly important for the development of future zero-energy office buildings. However, German building techniques must be developed to adapt to the Swedish context, as climate conditions and indoor comfort criteria differ between the countries. In Sweden, good examples of low-energy and nearly zero-energy residential houses have been built during the past decade. However, there is no example of a nearly zero-energy office building.

1.2 Objectives

The main objective of this research is to provide knowledge to the Swedish building industry, supporting the development of cost-effective office buildings with good indoor climate and very low energy use.

By identifying important design features and possibilities and limitations for Swedish conditions, the main goal is to reduce the annual energy use by 50%, compared to the requirements in the Swedish building code. This goal shall be achieved for the same investment cost as a normal office building.

The paper discusses recommendations and design guidelines for architects and engineers, regarding the design of future low-energy office buildings.

1.3 Method

Within this research, a literature review has been carried out with the main purpose to describe the current knowledge in design of low-energy office buildings. Previous studies and evaluations regarding building shape, size, envelope performance, solar protection, HVAC systems and lighting techniques have been studied. In addition, existing low-energy office buildings have been studied in order to identify general and specific solutions regarding building design, HVAC systems and techniques for lighting and office equipment. The results from both the review and the state-of-the art of existing office buildings have given valuable input for a parametric study carried out on a fictive office building with the dynamic simulation software IDA ICE 4. Important design features have been revealed in the simulation study and a potential office building with a good indoor climate, which uses less than half the energy compared to a new office building, including user related electricity have been presented.

1.4 Thesis disposition

Chapter 2 gives a theoretical framework based on a literature review regarding different design strategies for energy efficient office buildings.

Chapter 3 presents the state-of-the-art of 24 existing low-energy office buildings in Northern Europe.

Chapter 4 presents the results from the simulation study where different design parameters were studied in detail in order to see their impact on a building’s energy balance.

Chapter 5 summarizes the results and discussions from the previous chapters.

2. Theoretical framework

The main objective of this review is to describe the current knowledge in design of low-energy office buildings. Previous studies and evaluations regarding building shape, size, envelope performance, solar protection, HVAC systems and lighting techniques are presented. The results from this review will give valuable input for the simulation study.

2.1 Method

An extensive literature search was undertaken in 2009 by Leroux (2010), and completed with additional searches in the years of 2010-2012, to identify studies addressing design parameters in low-energy office buildings. Electronic databases searched were mainly SAGE and ScienceDirect. Web of Knowledge and Google Scholar were added in the supplementary search. These electronic databases were searched for full text papers published in English from 1990 to May 2009. The following keywords were used for the search: Building performance, Energy Use, Indoor Climate, Indoor Environment, Thermal Comfort, Building Simulations, Glazed Office Buildings, Mechanical ventilation, Solar shading devices, Computer simulation, Energy simulation, Thermal mass, Heating, Cooling, Natural ventilation, Office building, Low-energy, Passive office buildings, Passively cooled buildings, Energy efficient buildings, Computer simulation modeling, Primary energy, End energy, Net zero energy, CO2 and Greenhouse gas emissions.

Reviewed journal articles, thesis and conference proceedings from countries in Europe and North-America were selected for further study due to similar climate and building techniques. Journal articles from Asia were excluded from the study because of very humid and warm climate. The next selection was made by reading the titles and the abstracts of the texts and the final selection was made by reading the complete texts to see whether they were relevant to the study.

2.3 Regulations and definitions

This section briefly presents different regulations, concepts and terms underlying this thesis.

2.3.1 Current Swedish regulations

In the Swedish building regulation, the annual energy use is defined as the end-use energy (purchased energy) for space heating, space cooling, domestic hot water and facility electricity (fans, pumps, elevators, some facility lighting etc.). The user related electricity is not included. The specific energy use is the annual end-use energy divided by floor space. The space taken in consideration is the sum of all heated floor areas within the external walls (heated to more than 10˚C), internal walls and chimneys included. This area is called A_{temp} in Sweden. A_{temp} differ from the more common expression heated Net Floor Area (NFA). The NFA is defined in many different ways, but the most common definition is that the NFA is the sum of all heated floor areas within the internal walls and partitions (EN 15217). A_{temp} resembles the Gross Internal Area (GIA) which is defined as the floor area contained within the building measured to the internal face of the external walls. All internal constructions and chimneys included (Imperial College London).

Recently, in January 2012, an updated and stricter version of the Swedish building code (how many %) was established (BBR 2012), but in this thesis the second recent code (BBR 18) is used (Boverket 2011a). The energy regulation for non-residential buildings in the south climate zone is 100 kWh/m^2(A_{temp}),yr. An additional 0-45.5 kWh/m^2(A_{temp}),yr can be added due to large emissions and long operation hours.

2.3.2 Primary energy and end-use energy

Many European countries calculate and compare primary energy instead of end-use energy. End-use energy is the final delivered energy to the building, required for heating, hot water, cooling and electricity. Primary energy is defined as the total amount of a natural resource needed to produce a certain amount of end-use energy, including extraction, processing, transportation, transformation and distribution losses down the stream (Sartori and Hestnes 2007; Schimschar, Blok et al. 2011). Primary energy therefore gives an indication of how resource-efficient for example a certain heating system is (Hernandez and Kenny 2010) and it gives a simplified picture of the environmental impact and the caused greenhouse gas emissions (mainly CO2) but it does not deal with other environmental issues such as resource scarcity, acidification and ecotoxicity (Levin 2010). The final end-use energy is converted into primary energy with conversion factors. These multiplicative coefficients vary for each energy carrier and for each country (Sartori and Hestnes 2007). In Germany for example, electricity is multiplied by 3.0 and biomass by 0.1 (DIN 4701) and in Switzerland electricity is multiplied by 2.0 and biomass by 0.7 (MINERGIE 2010), all depending on the country's production form and mix. In Sweden, there are no national conversion factors in time of writing, but the use of direct-acting electricity is limited with regulations in the building code for new construction (Boverket 2011b). A weakness with primary energy is the difficulty to determine accurate conversion factors. End-use energy is more exact and easier to calculate and measure since it is in fact the purchased energy (Johansson, Nylander et al. 2007). End-use energy is considered a better and more just approach when describing a building's energy performance and when comparing energy-efficiency of different building envelopes (Persson, Rydstrand et al. 2005).

2.4 Important design principle low energy office buildings

A well-known design strategy for low-energy buildings and passive houses is the so called "Kyoto Pyramid" which was introduced by Rødsjø and Dokka and presented internationally for the first time in IEA Task 37 (Jansson 2010). A modified version, adapted for office buildings, is presented in this report in Figure 2.X with inspiration from "Guidelines for energy efficiency concepts in office buildings in Norway" by SINTEF Building and Infrastructure (Haase, Buvik et al. 2010). The strategy is based on the devise "the most energy-efficient kilowatt-hour is the one we never consume" and works as guidance for how to prioritize when designing low-energy buildings. It stresses the importance of reducing the energy demand before adding systems for energy supply which promotes robust solutions (heiselberg). The five steps are presented below.

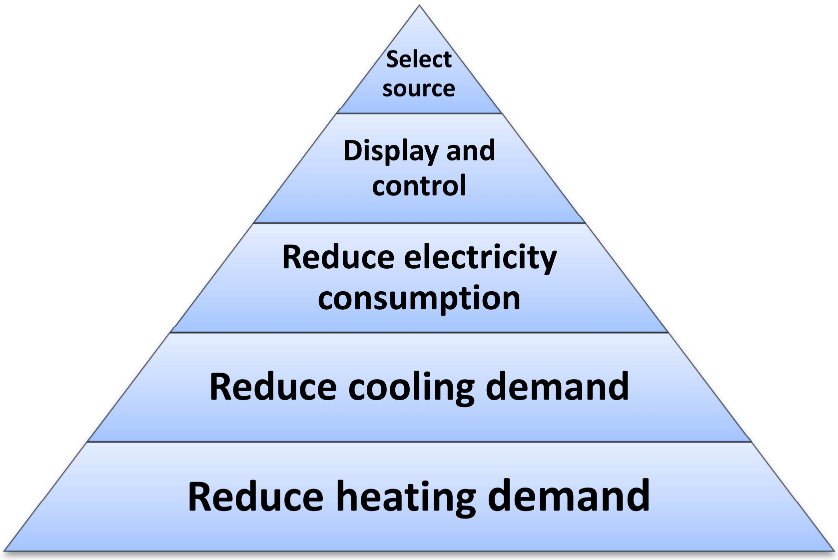


Fig 2.X. Modified version of the Kyoto Pyramid for office buildings as presented by Haase, Buvik et al. (2010)

Step 1 *Reduce the heating demand*

The first and most important step is to reduce the transmission and ventilation heat losses as much as possible since the heating energy still is the most dominating energy post in North European climate. Seek for a good building design, a well-insulated and airtight building envelope, an optimized window design, efficient heat recovery in the ventilation system, and customized airflows.

Step 2 *Reduce the cooling demand*

The cooling demand can be prevented with a good solar control and by reducing internal heat gains from equipment and lighting. The cooling demand can be further reduced by allowing a larger temperature variety in the indoor air. Use passive cooling and free cooling to a high degree.

Step 3 *Reduce the electricity consumption*

Minimize both the facility and the user-related electric energy with efficient pumps and fans (low specific fan power), customized airflows and low installed power for lighting and equipment. Shorten the operation hours and avoid standby losses.

Step 4 *Display and control the energy consumption*

Choose easy and user-friendly control and monitoring systems. Design for demand-controlled ventilation and lighting and less strict temperature set-points.

Step 5 *Select energy source*

The last thing to do is to choose energy sources to cover the remaining auxiliary energy demand. Examine to what extent renewable, sources like solar energy and geothermal energy, can be used and make sure to reduce the emissions of greenhouse gases.

In this thesis, focus is laid on the first three steps. Reducing heating, cooling and electric energy. Step 4 and 5 are just briefly discussed.

2.4.1 Building envelope and building shape

Regarding building design and energy saving measures in the building envelope, a majority of the conducted studies have been carried out on dwellings and residential buildings with a predominant heating demand. For office buildings, which struggle with both heating and air conditioning issues, the great focus in literature regards different HVAC systems.

Shape and Compactness

It is generally known that the shape of a building has an impact on the transmission heat losses and the uncontrolled air leakage through the building envelope. A relatively large envelope surface increases the exposure to the environment and the ambient air. Building compactness (C) is generally defined as surface-to-volume ratio, C=S/V [m^{-1}], where S is the envelope surface [m^2] and V is the internal volume of the building [m^3] (Depecker, Menezo et al. 2001; Gratia and De Herde 2003). Typical good values for compact office buildings are 0.1-0.3 according to guidelines by Haase, Buvik et al. (2010). Different geometrical shapes have different surface-to-volume ratios where the sphere has the lowest S/V and the pyramid has the highest S/V. The size of the geometry has a great effect on the surface-to-volume ratio where a large size gives a small surface-to-volume ratio. Therefore, building compactness is sometimes expressed as the relative compactness, RC= C/C_{ref} [-], where C_{ref} is the compactness of an ideal reference building with the same volume (for orthogonal buildings a cube) (Ourghi, Al-Anzi et al. 2007). Hence, the most compact building has a relative compactness close to 1.0 and different shapes with the same volume can vary between 0.6 and 1.0 (Pessenlehner and Mahdavi 2003). According to a simulation study performed on an office building in Belgian climate, by Gratia and De Herde (2003), the shape of the building plays a significant role on the energy consumption, and a non-compact building shape results not only in more exposed surface but also in more joints which cause larger cold bridges. The authors claim that is even preferable to reduce surface area rather than to add insulation since compactness decrease both energy and construction costs. Several floors and a square shape bring compactness. Depecker, Menezo et al. (2001) discovered, in a simulation study of 14 different building shapes in two different French climates, that the colder the climate (>2500 heating degree days, which corresponds to Paris) the stronger the correlation between shape and energy consumption. An increase in compactness by 0.1 m^{-1} increases the energy consumption with almost 4 kWh/m^2yr for the simulated apartment buildings with rather poor insulation compared to today's standard. No correlation was found for the warm climate in Southern France. This study indicates that the building shape effect is significant in Swedish climate, at least for residential buildings. (Pessenlehner and Mahdavi 2003) examined whether the simple correlation between compactness and heating load is reliable regardless of building shape (self-shading aspect), glazing amount and building orientation. The authors concluded that more compact buildings indeed result in somewhat smaller heating loads, when it comes to residential buildings in Austrian climate. Furthermore, the correlation between RC and heating load is strong despite different shapes, glazing designs and orientations. On the other hand, the study showed that the overheating tendency increases with increasing RC, however with a relative week correlation. This indicates that the correlation between compactness and total energy consumption may be week, or even reverse, for office buildings with cooling loads.

Insulation levels

The insulation levels, mainly in residential buildings but also in office buildings, have increased greatly the past decade. It has come to a point where we ask ourselves whether we should go even further or if more insulation only leads to higher material and construction costs, unused floor space and higher risks. One risk with more insulation is the increase in overheating hours which is particularly severe in office buildings with active cooling. Gratia and De Herde (2003) stated, in a simulation study of an office building in Belgian climate, that for the same level of internal gains, a better-insulated and a more airtight building gets warmer in the summer than a similar building with less insulation and therefore needs more cooling energy. On a yearly basis though, they showed that the total energy consumption is much smaller for a well-insulated office building. Another risk with high insulation levels is the potential risk of moisture problems and mould growth in wooden constructions due to a different micro climate within the element Berggren, Stenström et al. (2011). Thicker insulation will lead to colder outer parts of walls and roof structures, partly because of the increased heat resistance, but also because of the natural convection that will occur within an unbroken, thick insulation layer. The moisture distribution in the wood frames follows the temperature distribution in the structure, and lower temperatures gives higher relative humidity (Geving and Holme 2010; Uvslökk, Skogstad et al. 2010). Geving and Holme (2010) carried out simulations and laboratory experiments on different envelope constructions in order to find out the risk of moisture problem in well-insulated constructions. The authors could see an increase in relative humidity in the constructions during winter due to thicker insulation, and a negligible increase during summer. On the other hand, they found out that other factors, like resistance in the vapor barrier and the humidity in the indoor air, actually influenced the relative humidity more than increased insulation thickness did. This result indicates that the risk of mould growth in well-insulated office constructions may not be severe since office buildings in general have dryer indoor air compared to residential buildings, because of a low internal moisture production and high ventilation rates. It is important though, to be aware that it takes longer time to dry out moisture in wood frame walls when the insulation is thick. Not only is the total amount of built-in moisture higher due to more wood in a thicker wall, but in addition the insulation increases the average vapor resistance from a point in the structure to the outdoor air (Geving and Holme 2010). Well-insulated constructions are not as forgiving as less insulated are, and it is therefore crucial to protect the structure from water during the construction phase and to allow it to dry to a reasonable level before closing it with a vapor barrier (Samuelsson 2008).

For a large office building with many floors, it is more important to focus on the insulating performance of walls and windows than roof and floor since the façade is a large part of the total envelope surface. There are no specific requirements for insulation thicknesses in the Swedish building code today. The passive house recommendations might therefore be a useful key in order to find suitable insulation levels for low-energy office buildings. There are rules and recommendations for U-values both in the International Passive House standard and the Swedish passive house criteria. According to the Passive House Checklist (Passive House Institute, PHI (2012a) the opaque envelope elements must be super-insulated with U-values of maximum 0.15 W/m^{2}K and if possible 0.1 W/m^{2}K. The Swedish passive house recommendation also strives for 0.1 W/m^{2}K in those building elements. Windows must have a U-value of 0.8 W/m^{2}K or better (frames included) according to the most recent criterion (Nollenergihus 2012). The former criterion required maximum 0.9 W/m^{2}K (FEBY 2009).

Airtightness

An important parameter in terms of energy use for heating and cooling in a building is the envelope airtightness. Uncontrolled air leakage yields higher energy consumption since the air that leaks into and out of the building envelope does not pass the heat exchanger in the air handling unit. Uncontrolled air leakage can contribute to comfort problems in terms of draught, which can result in raised indoor temperatures in order to improve comfort. Airtightness in large and complex buildings is difficult to measure, and the knowledge of actual airtightness in Swedish office buildings and the effect it has on the energy balance is generally very low. In 2009, Blomsterberg completed measurements in a modern glazed office building, The World Trade Center, in Malmö. The measured airtightness (blower door EN 13829) was 0.61 l/sm^2 at 50 Pa pressure difference which is well below the former requirement in the Swedish building code BBR of 1.6 l/sm^2 at 50 Pa pressure difference (Blomsterberg 2009). The envelope airtightness is not regulated in the Swedish building code today, but the Swedish passive house criterion requires an airtightness of maximum 0.3 l/sm^2 at 50 Pa pressure difference (Nollenergihus 2012). The international Passive House Institute requires maximum 0.6 ach at 50 Pa pressure difference (PHI 2012a). For comparison of the two criteria, 0.3 l/sm^2 (q_{50}) corresponds to 0.6 ach (n_{50}) when the compactness is approximately 0.55 m^{-1}, which is a rather poor compactness. The more compact a building is, the stricter is the Swedish requirement. For a really compact building with a compactness of 0.1 m^{-1}, the Swedish demand corresponds to only 0.1 ach. The different quantities and methods are defined in European Standard EN 13829 (CEN 2000).

Thermal mass and thermal inertia

There are divided opinions whether a high thermal mass and thermal inertia actually can save heating and cooling energy or not. Many claim at least that thermal mass prevents overheating hours and create a better and more stable thermal climate with smaller temperature variations. The desired effect is that heat from solar gains and internal gains during the day is stored in the construction and then slowly released into the room at a later time, reducing both heating peak loads in winter and cooling peak loads in summer. The effect is greater when it comes to saving cooling energy since the cooling peak load has a diurnal variation and effectively can be smoothened with high thermal mass (Kalema, Jóhannesson et al. 2008). The heating load variation is mainly annual. Thermal mass is therefore more effective in non-residential buildings which have large heat gains during day and no operation during night when the heat is released. Thermal mass is the construction mass incorporated in floors, external walls and partitions (Balaras 1996) and it describes the ability to provide inertia against temperature variations (Dodoo, Gustavsson et al. 2012). For the material to effectively store heat, it must have a high density and thermal capacity in order to absorb and store heat, and a proper thermal conductivity which determines the time lag for absorbing and releasing heat (Balaras 1996; Dodoo, Gustavsson et al. 2012). The effect of thermal mass also depends on the actual heating and cooling loads which are affected by building design, insulation levels, outdoor climate, solar radiation through windows, building orientation, ventilation rate and occupancy patterns and internal heat gains (Balaras 1996; Kalema, Jóhannesson et al. 2008). This makes it very difficult to measure the real effect of thermal mass since it is almost impossible to assure that the conditions in the compared buildings or rooms are exactly the same. Many researchers claim that only the mass of the innermost layers in a building plays an active role in heat accumulation and temperature reduction (Balaras 1996; Gratia and De Herde 2003; Di Perna, Stazi et al. 2011). This parameter is called internal thermal inertia or internal areal heat capacity. Suspended ceilings and carpets reduce the internal thermal inertia.

Results from a variety of experimental and simulation studies around the world report very different energy saving potential, ranging from just a few negligible percent up to more than 80 percent according to a recent review (Aste, Angelotti et al. 2009). Dodoo, Gustavsson et al. (2012) compared the effect of thermal mass on space heating energy and life cycle primary energy between concrete- and wood-framed residential buildings in Sweden. Their results indicate that the influence of thermal mass on final space heating demand is small (0.5-2.4%) and that this small saving is outweighed by the larger life cycle primary energy use for the concrete alternative. Høseggen, Mathisen et al. (2009) studied the potential energy savings of exposing concrete in the ceiling compared to a suspended ceiling in a passively cooled office building in Norway. Their results show that there are only minor differences in total heating energy demand (<3%). On the other hand, the exposed concrete reduces the hours of excessive temperatures (>26˚C) by factor two, and the maximum indoor air temperature was reduced with more than 1˚C the warmest day of the year. The effect was greater the larger the internal heat gains were. Aste, Angelotti et al. (2009) carried out a parametric study in EnergyPlus on the effectiveness of thermal inertia in 24 different external walls in a model of a residential building in Milan in Northern Italy. They varied the operational parameters (ventilation rates and solar shading devices) in order to get maximum effect. The results showed that when the maximum heating energy saving potential of 10% occurred, the cooling energy saving was only 1% and when the maximum cooling energy saving potential of 20% occurred, the heating energy saving was non-existent. Kalema, Jóhannesson et al. (2008) investigated the effect of thermal mass in an actively cooled apartment building in a Nordic climate. The simulations were carried out with seven different calculation programs. The results indicate that going from extra-light to massive constructions decreases the need for cooling energy (13-21%) and also slightly the need for heating energy (5-7%) in well-insulated Nordic buildings. The authors also showed that the effect of thermal mass on heating energy is clearly higher in south Sweden (Malmö) than north Sweden (Luleå). Furthermore, the simulations indicated that the larger solar gains and internal gains, the larger the effect of thermal mass. Similar results were established by Di Perna, Stazi et al. (2011) who carried out an experimental and parametric study of a school building with different thermal internal inertia in different climates. In Loreto in central Italy, the discomfort hours were reduced from 21% to 15% but in London no difference was seen because there was not really a problem with overheating from the beginning. According to a review by (Balaras 1996), heat storage is most effective when the diurnal variation of ambient temperature exceeds 10˚C. Balaras also claims that creating a time lag between the peak load and the peak in room temperature is most important in rooms toward south and west. An eight hour time lag is sufficient to delay the heat transfer from midday until evening hours. A couple of studies indicate that medium mass construction levels have the best energy-saving performance and that further improvement in thermal mass, from medium to high mass, generally has a negligible effect (Morgan and Krarti 2007; Kalema, Jóhannesson et al. 2008). Artmann, Manz et al. (2008) studied the effect of thermal mass on cooling with natural night ventilation in a model of a standard office room with the building simulation programme HELIOS. They found that the impact of thermal mass in internal walls depends on room geometry. In a large open plan office the ratio of wall-to-floor area is small and the construction of the walls thus becomes less important. Thermal mass in the ceiling is always favourable though. A concrete ceiling in direct contact with the room air reduced overheating (>26˚C) by a factor two compared to a suspended ceiling.

Potential disadvantages when it comes to high thermal mass and internal thermal inertia are seldom discussed in literature. As mentioned above, Dodoo, Gustavsson et al. (2012) discussed that the savings in heating and cooling energy due to higher mass can be outweighed by the larger life cycle energy use for concrete compared to wood-framed constructions. Other weaknesses can be higher material costs and comfort problems due to radiation from cold surfaces in the morning. Furthermore, indoor temperatures can continue rising after a heat wave even though the ambient temperature is cooler because of the stored heat that is released. Finally, exposed internal thermal inertia often conflicts with the placing of noise absorbers in an office environment since ceiling absorbers and floor carpets are removed.

Glazing, daylight and solar control

The positive effects of fenestration and daylight access in buildings are both esthetical and physical. Glazed facades give the design a light and open appearance and provide a view out for the occupant. It also allows the occupant to keep track of time and weather conditions. In a literature review, Dubois and Blomsterberg (2011) stress the importance of daylight for occupants' health and well-being and claim that most people prefer daylight to electric lighting. Windows offer a visual rest center to relax eye muscles on a distant point (Gratia and De Herde 2003). On the other hand, too much glazing has the opposite effect. It often results in unwanted solar gains and direct sunlight with both thermal and glare discomfort. Thus the shading devises will be used much of the time which will reduce the amount of daylight and all its positive effects, and in addition increase the electric lighting. Excessive glazing will also increase the energy consumption for heating and cooling due to large heat losses and unwanted solar gains. Poirazis, Blomsterberg et al. (2008) carried out dynamic simulations with IDA ICE on a typical large office building in Sweden in order to study the impact of different glazing-to-wall ratios (GWR) on the energy use. The simulation results show that both heating energy and cooling energy increases strongly with increased GWR. The total energy use increases with 23% when GWR is increased from 30% to 60% and with 44% when GWR is increased from 30% to 100%. Furthermore, a larger GWR does not necessarily reduce the electricity use for lighting because of glare problems and more frequent use of shading devices.

One important design aspect is thus to optimize the size, shape, position and orientation of windows in low-energy office buildings, securing adequate daylight but preventing glare and overheating problems. Dubois and Flodberg (2012) carried out a parametric study in the dynamic daylight simulation program DAYSIM in order to find reasonable glazing-to-wall ratios (GWR) in office buildings at high latitudes with peripheral individual rooms. A typical single office room was modeled and parameters studied were, among others, climate, orientation, GWR, surface reflectance, and solar shading control. The main metrics for evaluating available daylight were "continuous daylight autonomy" (DA_{con}) and "daylight autonomy maximum" (DA_{max}). DA_{con} can be explained as the amount of daylight illuminance that is available at a given timestep relative to the required amount of daylight illuminance. Thus, if 500 lx is required and 400 lx is provided by free daylight, DA_{con} is 400/500=80% for that timestep. Levels of more than 80% represent "excellent" daylight and levels of 60-80% represent "good" daylight as introduced by Zack Rogers in 2009 according to Dubois and Flodberg (2012). DA_{max} is defined as the percentage of times during a year when the illuminance is at least 10 times higher than the required value which indicates direct sunlight and a high risk of glare discomfort. The proposed acceptable limit is maximum 5% and above this limit, the occupants are expected to use solar shadings (suggested by Zack Rogers in 2009).

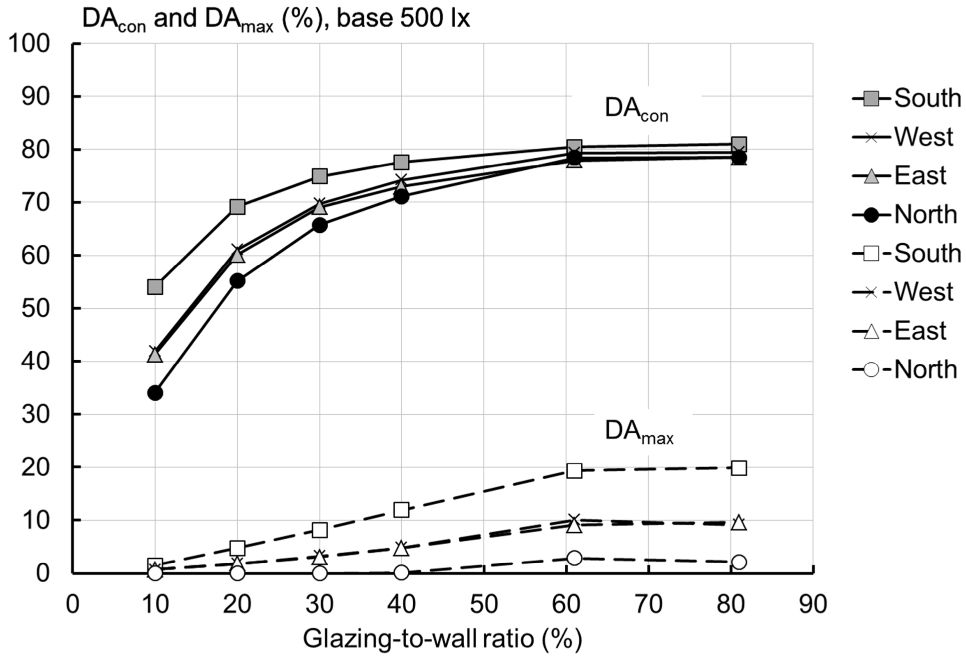


Fig 2.X. DAcon and DAmax as a function of GWR in relation to orientation for a single office in Stockholm. A floor average during office hours, no blinds. With permission from Marie-Claude Dubois 2012.

Some of the simulation results are shown in Fig 2.X. It is clear that the south orientation has the highest DA_{con} and the north orientation has the lowest DA_{con}. East and west orientations have similar DA_{con} and DA_{max}. The same trend was found for all studied climates. All orientations show the same interesting relationship between GWR and available daylight. The DA_{con} rises steep when GWR is increased from 10% to 30% and almost stabilizes after GRW 40%. The benefits of increasing GWR from 40% to 60% are marginal and there is no point in increasing GWR from 60% to 80%. Regarding direct sunlight and glare, south orientation has the highest risk of glare, already at GWR 20%. For east and west orientations, the DA_{max} limit is reached for GWR 30% and for north orientation there seems to be mainly diffuse daylight and no glare problem for any GWR. The authors' general design advice is to strive for GWR 20% on the south façade, GWR 30% on east and west facades and finally GWR 40% on the north façade, considering daylight aspect only. These glazing ratios will provide "good" daylight (DA_{con} = 70%) and meanwhile keep the risk of glare below the acceptable limit (DA_{max}< 5%). The authors also performed additional thermal simulations of the peripheral office room in IDA ICE for analysis. The result indicates that the smallest GWR always yields the lowest total energy use for heating, cooling and electric lighting. Even for the south orientation with a lighting system controlled with daylight dimming. Furthermore, the study shows that there are negligible differences in DA_{con} between Stockholm, Malmö and Gothenburg. Östersund has slightly more limited daylight though. The main conclusion of the study reveals that although DA_{con} is more limited in the Swedish cities compared to cities at lower latitude, it is still possible to achieve good to excellent daylight design with reasonable glazing-to-wall ratios of 20%-40%, depending on orientation, glazing visual transmittance and inner surfaces' reflectance.

An additional, similar study was carried out by Dubois and Du (2012) for a landscape office with four rows of work stations. This study shows that the good and excellent levels achieved in peripheral office rooms are more difficult to achieve in deep landscape offices in

Stockholm. For the first work station, right next to the window, DA_{con} is “good” to “excellent” for all orientations and glazing-to-wall ratios above 20%. For work stations further into the room on the other hand, DA_{con} decreases significantly and large GWRs are needed to achieve “good” daylight. GWR 80% is required for providing “good” daylight at the third work station and no GWR can provide “good” daylight on the forth work station from the façade, regardless of orientation. A south orientation provides significantly more daylight than a north orientation though. However, the risk of glare at the first work station is very high for all orientations but the north, and a high DA_{max} will initiate the use of blinds which will reduce the daylight autonomy, especially for work stations located further away from the window. Dubois and Du’s design advice is to position circulation or informal meeting spaces along the south, east and west façades, and computer work stations further into the room. This would encourage keeping the window view open and free from shading devices. On the north façade, work stations can be positioned directly close to the window since there is no direct sunlight. Instead, the authors suggest that deep landscape offices perhaps should not be planned at all on north facades since they require large GWR which will increase heat losses. The study also shows that an increase in ceiling height and additional glazing in the upper part of the facade has a positive effect on DA_{con} for work stations located in the back of deep rooms. In addition, separated solar shadings for lower and upper parts of the windows can provide daylight further back in the room even when blinds are down on the lower part in order to prevent glare discomfort. Another interesting result from the study is the large impact furniture has on daylight autonomy in deep landscape offices. Typical office furniture can reduce DA_{con} with up to 35%, why this aspect must be considered when studying and planning lighting design in landscape offices.

One important parameter to consider when performing daylight and energy simulations is the operation of blinds. The blinds have a large impact on heating, cooling and lighting energy and the usage can be difficult to predict when the blinds are manually controlled. Many occupants are so called “passive” users and forget to pull up the blinds again when they are not required. Dubois and Blomsterberg (2011) discuss that a number of researchers have attempted to investigate whether occupants in office buildings use their shading devices according to predictable patterns and if these patterns are dependent on window orientation, time of day, sky condition, season, latitude and workstation position. Leslie, Raghavan et al. (2005) claim it has been found that occupants’ decisions to manually close their blinds correlates with the solar beam irradiance on an interior task plane, but that the actual irradiance threshold value is under debate. They refer to two different blind control models. In Reinhart’s model, blinds are lowered if beam irradiance exceeds 50 W/m^2 and they remain down until the following morning. In Newsham’s model it is assumed that occupants open their blinds in the morning and close them during the day if beam irradiance exceeds 233 W/m^2. Dubois and Blomsterberg found in their review that solar radiation levels above 250-300 W/m^2 on the glass normally encourage blind utilization and for radiation below 50-60 W/m^2, occupants do not use shading devices. In various simulation programs used in Sweden default solar radiation values are 100 W/m^2 (inside glass, IDA ICE), 150 W/m^2 (ParaSol) and 250 W/m^2 (VIP Energy). Automatic blind management was studied by van Moeseke, Bruyère et al. (2007) in TRNSYS. They studied the impact of management strategies for external shading devices in low-energy buildings in Belgium. The results showed that a control mode based on irradiation level only causes an important increase in energy demand for heating due to the decreased solar gains during winter. The authors suggest a combination of both irradiation and temperature control. Having a temperature set-point of 23-24˚C combined with an irradiation level of 200-300 W/m^2 is ideal in order to reduce both over-heating hours and closed mode hours. Goethals, Breesch et al. (2011) carried out thermal simulations of an office building with movable external blinds automatically lowered when the incident solar radiation exceeded 150 W/m^2.

Gratia and De Herde (2003) presented various guidelines for good daylight design. They claim that the higher the position of the window is, the better the bottom of the room is enlightened and the deeper the naturally lit zone is. The level of illumination decreases with one double distance of the height of the window top. Furthermore, ceiling height and ceiling reflection plays an important role for the daylight distribution further into the room. The importance of ceiling reflectance is supported by Dubois and Blomsterberg who stress that the majority of daylight that penetrates beyond the 1st work station is reflected from the ceiling at least once, in their review and that increased ceiling reflectance leads to a more uniform distribution of daylight throughout the space. Gratia and De Herde recommend following inner surface reflections (R):

Walls	$R > 0.5$
Ceiling	$0,7<R<0,8$
Floor/desk	$R >0.5$

Tables and desks often represent a great part of the office space and therefore their reflectance can have as much influence as the floor. To improve the penetration of light in a room it is preferable to keep floor and surfaces of work relatively clear (Gratia and De Herde 2003). A bright desk colors is also beneficial because it helps reducing the contrast between paper and desk surface which improves the visual comfort. On the other hand, too reflective horizontal surfaces can lead to disturbing reflections and glare (Dubois and Blomsterberg 2011).

Dubois and Flodberg (2012) showed that the effect of inner wall reflectance for daylight penetration can be significant and even as important as the effect of orientation. This is especially true for small GWR.

Orientation

The impact of building orientation on energy consumption and thermal comfort highly depends on the design of the facade. Orientation must be considered when designing glazing amounts, solar shading devices and solar energy devices. Poirazis (2008) showed, that for an office building with identical short sides and long sides, orientation has a negligible impact on energy consumption. It is possible that the impact of building orientation is negligible when performing a whole building annual energy balance. However, orientation ought to have great impact on thermal comfort and lighting comfort in the rooms along the façade due to direct solar radiation. Gratia and De Herde (2003) claim that for a rectangular building, a north-south building orientation is better than an east-west orientation when it comes to reducing the total heating and cooling demand. Having the largest window area towards north reduces the cooling demand more than it increases the heating demand. Artmann, Manz et al. (2008) argue that if solar gains are low compared to internal heat gains, the effect of façade orientation on overheating degree hours is relatively small. However, for an office room oriented to the north, the overheating hours can almost be half compared to the other orientations. Haase, Buvik et al. (2010) claim that windows on the east and west facades often cause the overheating hours because of the low angle of the sun in these directions.

2.4.2 HVAC

There are a number of different supply and distribution strategies for heating, ventilation and air conditioning in office buildings. The role of the distribution system is to secure a healthy indoor environment and a good thermal climate. The design of the distribution systems highly affects the building's energy use. Efficient supply and distribution strategies have been studied in several low-energy office buildings in Europe. Natural ventilation, cooling with night ventilation, TABS, earth-to-air heat exchangers and geothermal bore holes are common techniques which are reviewed in this section. In Sweden, such innovative HVAC techniques are scarcely used. The district heating and cooling network is well developed and according to recent statistics (Boverket 2010), more than 80% of the Swedish non-residential buildings use district heating. As much as 90% of the 123 existing office buildings in the investigation performed by the Swedish Energy Agency use district heating. The remaining buildings are mainly heated with electricity and gas. For cooling supply, water-cooled compressor chillers still dominate in Sweden (68%) but district cooling is getting more and more frequent in new office buildings (24%) (Energimyndigheten 2007). Regarding air distribution, 95% of the non-residential buildings in Sweden have a mechanical balanced ventilation system (Boverket 2010).

Heating and cooling

Heating and cooling can be distributed to the room either with water or with air as a medium. Heating distribution with water is most common in Swedish buildings today (Jardeby, Soleimani-Mohseni et al. 2009). Water-borne radiators are most common, with central control of the water temperature (depending on ambient temperature) and individual control of the water through-flow to the radiator. Other water-borne systems are fan-coil batteries and floor heating. A fan-coil battery is a room unit with a fan and a battery which is supplied with warm or cold water. Room air is circulated through the unit where it is heated or cooled with a rather fast reaction time. A floor heating system has much larger heat-emitting surface compared to a radiator which admits a lower water temperature. However, the floor heating system reacts slowly to adjustments. Heating distribution with ventilation air requires a small heating demand. The air is heated with heating batteries in the supply ducts. The system is more difficult to control, but in return it allows a faster temperature adjustment. The normal strategy in office buildings is to have a combination of air and water distribution, with a central heating battery in the air handling unit, for pre-heating the supply air, and a water-borne room unit for additional heating (Jardeby, Soleimani-Mohseni et al. 2009).

For cooling distribution both water and air-borne systems are common in Swedish office buildings (Jardeby, Soleimani-Mohseni et al. 2009). Water-borne cooling systems are not as space consuming as air-borne systems which requires large ventilation ducts. The most common water-borne system is having active cooling baffles which are placed under the ceiling. The warm air in the room is transferred to the cold water in the baffles with natural convection. The baffles are normally designed with supply and return water temperatures of 14 and 17˚C. The surface temperature of the cooling baffle must always be warmer than the dew point of the room air in order to avoid condensation. As mentioned above, water-borne fan-coil batteries can be used both for heating and cooling in a room. The fan-coil battery has an enhanced cooling efficiency compared to the cooling baffle but in return it makes more noise (Källman, Hindersson et al. 2004). Cooling with air is convenient since fresh air needs to be provided to the building with the ventilation system anyway in order to remove emissions. Moreover, the ambient temperature in Sweden is colder than the indoor temperature a big part of the year and free cooling with outdoor air can be utilized to a great extent. The remaining cooling is provided by the cooling coil in the air handling unit. However, the specific heat capacity in air is low and large airflows and great amounts of fan energy are required to meet the cooling load (Källman, Hindersson et al. 2004).

There are other cooling supply systems beside district cooling and conventional water-cooled compressor chillers. Absorption chillers resemble the compressor chillers but they are run on a heat source instead of electric power. For instance, district heating, combustion heat or excess heat from the building can be used as heat source. Absorption chillers need very little electricity but in return the COP is low. Evaporative chillers are an alternative when air is used for cooling distribution. The device cools the warm and dry air by making it pass liquid water and evaporate. The cooling efficiency is further improved if the air first is dehumidified with heat from for instance district heating, excess heat or heat from solar collectors. This combination of dehumidification and evaporative cooling is called sorptive cooling and is only possible for airborne cooling (Jardeby, Soleimani-Mohseni et al. 2009).

Free cooling is defined as cooling when a natural heat sink is used for cooling, for instance outdoor air, geothermal bore holes and lake water. With an airborne cooling system, the cooling demand can be met by the outdoor air as long as it is colder than the supply air temperature in the air handling unit (approximately 16˚C) which actually occurs most of the time in Sweden (80-90%) (Jardeby, Soleimani-Mohseni et al. 2009). Cooling towers with free cooling from outdoor air can be used for waterborne cooling systems when the ambient temperature is colder than 7-10˚C. Reversible heat pumps can be used both for heating and cooling production. Geothermal heat pumps are efficient for cooling since free cooling from the bore hole can be extracted meanwhile the bore hole is charged with heat for the winter season. When the free cooling from the bore hole is insufficient, the pump is activated to raise the cooling efficiency. (Jardeby, Soleimani-Mohseni et al. 2009). One form of free cooling is night cooling where the thermal mass in the building construction is used as heat sink. Cooler night air is stored in the interior materials and some of the excess heat during day will be consumed for heating the materials. Night cooling is often improved with increased airflows during night. Another free cooling system using the building thermal storage as heat sink is the thermo-active building system (TABS). TABS can be either water or airborne and they operate at temperatures close to the room temperature (Henze, Felsmann et al. 2008). Thus natural heat sinks such as the ground, ground water or ambient air can be used (Bine 2007).

Mechanical ventilation

A conventional mechanical ventilation system can be designed with constant or variable airflows. In order to make the fans more energy-efficient, either the airflow, the total pressure drop or the number of operation hours must be reduced.

In a constant air volume (CAV) system, the airflow is kept constant but the supply air temperature is allowed to vary depending on room temperature or ambient temperature. The supply air temperature can also be constant, as long as the rooms are equipped with separate room units for heating and cooling (Jardeby, Soleimani-Mohseni et al. 2009). The positive aspects with constant airflows are the pressure drops, which are kept constant. CAV systems can be designed with two-speed motors which enables a reduced speed when the cooling load is small (Källman, Hindersson et al. 2004).

In a variable air volume (VAV) system, the airflow to each room varies but the supply temperature is kept constant. However, the supply air temperature can be varied with the seasonal ambient temperature. The indoor temperature determines the required airflow. Having variable airflows can save much heating energy since only the essential amount of air is distributed to each zone and hence less air needs to be treated with room units. VAV systems are often combined with a demand controlled ventilation (DCV) system. A DCV system is mainly a control system which regulates the airflow depending either on CO_2 level, occupant presence or humidity. However, it is usually the temperature requirement that determines the airflows rather than the CO_2 limit in office buildings (Jardeby, Soleimani-Mohseni et al. 2009).

Natural and hybrid ventilation

Natural ventilation, or a hybrid of both natural and mechanical ventilation, can be adopted in order to save auxiliary energy for fans. This ventilation strategy is not as common in Swedish office buildings as in for example Germany, Belgium and Denmark. The technique is often combined with passive night cooling and it has been evaluated in many European low-energy office buildings. The challenge with natural ventilation is to achieve a sufficient air change rate with buoyancy forces or wind forces only, but if this is not secured a small mechanical system can be added as back-up. The flow path of the air depends on the design and placement of openings in the façade and within the building. The single-sided ventilation strategy implies that openings are placed at different heights in the external wall, creating a stack effect and natural ventilation within the room. Cross ventilation requires openings within the building, creating a cross flow from one façade to the other.

Nì Riain, Kolokotroni et al. (1999) investigated the cooling effect of various ventilation flow paths in an existing naturally ventilated office building in the UK. The 3 floor office is L-shaped with both individual and open plan offices. The main components of the natural ventilation system are operable windows, ventilation stacks to extract stale air, and a sinus shaped concrete ceiling with internal channels for air distribution and night cooling. At night, windows are automatically opened and so are the ducts in the slab in order to cool the slab down. During the tests, different ventilation paths were opened in sequence and the airflow rate was estimated. The initial measurements the first summer indicated that acceptable ventilation was provided, the CO_2 -levels peaked just below 800 ppm and generally the concentrations were below 600 ppm. The indoor temperature sometimes exceeded 25˚C but only when the outdoor temperature exceeded 30˚C. Night ventilation coupled with exposed thermal mass and minimisation of solar and internal heat gains effectively reduced the effect of high external temperatures. The authors concluded that cross-ventilation, either directly to the office space or indirectly through the concrete slab, can provide the necessary day ventilation to satisfy cooling purposes. During hot and calm days though, the passive stacks can provide more ventilation than the cross-ventilation system.

Gratia, Bruyère et al. (2004) compared different strategies for natural ventilation. Simulations were carried out in TAS on a rectangular 5 floor office building with peripheral individual office rooms with weather data for Belgium a sunny summer day. Internal walls between the office modules and the corridor were modeled with operable windows above the doors to facilitate the air flow between northern and southern spaces. Each office was modeled with four windows, two top and two below, to allow natural ventilation. The efficiency of natural day ventilation, natural night ventilation and ventilation rates due to different positions of the openings were studied. The authors found out that natural day ventilation is most efficient with a single-sided strategy rather than a cross ventilation strategy, since it allows double air inlet. At a mean airflow rate of 4 ach, the single-sided ventilation reduces the cooling load by

31% but the cross ventilation only by 11%. During night, cross ventilation is almost as efficient as single-sided ventilation because of the length of the ventilation period. At a mean air flow rate of 8 ach, the single-sided strategy reduces the cooling load by 38% and the cross ventilation strategy by 36%. Cross ventilation is not possible when the building is wind protected or when wind direction is parallel to windows. The study also showed that the position of the openings is as important as the area of the openings. A tall window uses the stack effect better than a horizontal window. If the ventilation is single-sided it is preferable to dispose of two openings on different heights of the wall and when the ventilation is cross the opening levels should be at different height at each side of the building. Finally, Gratia, Bruyère et al. claimed that since wind and temperature differences are the driving forces causing air flows through the building, there will be times, even with the best design, when ventilation will not be sufficient enough.

van Moeseke, Bruyère et al. (2007) studied the impact of cooling by intensive natural ventilation in low-energy office buildings. Various control rules were simulated with TRNSYS and Belgian weather data was used and a heat wave was simulated for the natural ventilation set. A south-oriented office room with GWR 40% and exposed concrete in external wall, ceiling and floor was modeled. The day ventilation rate was constantly 4 ach in one simulation and 1.5-4 ach in another, varying with the outdoor temperature. According to the results, outdoor temperature control mode is not efficient enough to limit over-heating hours, and compared to the model with constant air flow, it only leads to small savings in heating energy (3-5%). The authors concluded that since the choice of management and parameters strongly impacts the cooling performance, designers must carefully consider the control systems in order to build high comfort low energy buildings.

Hummelgaard, Juhl et al. (2007) recorded and compared occupant satisfaction and indoor environment characteristics in four naturally and five mechanically ventilated open plan office buildings in Copenhagen. Air temperature, air humidity and CO_2 concentration were logged and occupant responses were collected simultaneously in the different buildings during a working day in October. The questionnaires focused on occupants' overall assessment of the indoor environment, the thermal sensation, their perception of personal control, and the frequency of symptoms occurring during the past three months. The results from the indoor climate measurements showed that temperatures, relative humidity and CO_2 concentration varied more among the naturally ventilated buildings while the mechanically ventilated buildings were more alike. The highest temperatures were found in two of the naturally ventilated buildings with a peak around 4 o'clock pm. The temperature varied between 22.1-26.3 ˚C in the naturally ventilated buildings, and between 21.3-24.8 ˚C in the other buildings. The relative humidity was 28-45% in the naturally ventilated and 28-47% in the buildings with mechanical ventilation. The concentration of CO_2 was constantly low in the mechanically ventilated buildings (405-555 ppm) while it varied between 425-1000 ppm in the naturally buildings. Despite the higher concentration of CO_2 and the higher temperatures with more variation, 70% of the occupants in the naturally ventilated buildings were satisfied with the indoor environment, whereas only 59% were satisfied in the mechanically ventilated offices. Overall symptoms, like "difficult to concentrate" and "dry, itchy or red skin", as well as building related symptoms, like "eyes itching/irritation" and "dry, itchy or red skin", occurred more often in the buildings with mechanical ventilation. The occupants' thermal sensation (rated from -3 to +3 on the ASHRAE scale) was in average -0.2 for the naturally ventilated offices and +0.1 for the mechanically ventilated buildings, thus both results were near neutral. The contradictive results have, according to the authors, been indicated in earlier studies as well and one possible explanation is that occupants in naturally ventilated buildings have lower expectations of the indoor environment than people in climate-controlled buildings with less fluctuating pollutions and temperatures.

Night ventilation and passive cooling

Cooling with night ventilation and passive cooling with thermal-active building systems or earth-to-air heat exchangers are often combined in low-energy office buildings in order to improve the cooling efficiency. Night ventilation can affect the day time internal conditions by reducing the peak air temperatures, reducing air temperatures throughout, reducing slab temperatures and creating a time lag between external and internal peak air temperatures. Night ventilation has almost become a standard in the UK for "green" office buildings using natural ventilation (Kolokotroni and Aronis 1999). Thermo-active building systems (TABS) cool and heat the building structure using tube heat exchangers integrated with building elements. TABS are thermally activated by either water or air and operate with temperatures close to the room temperature. Thus free energy from surrounding heat sinks such as the ground, ground water and ambient air can be used. The cooling water temperatures are often 18-22˚C and the heating water temperatures no more than 27-29˚C. TABS can also be called slab cooling and heating, underfloor cooling and heating, concrete core temperature control, hydronic radiant heating and cooling. In buildings with TABS, room temperatures cannot be individually or quickly adjusted. TABS were introduced in office buildings in Switzerland in the early 1990s. During the last decade TABS have been gaining an increasing market share in Western Europe. (Bine 2007; Henze, Felsmann et al. 2008). Pfafferott, Herkel et al. (2005) state that passive cooling is one promising approach in moderate climates to reduce the energy demand for cooling without reducing thermal comfort and without increasing facility electricity. However, the performance depends on complex correlations between heat gains, heat losses and heat storage. Kalz, Herkel et al. (2009) claim that cooling from ambient air with mechanical night ventilation is harvested with a rather poor efficiency due to the high electricity use for the fans. The cooling effect is particularly limited during persistent heat waves. The required air change rates and the actual cooling effects have been investigated by several researchers.

Kolokotroni and Aronis (1999) investigated the applicability of night ventilation in air-conditioned office buildings in order to find out if it also can be a good strategy for a mechanically ventilated building, considering the increased consumption of fan energy. The simulated building was a standard air-conditioned office building in the UK with medium thermal mass and the cooling season was chosen as simulation period. A parametric study was carried out, varying internal gains, thermal mass, glazing ratios, solar shadings, building orientation, night cooling strategy (balanced mechanical ventilation or natural ventilation) ventilation rates and operation time. The simulation results showed that mechanical night ventilation can lead to an increased energy use because of the fan operation. The use of a natural, single-sided night ventilation concept in the reference building, on the other hand, yielded a 5% reduction in energy consumption, corresponding to approximately 1 kWh/m^2yr. According to the parametric study, the maximum effect from night ventilation is achieved when the building has more exposed thermal mass, followed by improved airtightness, reduced glazing-ratio and reduced internal heat gains. An optimized building; heavyweight with exposed concrete ceilings, airtight with an infiltration rate of 0.1 ach, a glazing-ratio of 20%, a reduction of internal gains by 10 W/m^2 and with natural stack ventilation during night with a ventilation rate of 10 ach, can save up to 9 kWh/m^2yr compared to the reference case.

Pfafferott, Herkel et al. (2003) carried out full-scale experiments in an existing German office building (Fraunhofer ISE) in order to determine the efficiency of night ventilation dependent on air change rate, solar gains and internal heat gains. The building has hybrid ventilation with a minimum air change rate of 1 ach during working hours and a night ventilation air change rate of up to 5 ach. The experiments were evaluated by using both a parametric model and a simulation program in order to develop a method for data evaluation in office buildings with night ventilation. During the experiments, meteorological data, air change rates, air temperatures, surface temperatures and the operative room temperature were measured in two rooms, one with and one without night ventilation. The results show that room temperatures exceed 25˚C in less than 8% of the working hours. Due to thermal stratification and solar radiation there is an increase in temperature of 0.5˚C from one floor to the next. As expected, the night ventilation efficiency increases with the air change rate and decreases with the ambient temperature. The comparison between the measurements and the results from the parametric model shows that the parametric model is correct to use when calculating the mean air temperature but not so accurate when calculating the temperature amplitude. The result from the building simulation shows a good agreement between measurements and simulation results when the input parameters and boundary conditions are well known. However, different user behaviour results in energy and temperature variations of great magnitude. A simulation with standardized input shows that night ventilation reduces the mean air temperature by 2-3˚C.

Pfafferott, Herkel et al. (2004) evaluated the night ventilation concept in a low-energy office building in Germany (DB Netz) in order to quantify the cooling capacity and study the thermodynamic phenomena. The office building was designed, constructed and monitored for two years within the German research program SolarBau with the general benchmark of a total primary energy demand below 100 kWh/m^2yr. The building has a central atrium for cross ventilation and daylight inlet. The ventilation strategy during office hours is hybrid with both natural and mechanical ventilation. Night ventilation is automatically activated during summer nights (2 a.m.-8a.m.) and the airflow depends on stack effects due to the atrium. In addition, the ventilation system has an earth-to-air heat exchanger for pre-cooling the supply air. The monitoring results show that general comfort criteria were not strictly matched since the operative room temperature exceeded 25˚C during 11-15% of the working hours. Tracer gas technique was used to get more detailed information on airflow rates and flow paths in different opening states. The experiments showed that the air change rate is higher during night than during day (due to stack effect) and higher with open rather than closed doors (small flow resistance). Furthermore, the effect of the night ventilation is higher in the peripheral rooms than the rooms close to the atrium because the rooms closest the façade get more benefit from the cool outdoor air. The simulations indicated that the most efficient strategy is hybrid day ventilation in combination with pre-cooled supply air from an earth-to-earth heat exchanger.

Jaboyedoff, Roulet et al. (2004) presented some of the work within the frame of the European project AIRLESS. The main objective of the energy part of the project was to assess the impact on energy consumption of the use of natural and mechanical ventilation in administrative buildings. A three-storey building, with offices facing south and an atrium facing north, was modelled with TRNSYS. The natural ventilation system consisted of automatic controlled pivoted window parts and interzone openings. To investigate the influence of window openings three different opening sizes were simulated; 2%, 4% and 8% of the façade area. Other parameters studied were airflow rates, thermal mass, humidity, heating and cooling energy, heat recovery, airtightness, cooling set-point temperatures, duration of the fans and geographical influences (Oslo, Zurich and Rome). The results from the study show that the annual duration of the temperatures above 25˚C is about 200 h for a light building with small openings, and only 20 h for a heavy building with large ventilation openings. Furthermore, the airtightness is a parameter of great importance; a leaky envelope can more than double the heating energy use. Changing the cooling set-point temperature from 26 to 24˚C increases the cooling energy by more than 50%. Operation of the ventilation 24h per day increases the heating demand by about 25% in Oslo but also allows a reduction of cooling energy by about 25% in Rome. The use of heat recovery allows a reduction of heating energy by about 50% in Oslo. For a Zurich building, with high performance envelope and low airflow rate for high-energy efficiency, it is not possible to remove the heat accumulated during the day when the ventilation does not operate at night. Humidification and mechanical cooling are significant energy users and should therefore be avoided whenever possible without reducing the comfort. An efficient and economical cooling strategy is to combine a mechanical ventilation system designed for the minimum hygienic airflow rate with passive cooling using natural night ventilation.

Breesch, Bossaer et al. (2005) evaluated the passive cooling effect and thermal comfort in the low–energy office building SD Worx in Belgium, with natural night ventilation and an earth-to-air heat exchanger. The well-insulated building consists of two office floors and an atrium on the south side. During the cooling period, the earth-to-air heat exchanger pre-cools the supply airflow daytime and the natural ventilation system cools the exposed surfaces during night time ambient air entering from operable windows. Measurements during summer 2002 were used to show outdoor and indoor temperatures, airflow rates in the mechanical ventilation system and control parameters in the cooling season. In addition, simulations were carried out in TRNSYS and COMIS in order to estimate the relative importance of the different techniques. The measurements showed that the night ventilation was in operation during 60% of the nights in the cooling season. The temperature drop was higher on the first than on the second floor because of stack effects. The ambient air temperature peak was on average postponed for 5h and therefore the indoor air temperature peaks occurred after the office hours. The earth-to-air heat exchanger secured that the maximum temperature of the supply air never exceeded 22˚C. During days with a maximum external temperature between 12 and 22˚C, the cooling effect was limited. A heating demand was noticed when the maximum outdoor temperature was below 12˚C. Thermal comfort was evaluated and according to the authors an excellent thermal summer comfort was reached. 26˚C was only exceeded in 0.3% of summer working hours and 25˚C was exceeded in 8.2% (operative temperatures). The simulations and comparisons with measurements showed that the actual outdoor climate was slightly warmer than the simulation weather data. Yet, the simulation model showed a slightly worse thermal comfort with more working hours exceeding 25 and 26˚C. Furthermore, in contrary to measurements, the simulated temperatures hardly differed between the floors. The impact of natural night ventilation versus earth-to-air heat exchanger was estimated by comparing the thermal summer comfort of the building. Natural night ventilation appeared to be much more effective than an earth-to-air heat exchanger. If the internal heat gains were kept low the natural night ventilation alone could provide a good thermal comfort. An earth-to-air heat exchanger alone with no other cooling system performed poorly.

Eicker , Huber et al. (2006) evaluated one of the first passive house office buildings, Lamparter in Germany. The building was constructed in 1999 and monitored over three years in order to analyze the summer performance of a highly insulated, well sun-protected and mechanically ventilated building. The cooling system consists of a passive night ventilation concept, whereby the user has to manually open the upper section of the windows, and by an additional earth-to-air heat exchanger which pre-cools the supply air during the day.

Monitoring results showed that during the typical summers of 2001 and 2002, the night ventilation concept was efficient with only 2% of all office hour room temperatures above 26˚C (50-60h). In 2003 though, with a mean summer temperature 3.2˚C higher than usual, 9% of the office hours had room temperatures above 26˚C (230h). Air change rates were measured using tracer gas technique during 170 night hours in the summer of 2003. The average air change rate turned out to be 9.3 ach at an average wind speed of 1.1 m/s. The air exchange was strongly wind induced. Because of the night ventilation, the room temperature level dropped by 3˚C from the daily peak during the hot month of August. Simulations were carried out with TRNSYS in order to see how to improve the night cooling efficiency. One solution could be automatic control of the window openings, postponing the opening until later in the evening when the ambient temperature is cooler. When the windows are manually opened by the users at the end of the working day (6 p.m.), the room first gets heated by the warm ambient air which can reduce the night cooling potential by 20-30%. The contribution of the earth-to-air heat exchanger during day time operation was also investigated, both experimentally and theoretically. Temperature sensors were placed inside the pipes and the humidity of the air was measured at the inlet and the outlet of the pipes. The pipes lie in a depth of 2.8 m where the soil temperature is almost constant, closely matching the annual mean ambient temperature. By ventilating the ambient air through the system the supply air is cooled in summer and heated in winter. The measurements showed that the heat exchanger performed very well in the warm summer of 2003 and the supply air was pre-heated and pre-cooled by around 10˚C. The outlet temperatures were kept below 20˚C 95% of the time and never dropped below 0 ˚C, which is excellent to prevent freezing of the heat recovery unit in the mechanical ventilation system. The annual coefficients of performance (COP) were calculated from the sum of heating and cooling energy divided by the additional fan electricity required to run the supply air through the tubes. The calculated COP reached very high levels; between 35 and 50 (due to small pressure losses) and covered about 20% of the average internal loads. However, the earth-to-air heat exchanger could not fully remove the daily cooling load because the required ventilation rate was too small.

Pfafferott, Herkel et al. (2007) analysed room temperatures in existing, passively cooled low-energy office buildings in Germany. The 12 case buildings are all within the research program EnBau and designed for a primary energy demand below 100 kWh/m^2yr for heating, ventilation, lighting and technical services. All buildings have hybrid day-ventilation concepts and most have night ventilation for pre-cooling the building. Some have TABS (concrete slab cooling) and some earth-to-air heat exchangers. The weather at the building site and the room temperatures were monitored over 2-3 years. The comfort was evaluated for the hourly mean room temperature during weekdays and normal office hours. The study indicates that passively cooled low-energy office buildings provide a good thermal comfort in moderate European summer climate according to the European standard. If extreme weather conditions are given, like in summer of 2003 with long heat waves, buildings with night ventilation and earth-to-air heat exchanger exceed their capacity limits of thermal comfort. Water-driven cooling (TABS), using the ground as heat sink, provides a good thermal comfort even in extreme weather conditions. The new European standard take in consideration that occupants in naturally ventilated buildings perceive higher room temperatures as comfortable, supported by several research projects.

Haves, Linden et al. (2007) performed thermal simulations of a naturally ventilated office tower in San Francisco in order to evaluate different ventilation strategies for space cooling. The building is a narrow-plan, high-rise tower elongated in the NE-SW direction. Simulations were carried out with Energy Plus and COMIS with the assignment to find out whether there is a need to use buoyancy effects to supplement the wind. The paper also describes the airflow and temperature distribution in the occupied spaces arising from different combinations of window openings and outdoor conditions. Different ventilation configurations were simulated for the cooling season (April to October). The windows were opened whenever the inside air temperature exceeded both the set-point and the ambient temperature. An adaptive comfort criterion model for naturally ventilated buildings was used (ASHRAE 55). The adaptive model has an upper limit for the operative temperature of 26-28˚C and it assumes that occupants will change their clothing in response to changing conditions. The main observations from the study reveal that wind-driven night ventilation produces reasonable daytime comfort conditions and that a combination of wind-driven and internal stack-driven ventilation produces only a modest improvement in performance. Internal stack-driven night ventilation is less effective than the wind-driven case. Furthermore, additional external chimneys do not improve the performance of the combined case. The airflow study shows that the geometry of the user-controlled windows has a large impact on the airflow, the opening area and the ventilation efficiency. It is therefore desirable that the user operable opening has the maximum possible momentum flux which can be achieved by introducing a flow deflector. With this study, the authors show the importance of careful simulations in order to optimize the ventilation strategy and window geometry and thereby improving the ventilation efficiency and increasing confidence in the system.

Artmann, Manz et al. (2008) decided to identify the most important parameters affecting night ventilation in order to reduce uncertainties in the prediction of thermal comfort in buildings with night-time ventilation. The night ventilation concept is simple but the cooling effectiveness is affected by many parameters, which makes predictions uncertain and architects and engineers hesitant to apply the technique. The HELIOS building simulation programme was used to model a standard office room, occupied by two persons as base case. The external façade, including two windows with external sunscreens was oriented to the south. The parameters studied were different levels of thermal mass, internal heat gains, air change rates, heat transfer coefficients and different sources of climatic data. The Performance was rated by evaluating overheating degree hours of the operative room temperature above 26 ˚C. The study shows that cooling by night ventilation depends mostly on climatic conditions, building construction and internal heat gains. The external climatic conditions were found to have a very large impact on overheating. Not only local, but also annual climatic variability has a large affect. The weather data from the warm summer of 2003 clearly showed that simulations based on commonly used climatic data do not always allow reliable predictions of thermal comfort. The impact of thermal mass in internal walls depends on room geometry. In a large open plan office the wall-to-floor ratio is small and the construction of the walls thus becomes less important. The thermal mass of the ceiling is always favourable though, a concrete ceiling in direct contact with the room air reduced overheating by a factor two compared to a suspended ceiling. Varying the internal heat gains from persons, equipment and electric lights had about the same impact as the thermal mass. If high internal heat gains are combined with a low thermal mass, no air change rate will be sufficient enough to avoid overheating. As solar heat gains were generally low compared to internal heat gains, the effect of façade orientation on overheating degree hours was relatively small. A clear difference was found only for an office oriented to the north, where the overheating degree hours were almost halved. Regarding the night ventilation rate, the cooling effect changes rapidly when the air change rate is increased from 0.5 to 4 ach. This makes predictions of thermal comfort uncertain when the airflow depends on ambient temperature and wind conditions which make it difficult to predict. When natural ventilation depends only on buoyancy forces, the airflow is small when the ambient temperature is high, making the cooling effect minor during warm periods. Therefore, the authors recommend that a mechanical system shall be used whenever natural forces are insufficient. When the airflow rate exceeds 10 ach, the cooling effect is not improved any more. The effect of the daytime ventilation rate was relatively small compared to the night ventilation rate. Heat transfer between the internal surfaces and the room air was found to have only a minor effect.

Høseggen, Mathisen et al. (2009) carried out simulations with ESP-r on a real office building with the assignment to estimate potential energy savings and comfort performance of exposing the concrete in the ceiling. The building (Røstad) is located north of Trondheim in Norway and it has demand controlled ventilation with an earth-to-air heat exchanger for pre-cooling the supply air. In the simulations, the impact of exposed concrete, occupancy rate, ventilation strategies and night time airflows were studied. The results showed that the cooling effect with night ventilation increased rapidly with air changes between 1-5 ach. For larger air change rates the cooling effect stabilised and air change rates exceeding 10 ach did not improve the performance further.

Goethals, Breesch et al. (2011) carried out simulations of a night cooled office room in Belgium with TRNSYS in order to investigate the sensitivity of the night cooling performance to convection algorithms. Night cooling with mechanical ventilation and air change rates of 6 and 10 ach was simulated. The night ventilation assumed activated when all of the following conditions were fulfilled:

- Monday – Sunday night, between 22.00 and 6.00
- Outdoor air at least 2°C colder than return air
- Return air warmer than 16°C
- Ceiling temperature warmer than 22°C

The results showed that the choice of the convection algorithm strongly affects the energy and thermal comfort predictions. The authors concluded that for night cooled spaces, a correct description of the convective heat transfer is regarded necessary.

2.4.3 User related electricity and internal gains

The user related electricity, or tenant electricity, is an important energy post in office buildings. Not only does it account for a large proportion of the total energy use, it indirectly increases the cooling energy due to the high internal gains it causes. Gratia and De Herde (2003) claim that the internal gains have a great, non-linear, impact on cooling loads. If half as much internal gains from lighting and equipment is secured, the indoor air temperature can be reduced by 3-4˚C. Eicker , Huber et al. (2006) monitored and analysed two office rooms in detail in a passive house office in Germany. The total hourly internal gains turned out to be 30-35W/m^2 for an individual office room and 50 W/m^2 for a room with two work stations. Most of the gains were due to the office equipment (approximately 17 W/m^2 and computer, 11 W/m^2 for lighting and 6 W/m^2 and person).

The most recent inventory of electricity consumption in Swedish office buildings is the "Step by step STIL" survey performed by the Swedish Energy Agency in 2005 (Energimyndigheten 2007). 123 existing office and administration buildings of different age were studied and the average electricity use for lighting, computers and other user related office equipment was 57 kWh/m^{2}yr. This number is in line with the recommended standardized input for energy calculations in office buildings provided by the SVEBY programme which stands for "Standardize and verify the energy performance of buildings" (SVEBY 2012). The SVEBY programme suggests that 50 kWh/m^{2}yr is a normal tenant electricity use in modern Swedish office buildings. The programme estimates that if the building is improved with "best practice" equipment, lighting and control systems, the user related electricity can be reduced to 39 kWh/m^{2}yr. Further improvements with new and efficient technique may reduce the user related electricity to 18 kWh/m^{2}yr in the future.

Lighting

123 existing office and administration buildings of different age were studied in the "Step by step STIL" survey (Energimyndigheten 2007) and lighting energy was one of the largest energy posts. The average lighting energy consumption for the 123 buildings was 23 kWh/m^{2}yr. However, the spread was significant and the minimum value was 7 kWh/m^{2}yr and the maximum value 53 kWh/m^{2}yr. The studied buildings had an average installed lighting power density (LPD) of 10.5 W/m^2. The average LPD in individual office rooms was 13 W/m^2 and in landscape offices 12 W/m^2. This can be compared to the building industry's current guidelines of maximum 10 W/m^2 in individual rooms and 12 W/m^2 in landscape offices (Ljuskultur 2010).

An extensive literature review was carried out by Dubois and Blomsterberg (2011) in order to find out the energy saving potential for lighting in office buildings. The authors listed a number of different strategies to reduce energy use for lighting in office buildings:

Improvement in lamp technology, ballast technology and luminaire technology

Many existing office buildings in Sweden have T8 fluorescent lamps (26 mm), even though the thinner and more efficient T5 (16 mm) fluorescent lamps were introduced already in 1995. T5 lamps are being installed in almost all new office buildings and modern T5 lamps have luminous efficacy up to 104 lm/W which is 20% more efficient than T8 lamps (OSRAM 2012). The luminous efficacy of light emitting diodes (LED) is increasing rapidly and can today reach 100 lm/W. However, the authors believe that conventional light sources will have a major role to play for some time yet. Most existing office buildings in Sweden still use the conventional wire-wound ballast devices which consume 10-20% wattage of the lamp. High frequency (HF) electronic control ballast use less than half the energy required by the wire-wound types. Furthermore, HF lighting has a better lighting quality, flicker-free lighting, reduced power demand, longer life time and are compatible with lighting control systems. The luminaire value describes the efficiency of the lighting fixture and how much of the lamp flux that is emitted into interior space (useful lumen). It depends on the quality of reflectors, diffusers, filters and ambient temperature of the lamp. Modern fixtures with coated reflectors and holographic diffusers can have luminaire values of 75% and higher. (Dubois and Blomsterberg 2011)

Use of task lighting

One efficient way of saving lighting energy can be having separately controlled task lighting (desktop lamps) together with the general lighting. The task light ensures the required 500 lux immediately at the desk and the general lighting can be adapted according to available daylight. 22-25% lighting energy can be saved compared to fixed general lighting. Desktop lamps should never be used as the sole light source though, because of the increased risk of visual fatigue. The level of background luminance is important since it influences visual, emotional and biological aspects. (Dubois and Blomsterberg 2011)

Reduction of illuminance levels

In Sweden, an illuminance level of 500 lx is recommended on the task area for individual office rooms while 300 lx is normally accepted as general lighting for landscape offices (Ljuskultur 2010). Several studies indicate that people generally prefer lower levels than 500 lx in office rooms but the preferred illuminance level is highly individual. By using 400 lx as a design criterion, a 20% decrease in energy consumption could be expected without reducing the number of satisfied workers. One suggestion is to install a range of adjustable task illumninaces for particular situations rather than a single level. Some people would probably choose lower levels than recommended. (Dubois and Blomsterberg 2011)

Reduction of switch-on time

The lighting energy consumption is affected by installed power and off course the number of hours the lights are on. The European standard EN 15193 recommend a total utilization time for electric lighting in offices of 2500 hours per year. This corresponds to approximately 10 hours per day (5 days/week, some national holidays excluded), which is a reasonable value considering a small amount of flexible working hours. The recommended number of hours requires that the lighting system must be completely switched-off after operation. This will probably involve some kind of automatic power-break to avoid losses due to lights left on by mistake. (Dubois and Blomsterberg 2011)

Use of lighting control systems

Lighting energy can be considerably decreased by using lighting control systems for reducing switch-on time and power. Studies have shown that manual dimming can save 25% energy and switch-off occupancy sensors can save 20-35%, normally 25% with a sensor time delay setting of 20 min. Daylight harvesting in office buildings is not only important for the health and well-being of people. The utilization of daylight can be effective in order to reduce the electric lighting consumption. Direct savings in terms of reduced electricity for electric light and also indirect savings because of reduced internal heat gains and reduced cooling demand. Research has shown that daylight controlled lighting systems with an automatic on/off switch or photoelectric dimming have the potential to reduce the electrical energy by as much as 30-60%. Equipment for dimming is more expensive than on/off switching systems though. Dimming ballasts are less efficient than non-dimming ballasts and they consume 10-20% power even at the lowest possible light output. The daylight availability in peripheral rooms allows lighting energy savings of 25-60% for a dimmed lighting system.

(Dubois and Blomsterberg 2011)

The review, which is based on different measurements and simulations, indicates that about 10 kWh/m^2yr is a realistic target for electric lighting in future low energy office buildings. This is a 50% reduction compared to the actual average lighting energy use in Sweden. Even lower consumptions are achievable by accepting lower illuminance levels (400 instead of 500) and by using efficient task lamps.

Dubois and Flodberg (2012) investigated the effect of various switching and dimming strategies for electric lighting systems with the dynamic daylight simulation program DAYSIM and the user behavior control model Lightswitch. The model predicts when occupants will use their blinds and when they will switch on and off the electric lighting. Figure 2.X shows the electric lighting consumption for different control strategies in relation to glazing-to-wall ratio (GWR) for a peripheral single office room towards south in Stockholm. The slope of the curves indicates that the choice of electric lighting strategy has greater impact on electricity use than the GWR. One interesting finding is the fact that the system with occupancy sensor with automatic switch on/off actually yields more energy than the ordinary manual switch near the door. The reason is that lights automatic switch on when the room is occupied, even if there is sufficiently available daylight. To prefer is the occupancy switch-off which according to the study yields around 25% savings compared to the manual switch by the door. This system automatically switches the light off when the room is empty and the occupant will have to switch it on manually when he or she returns. The most efficient system is photoelectric dimming with occupancy switch-off which allows savings of at least 50% compared to the manual switch. With this system, daylight sensors reduce the electric light when useful daylight is available, and the lights are automatically switched off when the room is unoccupied. The system makes it possible to achieve an annual electricity use beneath 10 kWh/m^{2}yr. Moreover, the study indicates that the initial lighting power density (LPD) is an important design feature. An LPD of 8 W/m^2 combined with a simple occupancy switch-off system is another strategy in order to achieve an electricity use of 10 kWh/m^{2}yr.

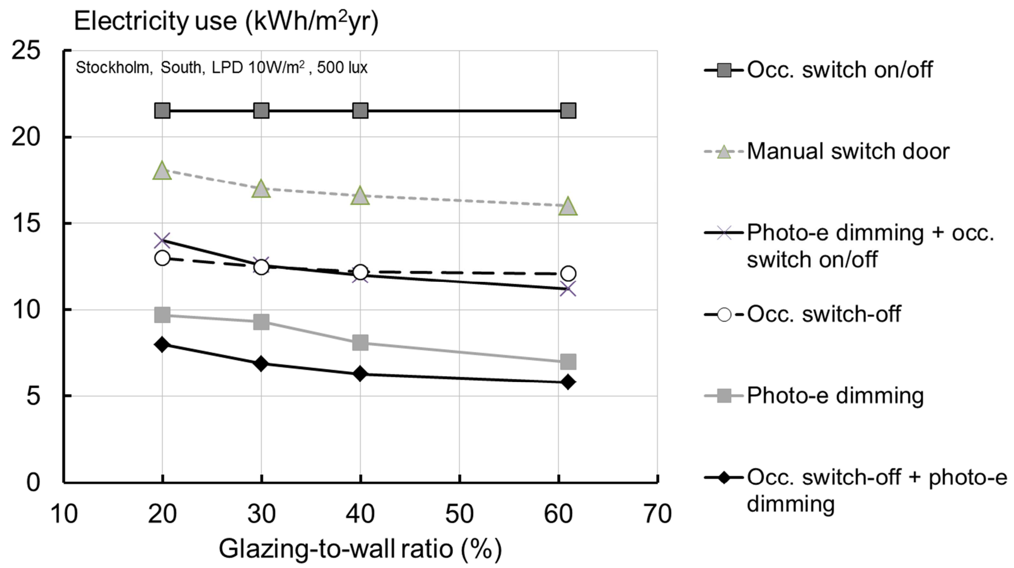


Fig. 2.X Electric lighting consumption as a function of switching and/or dimming strategy in relation to GWR for a south orientation in Stockholm with LPD 10 W/m2 and benchmark illuminance of 500 lx. With permission from Marie-Claude Dubois 2012.

Resembling results were found for an open landscape office in a study carried out by Dubois and Du (2012). Different lighting strategies were investigated for an open landscape office in Stockholm with varying GWR and orientation but without solar shadings. The control system with occupancy switch on/off yields the highest electricity use, while a perfectly commissioned photoelectric dimming system can save more than 50% compared to a conventional manual switch near the door. The saving potential is still high at the third row from the façade, but deeper into the room it decreases because of limited useful daylight. The additional savings from an occupancy switch-off system are quite small since an open landscape room with many work stations is occupied most of the time during office hours.

Equipment

The 123 inventoried office buildings in the "Step by step STIL" survey (Energimyndigheten 2007) showed an average electricity consumption for computers of 15.4 kWh/m^2yr and for server rooms of 10.7 kWh/m^2yr. The electricity use for other equipment, such as printers, copy machines and mini-kitchens, was 8 kWh/m^2yr in average. Hence, the total tenant electricity for office equipment was 34 kWh/m^2yr. In addition, facility electricity other than fans was 9.5 kWh/m^2yr (pumps and elevators for instance) but this is not user related.

There is great energy saving potential when it comes to office equipment. Modern computers and displays have lower equipment power density (EPD) and use less standby power. It is also important to reduce the operation hours by preventing equipment left on by mistake or left in standby mode outside office hours. Jagemar and Olsson (2004) carried out detailed measurements of electricity use in three Swedish office buildings built in 1998-1999 (two with individual rooms and one with open landscape office). The study showed that in two buildings, computers and other equipment were left in a sleep mode during night. Thus, the equipment power was 4 W/m^2 outside office hours. In the third building, computers were shut off during night and the equipment only consumed 0.5 W/m^2 during nights and weekends. Computers, displays and chargers consume power even when they are turned off. According to the SVEBY programme, 15% of the EPD can be assumed outside office hours. There is great saving potential in using power strips and multiple sockets which make it easy to turn off the equipment completely during night. Alternatively, modern equipment with low off-mode power can be used, for instance equipment qualified according to the ENERGY STAR Label from the US Environmental Protection Agency (EnergyStar 2012). Several computers with this label consume less than 2 W in off-mode, an all the displays consume less than 1 W in off-mode.

A realistic EPD for a conventional stationary workstation with display is 125 W according to the SVEBY programme (SVEBY 2010). An energy efficient alternative is a modern laptop or notebook instead with EPD 12 W (EnergyStar 2012). Even with a separate display this option can be really efficient. Modern suitable Liquid Crystal Displays (LCD) consume 20-35 W depending on size (EnergyStar 2012).

Occupancy

The occupancy attendance in office buildings has a large impact on internal gains since it affects also the use of lighting and equipment. The SVEBY programme suggests an occupancy factor of 0.7 in energy simulations (SVEBY 2010). However, this value is of current debate and the general idea is that the value is lower in reality. Maripuu (2009) completed a study of occupancy patterns in office buildings as a part of a doctoral thesis about demand controlled ventilation in commercial buildings. In a literature review, Maripuu discovered that there are relatively few studies conducted on occupancy patterns. There are also very few guidelines about the occupancy factor to be used in the design process. The occupancy rate is defined as the actual number of occupied rooms, divided by the total number of rooms. Maripuu found out that the occupancy rate is highly dependent on the type of operation in the building. The occupancy rates found in the review by Maripuu are summarised in table 2.X and in addition, occupancy rates monitored by Blomsterberg and Høseggen, Mathisen et al. (2009) are included. In addition to the review, the author carried out own field monitoring in a university administration building in Gothenburg, Sweden. Patterns were monitored in different types of rooms with occupancy sensors installed to the supply air devices. The occupancy attendance was monitored during the period of September 2007 to September 2008. The impact of the switch-off delay time of the sensors was also evaluated. The results showed that the maximum occupancy factor occurring in the building was 0.7. The average occupancy factor during normal working hours (8:00-16:00) was about 0.4. The average occupancy period during a whole day (7:00-18:00) was 33% for office rooms, 16% for meeting rooms, 45% for copy rooms, 41% for break rooms and 14% for archives/library. With a 5/10-minute switch-off delay time of the sensors the occupancy factor and occupancy periods increased with 5-10%. Due to limitations in the technology of the sensors it was only possible to determine whether a room was occupied or not. The sensors did not give any information about the number of people in the room. The office rooms were designed only for one person though.

Table 2.X Occupancy rate found in literature (Høseggen, Mathisen et al. 2009; Maripuu 2009).

Report/Survey	Building	Method	Average Occupancy factor	Peak Occupancy factor	Time period
SBN 67 Swedish old building code	Fictive office	Proposed profiles	0.7 (>100 persons) 0.8 (11-100 persons) 1.0 (<10 persons)		?
ASHRAE/IESNA 90.1-1989	Fictive office	Proposed profiles	0.76	0.95	Weekdays 8:00-17:00
Keith and Krarti	Academic research facility	Monitoring	0.49	0.94 (10 rooms) 0.77 (50 rooms)	Weekdays 8:00-17:00
Johansson (2005)	University office (SWE)	Monitoring Sensors	0.33	0.49	Weekdays 8:00-18:00
	Municipality (SWE)	Monitoring Sensors	0.54	0.79	Weekdays 8:00-18:00
	Industrial office (SWE)	Monitoring Sensors	0.51	0.88	Weekdays 8:00-18:00
Halvarsson et al. (2005)	Office (NO)	Monitoring Sensors	<0.35 (90% of time)	0.62	?
	Education (NO)	Monitoring Sensors	<0.23 (90% of time)	0.47	?
Mathisen and Halvarsson (2007)	Office	Monitoring Sensors	0.6	0.84	?
	University office	Monitoring Sensors	0.2 <0.12 (90% of time)	0.3	?
Bernard et al. (2003)	10 companies (FR)	Monitoring Sensors	0.4	0.7	Weekdays 10h
Jagemar and	Office	Evaluating electric	0.3-0.5	0.7	Weekdays

Olsson (2004)		lighting			8:00-18:00
Blomsterberg (2011)	WSP Office (SWE)	Monitoring Sensors	0.6		Weekdays 8:00-17:00
Maripuu (2009)	University Office (SWE)	Monitoring Sensors	0.4 <0.53 (90% of time)	0.7	Weekdays 8:00-16:00
Høseggen, Mathisen et al. (2009)	2 Office buildings (NO)	Monitoring Sensors (20 min delay)	0.4 and 0.6	0.65	Weekdays 8:00-16:00

Høseggen, Mathisen et al. (2009) discuss whether hourly averaging of the room occupancy is an adequate approach. In open landscape offices with several people it is probably applicable but in individual office rooms persons are either present or absent, 0.7 persons cannot be present. This simplified input approach can off course be a possible source of error in whole building energy simulations. An occupancy rate of 0.7 for example in the simulation model smooths the internal gains. In reality, empty room can have a heating load meanwhile occupied rooms have a cooling load.

2.4.4 Thermal comfort

When a group of people are exposed to the same environment, they will experience a range of thermal sensations. A person's thermal response to environmental conditions is strongly influenced by clothing and activity. The thermal environment affects people's health and productivity and since the salary cost for workers in office buildings is much higher than the operating cost, this is of great importance (Schiller 1988; CEN 2007). There are a number of national and international standards, criteria and guidelines for predicting and evaluating thermal comfort. Other indoor environmental parameters are air quality, humidity, lighting and acoustics but these are not discussed in this section.

Schiller (1988) studied the accuracy of different theoretical and laboratory based equations to predict occupant's thermal sensation in existing office buildings. International standards for thermal comfort are ASHRAE 55 and ISO 7730 which are both based on extensive research in laboratory facilities. From these experiments, equations have been developed to predict the average thermal sensation felt by a large group of people. These mathematical models describe the heat exchange between the human body and the environment, the physiological thermoregulation mechanisms of the body and the relationship between people's thermal sensation (psychological) and the physiological thermal strain on the body due to environmental and personal conditions. The data in this report are based on a field study of 10 representative office buildings in San Francisco, where physical measurements and subjective responses were collected during one winter week and one summer week in 1987. 2342 visits were made to 304 volunteers (62% females and 38% males). Each participant was visited at their desk 5-7 times and had to complete a thermal assessment survey addressing thermal sensation, thermal preference, comfort, mood, clothing and activity. Meanwhile, a mobile cart was placed at the workstation, measuring air temperature, dew point temperature, globe temperature, air velocity, radiant temperature asymmetry and illuminance. The subjects were asked to fill in the seven-point ASHRAE Thermal Sensation Scale (TS) (-3 cold, -2 cool, -1 slightly cool, 0 neutral, +1 slightly warm, +2 warm, +3 hot). Schiller adopted the conventional approach of regarding the central three categories (slightly cool, neutral, slightly warm) as comfortable and that people voting outside these categories (cold, cool, warm, hot) were dissatisfied with their thermal state. Percentage of dissatisfaction was calculated by counting the number of votes where TS>1.5. Based on the responses of activity and clothing the total clothing insulation (clo) and metabolic rate (met) were computed according to the 1985 ASHRAE Handbook of Fundamentals. Schiller analysed thermal sensation predictions based on several models occurring in literature; the original PMV and PPD (Fanger and ISO 7730), PMV_G and PPD_G (Gagge 1986) and TSENS (Gagge). The TSENS index was developed using responses from 1000 subjects tested in a University laboratory and a two-node transient heat balance model of the body. The results from the study showed that the mean "clo" of the occupants was 0.58 in winter and 0.52 in summer and the average "met" was 1.12 for the whole year. Meanwhile, the different predicted mean votes were compared to the measured mean votes and the neutral temperature ($T_{neutral}$) was determined, at which a large group of people voted 0 on the ASHRAE scale.

$T_{neutral}$

Measured	22.4˚C
TSENS	23.8˚C
PMV (Gagge)	23.9˚C
PMV (Fanger, ISO 7730)	24.8˚C

The measured neutral temperature was cooler than predicted by all of the methods. Fanger's PMV consistently predicted that people would feel cooler than they did. The best agreement between the actual thermal sensation and the predicted thermal sensation was in the region near neutral. As conditions moved away from neutral, predictions were more conservative and occupants voted at more extremes than predicted. The results also show that the measured and the calculated percent dissatisfied differed a lot. The optimum temperatures ($T_{optimum}$) where least people were dissatisfied occurred at:

$T_{optimum}$

Measured	12%	22.5˚C
PPD (Gagge)	5%	23.9˚C
PPD (Fanger, ISO 7730)	5%	24.8˚C

The predicted values showed less dissatisfaction than the measured and the differences were even larger at warmer temperatures. This can be explained by the wide range of clothing worn in the offices, as compared to the standard uniforms in the laboratory experiments. The average "clo" was 0.55 for the whole year but the range varied from 0.23 to 1.14. However, additional simulations indicated that the over prediction of neutral temperatures rather reflected the worker's preference for cooler conditions than the researchers interpretation of clothing or activity levels.

Humphreys and Hancock (2007) studied the thermal comfort in university lectures in the UK to see if people really want to feel "neutral" according to the ASHRAE scale. In February and March 2004, 133 students of the Oxford School of Architecture took part in observations where they during 5 lectures gave their thermal sensation on the ASHRAE scale, and also indicated what their desired sensation would have been at that time, on the same scale. The scale contains 7 different scale units (-3 cold, -2 cool, -1 slightly cool, 0 neutral, +1 slightly warm, +2 warm, +3 hot). There were also questions about their recent activity and their clothing and the air temperature was measured in the lecture room. The results showed that more than 40% of respondents felt "neutral" and about 30% felt "slightly warm" while 15% felt "slightly cold". The responses regarding the desired thermal sensation showed that 60%

wished to feel "neutral" but almost 30% preferred to feel "slightly warm". "Neutral" is therefore not necessarily the desired thermal sensation. The survey also showed that the respondents' desired thermal sensation varied from occasion to occasion, typically with a range of two scale units. For example, a person who normally likes to feel "slightly warm" may on occasion like to feel "neutral" or "warm", but would rarely stray beyond these limits. Notable is that neither differences in amount of clothing, nor differing levels of activity had a coherent effect upon the *desired* thermal sensation. Another result from the survey was that the optimum air temperature, with most people being satisfied, would have been 21˚C but the measured mean air temperature was 19.3˚C. The authors highly recommended that, when using the ASHRAE scale, to ask not only how the respondents feel but also how they would like to feel and then adjust the result by taking the actual sensation minus the corresponding desired sensation. Thus the adjusted thermal sensation indicates how much "too warm" or "too cool" the respondents feel.

Barlow and Fiala (2007) observed occupant comfort in a refurbished office building in the UK, as well as occupants' preferences when adapting low-energy strategies. The surveyed building is a three floor open landscape office in London, built in 1950 and refurbished in 2002. The building has natural ventilation and night time ventilation, double glazed windows, external awnings, both automatically and manually controlled, and a chilled beam cooling system automatically controlled. Eight surveys were conducted during March, April and June 2005. Between 15 and 25 persons responded on each survey day out of a potential office population of 87 people (N.B. only 17-29%). The occupants were asked to describe their subjective response to a range of thermal conditions; thermal sensation (the ASHRAE scale), air movement, visual comfort and the preferred changes in each case. They were also asked which adaptive opportunities they would support if available. Measurements of internal and external air temperatures, solar radiation levels, operative temperatures, air movement and relative humidity were recorded. The results showed that the mean clo decreased from 0.8 clo in late winter to 0.66 clo in early summer. People changed their clothing to reflect the external temperatures but less than 4% indicated a change of clothing to reflect the variations of the internal temperatures during a survey day. When occupants were asked to estimate indoor temperature they consistently underestimated the measured mean air temperature, on average by 3.2˚C. When asked which adaptive opportunities they would support, 74% voted for operable windows, 69% voted for control of solar glare (even though occupants consistently voted they were not at all suffering from solar glare in the surveys), 47% voted for opportunities to control solar gain, 56% voted for turning lights off locally and 59% voted against turning lights off automatically, 55% voted for being able to increase levels of ventilation and 50% voted for actively intervening to alter room temperatures. The wish for solar glare control declined during summer months suggesting that the low-level winter sun was a greater problem than the high summer sun.

Wagner, Gossauer et al. (2007) carried out a survey on workplace occupant satisfaction in office buildings in Germany. Modern low-energy buildings are often designed with passive cooling instead of active cooling and the authors wanted to see if this can affect the occupant satisfaction. The objective was to find out if there are significant differences in satisfaction due to building type, energy concept and season, and in addition develop a "satisfaction-index". The survey was carried out in 2004-2005 in 16 different office buildings with a range of size and energy concepts. A questionnaire with properties such as air quality, temperature, air velocity, humidity, acoustics and lighting was given to the participants. In addition, more general questions including office layout, well-being at work, health, amount of work, communication and the general acceptance of the workplace was assessed. The questions were answered within a 5-point scale ranging from “very dissatisfied” to “very satisfied”. In each building, surveys were carried out in winter and in summer in order to take into account the influence of diverse climate conditions on the occupant’s judgement. As complement, room temperatures and humidity values were measured. A cluster-analysis was used to identify different possible groupings of building characteristics. Approximately 1300 questionnaires were evaluated. In summer, the result of the mean satisfaction with the room temperature was 0.6 scale points below the mean satisfaction in winter. The mean ratings ranged from “moderately satisfied” to “dissatisfied” in summer and from “satisfied” to “moderately satisfied” in winter. A comparison of the perceived room temperatures with the measured room temperatures gave a measured neutral temperature of 23˚C in winter, which is almost 1˚C above the recommendation of ISO 7730, and 23.5˚C in summer, which is 1˚C below the recommendation. In winter, the dissatisfaction with temperature often corresponded with being “too cool” and the feeling of draft. In summer, the dissatisfaction was mostly associated with the sensation of being “too warm” as well as with dissatisfaction of the indoor air quality. In both winter and summer, the most important factor turned out to be the ability to affect the room temperature. Since the potential of affecting the temperatures is higher in winter, due to larger temperature difference between outdoor and indoor air conditions, this can explain why the occupants were more satisfied in winter. The evaluation of different energy concepts in buildings and thermal comfort did not give any reliable results. The large variety of architectural and technical concepts only allowed a qualitative evaluation of their effect on the occupant satisfaction. However, the only office built according to the passive house standard, with a low glazing fraction, natural ventilation and without radiators, resulted in a very high satisfaction and with moderate temperatures even in warm summer days.

Pfafferott, Herkel et al. (2007) analysed room temperatures in 12 passively cooled low-energy office buildings in Germany, using and discussing four different comfort standards. The evaluated standards are the international standard (ISO 7730), the preliminary European standard (prEN 15251), the German standard (DIN 1946) and the Dutch code of practise (ISSO 74). The case buildings are all within the research program EnBau and were designed for a primary energy demand below 100 kWh/m^2yr for heating, ventilation, lighting and technical services. The buildings are located in three different German climate zones; summer-cool, summer-hot and moderate. The weather at the building site and the room temperatures in several office rooms were monitored over 2-3 years. The comfort was evaluated for the hourly mean room temperature during weekdays and normal office hours. The four comfort criteria use different time periods of the outdoor air and different clothing levels and different temperature limits. The results for one of the example buildings (Fraunhofer ISE), showed that the upper comfort limit was exceeded during 6% for DIN 1946, 11% for ISO 7730, 1% for ISSO 74 and 4% for prEN 15251 during the summer of 2002. The comfort criteria can give different quantitative numbers (%) for comfort since the criteria are based on different studies, databases and consumptions. In addition, the qualitative assessment can differ from one criterion to the next; the most comfortable building according to one standard can be less comfortable according to another standard.

3. State-of-the-art

This chapter presents the state-of-the-art of low-energy office buildings in Northern Europe. The most recent level of development is evaluated by studying existing low-energy office buildings and defining general and specific solutions regarding building design, HVAC systems and techniques for lighting and office equipment.

3.1 Method

In order to find suitable low-energy office buildings to study, contacts within universities and building research organizations in Northern Europe were contacted and asked to list the most interesting projects in their regions. Subsequently, members of the reference group as well as key persons in large building companies in Scandinavia were contacted. Additional buildings were found through energy related web pages and real-estate news pages. Buildings of interest were office buildings completed or designed or completely retrofitted during the last decade. Geographically, the focus was on Sweden and European countries with an outdoor climate similar to Sweden's, for example the Nordic countries and Germany with surroundings. For qualifying to this study, the building had to be more energy efficient, by at least 25%, compared to other new buildings in the actual country, and/or have some kind of green focus and certification such as GreenBuilding, Passive House, Minergie, LEED, BREEAM and Miljöbyggnad. In the end, fourteen low-energy office buildings in the Nordic countries and ten located in other parts of Northern Europe were selected for further studies. In the next step, the contact person for each project was asked to fill in a detailed questionnaire. Requested material was general information about the constructor, contractor and architect as well as more specific information about building size, building envelope, materials, U-values, airtightness, glazing and solar shading devices. Furthermore, information about the operation, HVAC-systems, lighting strategy and energy consumption was requested. Only a couple of these questionnaires were filled in properly though. Most of the contacts handed in existing sales brochures and answered a couple of additional questions instead. This is likely to depend either on lack of time and interest or unwillingness to share company material with competitors. Besides the questionnaire, some of the recently completed projects in Sweden were visited in a field study. The gathered information was analysed and compared to different guidelines, the Swedish building code and the existing building stock. The validity of the received information could not be verified in a greater extent.

3.2 Existing low-energy office buildings in Northern Europe

In this section, examples of low-energy office buildings from Sweden, Norway, Denmark, Finland, Germany, Austria and Switzerland are presented. The fact that the different countries have different building regulations and definitions makes the comparison to Swedish conditions more difficult. For instance, Sweden is one of few countries within the European Union which focus in building performance and end-use energy instead of supply systems and primary energy consumption. To be able to compare the energy performance, the primary energy figures have been recalculated into end-use energy with actual primary energy conversion factors.

3.2.1 Sweden

Hagaporten 3, Solna

Fig 3.1. Visualisation by Strategisk Arkitektur

Location	Stockholm (N 59.36˚ E 18.02˚)
Climate	HDD 3203/ CDD 261
Completion year	2008
Client/developer	Skanska
Architect	Strategisk Arkitektur
Contractor	Skanska
Tenant	ÅF
Tot. floor area	33 265 m^2 A_{temp} +car-park
Floors	7
Operation	Office, restaurant, car-park
Office hours	6.30-18.00
Plan type	Open
Space efficiency	15 m^2/employee
References	(Skanska 2008a); Gräslund (2010); (Persson and Arvidsson 2010)

Building design

The open plan office space is located around an atrium with communication space, meeting rooms and natural daylight inlet. The building envelope has concrete sandwich walls U= 0.34 W/m^2K, roof U=0.13 W/m^2K and windows U=1.4 W/m^2K (incl. frame). The air-tightness was measured to 0.5 l/sm^2 at 50 Pa pressure difference. The glass facades towards south and west have g-values of 15% and external, motorized sun shading devices.

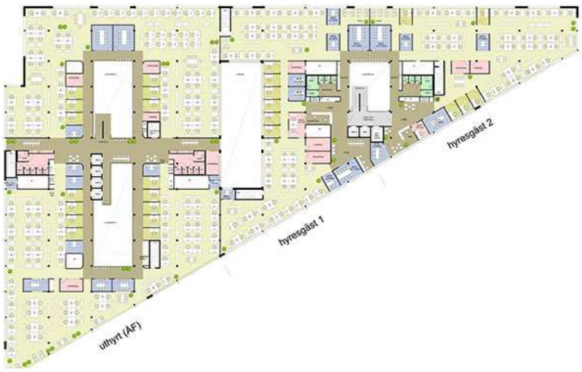


Fig 3.2. Plan by Strategisk Arkitektur

HVAC+L

The target indoor temperature is 22-23˚C. The building is provided with district heating and cooling. The AHU is equipped with a free-cooling battery which serves the cooling baffles with cold water when the outdoor air is below 15˚C. In addition, the free-cooling battery pre-heats the incoming ventilation air. The CAV ventilation has a low-speed high-efficiency AHU with a ring-formed duct system. SFP is low; 1.4 kW/m^3s^{-1} and the air-flow is 1.5 l/sm^2 with acceleration possibilities in meeting rooms. A coil heat exchanger with a measured efficiency of 67% recovers the heat from return air (including air from the garage). Occupancy sensors control the low-energy lighting system in spaces not regularly occupied, and the installed power for lighting is 5 W/m^2.

Energy performance

The specific end-use energy according to BBR was 79 kWh/m^2yr in 2009 (excl. tenant electricity). Hagaporten 3 is certified according to EU GreenBuilding and Miljöbyggnad (Gold).

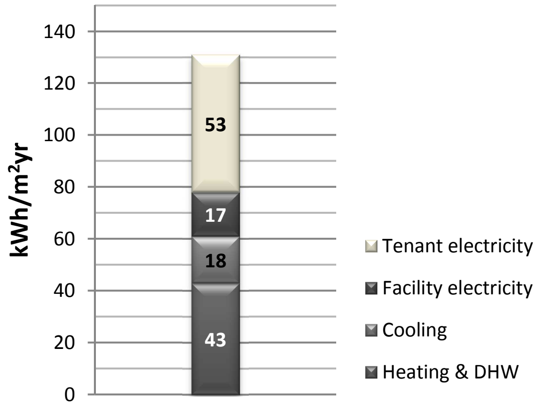


Fig 3.3. End-use energy (monitored 2009).

Jungmannen 3, Malmö

Fig 3.4. Photo by Midroc.

Location	Malmö (N 55.61˚ E 12.99˚)
Climate	HDD 2893/ CDD 215
Completion year	2010
Client/developer	Midroc Property Development
Architect	White
Contractor	Divided
Tenant	Ramböll
Tot. floor area	4800 m^2 A_{temp}
Floors	5
Operation	Office, restaurant, apartments
Office hours	Weekdays 8-18
Plan type	Open
Space efficiency	20 m^2/employee
References	Sjöqvist (2010); (Herneheim 2011)

Building design

The building has a compact shape and an open planned office space with a centred communication space. Room height is 3.0 m. The construction is heavy with concrete sandwich walls with metallic façade elements and a U-value of 0.25 W/m^2K. The U-values of the roofs are 0.13 and 0.22 W/m^2K. WWR is only 0.25 and the windows have a U-value of 1.3 W/m^2K (incl. frame) and a g-value of 0.32. In addition, there are external motorised blinds. The air-tightness was measured to 0.7 l/sm^2 at 50 Pa pressure difference.

Fig 3.5. Plan by White arkitekter.

HVAC+L

The target indoor temperature is 22˚C. The building is connected to district heating and cooling. Heating is distributed with radiators. Cooling is distributed with the supply air and night ventilation is possible for extra summer cooling. The ventilation system is a VAV-system with active ceiling air diffusers (Lindinvent TTD). Built-in sensors (presence and temperature) keep the airflow low and the supply temperature can be kept very low without causing draught problems. Cooling with ambient air is used most of the year. An efficient rotating heat exchanger with a measured efficiency of 80% recovers the heat from return air. The electric lighting system is controlled by the presence- and daylight sensors located in the air diffusers.

Energy performance

The specific end-use energy according to BBR is estimated to **43 kWh/m²yr** (excl. tenant electricity), calculated with VIP Energy. Jungmannen is certified according to EU GreenBuilding.

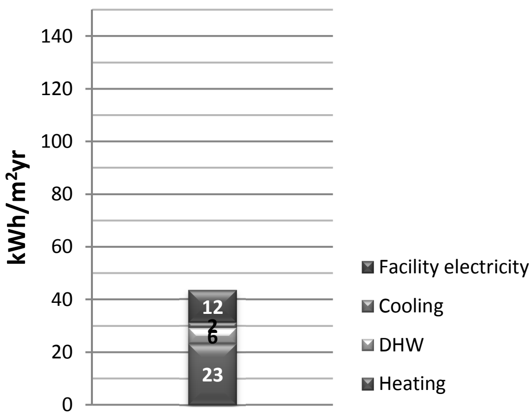


Fig 3.6. End-use energy (calculated).

Kaggen, Malmö

Fig 3.7. Photo by Rafael Palomo

Location	Malmö (N 55.61˚ E 12.99˚)
Climate	HDD 2893/ CDD 215
Completion year	2007
Client/developer	NCC Property development
Architect	Metro Arkitekter
Contractor	NCC
Tenants	NCC et al.
Tot. floor area	9400 m^2 A_{temp}
Floors	6
Operation	Office, café, hair dresser
Office hours	Weekdays 8-18
Plan type	Open
Space efficiency	13-20 m^2/employee
References	Söderling (2010)

Building design

The building has a square form and the open planned office space is located around a large atrium in south with communication space and natural daylight inlet. The building is compact with a surface-to-volume ratio of 0.2 m^{-1}. The general room height is 2.7 m but along the façade, where there are no ducts, the height is 3.0 m. The Building envelope is air-tight (not measured) and well insulated with an average U-value of 0.50 W/m^{2}K. The walls are concrete sandwich elements with a U-value of 0.31 W/m^{2}K. The WWR is 52% and the WFR is 20%. The windows have a U-value of 1.3 W/m^{2}K (incl. frame) and a g-value of 0.31. Internal sun screens are manually controlled.

Fig 3.8. Plan by Metro Arkitekter

HVAC+L

The control points for indoor air temperature are 21-25˚C. The building is provided with district heating and cooling and an electric boiler for hot service water production. A VAV-system with active ceiling air diffusers (Lindinvent TTD) with built in sensors (presence and temperature) keeps the airflow very low, about 30% of maximum on a yearly basis. The air-flow varies from 0.35-1.5 l/sm^2. Because off the efficient rotating heat exchanger (measured efficiency is 83%), and the low airflow there is no need for a heating battery in the air handling unit. The supply air temperature is 15-18˚C and SFP is 1.9 kW/m^{3}s^{-1}. The electric lighting system is controlled by the occupant- and daylight sensors in the air diffusers.

Energy performance

The specific end-use energy according to BBR was **65 kWh/m^2** in 2009 (excl. tenant electricity). Kaggen is certified according to EU GreenBuilding.

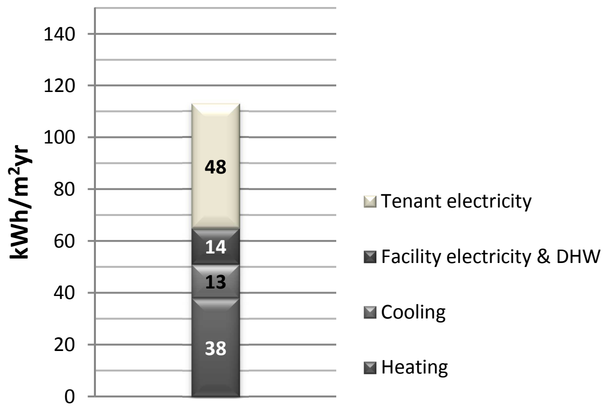


Fig 3.9. End-use energy (monitored 2009).

Kungsbrohuset, Stockholm

Fig 3.10. Visualisation by Strategisk arkitektur.

Location	Stockholm (N 59.33˚ E 18.05˚)
Climate	HDD 3203/ CDD 261
Completion year	2010
Client/developer	Jernhusen Blekholmen AB
Architect	Strategisk arkitektur
Contractor	Divided contract
Tenant	Jernhusen, Schibsted, et al
Tot. floor area	21 000 m^2 (office)
Floors	12+garage
Operation	Office, hotel, restaurant, garage
Office hours	18h weekdays
Plan type	Flexible
Space efficiency	10-18 m^2/employee
References	(Larsson 2010); Sundholm (2010)

Building design

The narrow-shaped building has a flexible indoor plan with both open plan office space and cell office rooms. The room height is 2.85 m. The building has a double skin façade with an outer, tinted and ventilated, glass façade to keep the solar heat out and an inner façade with 50% WWR. The windows are well insulated with U-values between 0.7-1.1 W/m^2K. The U-value of the walls is 0.2 W/m^2K and the average U-value of the envelope is 0.42 W/m^2K. The envelope is very air-tight with a measured air-tightness of 0.3 l/sm^2 at 50 Pa pressure difference.

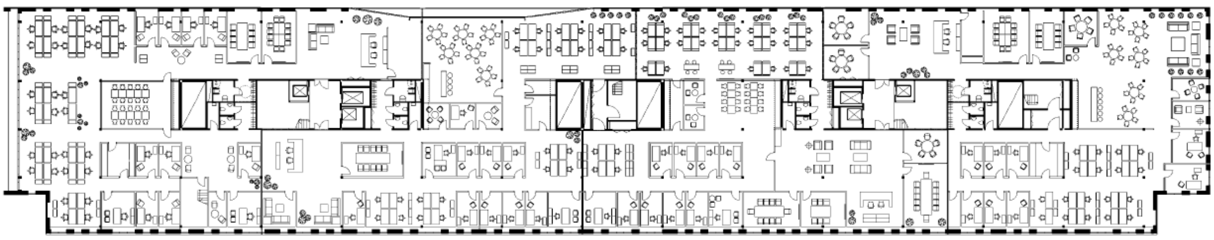


Fig 3.11. Plan by Strategisk arkitektur.

HVAC+L

The control set-points for indoor temperature are 20-26˚C. The building is connected to district heating and geothermal heating (partly from Lake Klara). Kungsbrohuset will also to some extent (15-25%) be heated by the 200 000 people passing daily through the Central railway station, ensured with an air-to-water heat exchanger. The cooling system is connected to district cooling and geothermal cooling (partly from Lake Klara). The cooling is distributed via active chilled beams and night ventilation is activated when needed. Each hour, the building gets detailed weather forecast via the GSM network, which helps optimizing heating and cooling systems. The ventilation is a CAV-system with acceleration possibilities in meeting rooms. The air flow is 1.5 l/sm^2 and the total SFP is only 1.0 kW/m^3s^{-1}. The efficiency of the heat exchanger is estimated to 75%. Installed power for electric lighting is 10-15 W/m^2 and stairwells are lit by natural daylight via fibre-optic cables. The power to television displays and mobile phone chargers is cut off during nights and weekends with a “green button”. The building’s energy use is displayed in real-time in the lobby, in order to inspire people to save more energy.

Energy performance

The specific end-use energy according to BBR is estimated to **47 kWh/m²** (excl. tenant electricity). The building is certified according to Miljöbyggnad (Gold target) and EU GreenBuilding.

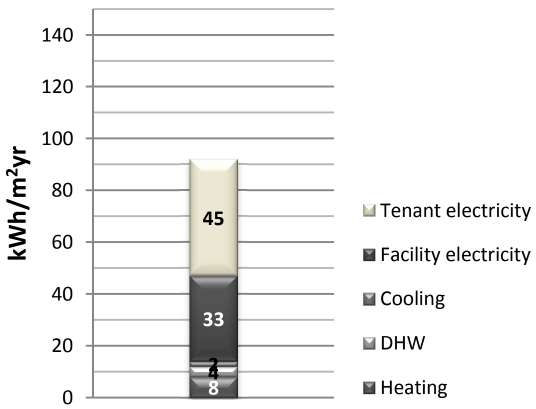


Fig 3.12. End-use energy (calculated).

Pennfäktaren (renovation), Stockholm

Fig 3.13. Visualisation by Reflex Arkitekter and Vasakronan.

Location	Stockholm (N 59.33˚ E 18.06˚)
Climate	HDD 3203/ CDD 261
Completion year	1977/2009
Client/developer	Vasakronan
Architect	Reflex Arkitekter
Contractor	Divided contract
Tenant	Many different
Tot. floor area	10 458 m^2 A_{temp} (office)
Floors	9+ garage
Operation	Office, restaurant, stores
Office hours	-
Plan type	90% open
Space efficiency	14 m^2/employee
References	(Zettergren 2010)

Building design

The building was originally constructed in 1977 but completely rebuilt in 2009 with a high eco-focus. The retrofitting was limited because of the low room height (2.35-2.6 m) and a complicated load bearing system. A glass façade with an additional outer glass for sun and noise protection was installed on the north facades. The windows on the south facades were replaced with new ones, which are screen printed with a graphic pattern for sun protection. The overall window U-value is ≤1.2 W/m^{2}K.

Fig 3.14. Plan by Reflex Arkitekter and Vasakronan.

HVAC+L

The control set-points for indoor temperature are 20-26˚C. The building is now provided with district heating and cooling and a new ventilation system. A total of 100m^2 solar collectors on the roof provide domestic hot water and a big part of the cooling demand via two sorption refrigeration machines (Desicool from Munthers) which cools the supply air. In addition, there are two conventional cooling machines. The ventilation is a VAV-system with a ring-formed duct system and heat recovery. The air flow is controlled by air temperature, CO2 and occupant sensors and the maximum air flow is 2.4 l/sm^2. Occupant- and daylight sensors control the lighting system, which has an average installed power of 7.2 W/m^2. There is a natural daylight inlet in the stairwell. Some of the electric power is produced by 44 m^2 PV placed on the roof. Vasakronan offers their tenants a "green leasing" which means that the rent will be reduced if they consume less energy.

Energy performance

Before renovation, the end-use energy was approximately 257 kWh/m^2 and year (excl. tenant electricity). The new end-use energy according to BBR is estimated to **98 kWh/m^2** (excl. tenant electricity). Pennfäktaren is certified according to EU GreenBuilding and pre-certified according to LEED Core and shell (Gold).

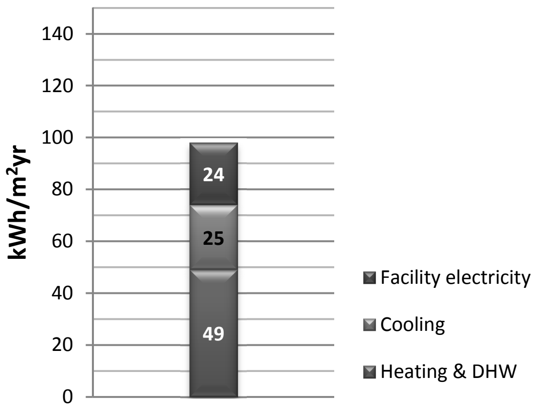


Fig 3.15. End-use energy (calculated).

Waterfront, Stockholm

Location	Stockholm (N 59.33˚ E 18.05˚)
Climate	HDD 3203/ CDD 261
Completion year	2010
Client/developer	Jarl Asset Management
Architect	White arkitekter
Contractor	PEAB
Tenant	Many different
Tot. floor area	24 420 m^2 A_{temp} (office)
Floors	11
Operation	Office (+congress, hotel)
Office hours	Flexible
Plan type	Flexible
Space efficiency	7-22 m^2/employee
References	(Waterfront 2009; Berglund 2010)

Fig 3.16. View by White.

Building design

This large office is one of three buildings in a large congress complex in the centre of Stockholm City. It has a load bearing construction of concrete joist floors and steel pillars. The north facing walls have glass façades and the other facades have floor-to-ceiling high narrow windows with tinted glass. The south façade is partly protected from the sun by the adjacent hotel and in addition there are internal sun-screens on all facades. The original plan was an open plan arrangement but most of the tenants preferred cell office rooms. The room height is 2.7 m.

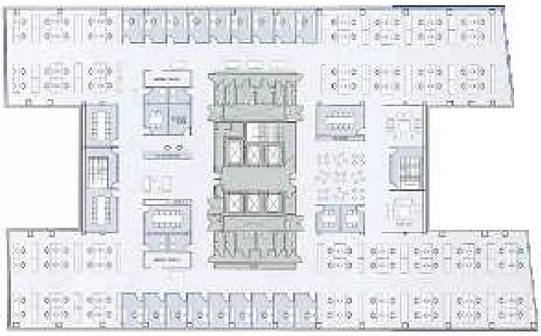


Fig 3.17. Plan by White.

HVAC+L

The HVAC system is designed to maintain an indoor temperature of 20-25˚C. Heating is distributed in a concordant system, i.e. heat is moved and distributed between the different buildings - from surplus to shortfalls- made possible because of the different operation hours and demands. The office is mainly heated with district heating and floor convectors. The building is cooled by water drawn from Lake Klara, stored in 250 tonne of ice tanks in the basement. The sea water pump covers 40% of the cooling demand; the rest is produced in the ice tanks. Cooling is distributed with ceiling baffles and the cooling output is 85 W/m^2. The cooling and heating systems are controlled by a weather forecast feed forward system. The ventilation system is a VAV-system with four separate air handling units on each floor. The air flow is CO2 controlled and can range from 20-100% with an average flow of 2.0 l/sm^2. Energy efficient fans and pumps are installed.

Energy performance

The end-use energy for heating and cooling in the office building is estimated to **42 kWh/m^2**. No information was found on other energy posts. Stockholm Waterfront will be certified according to EU GreenBuilding and LEED (class unknown).

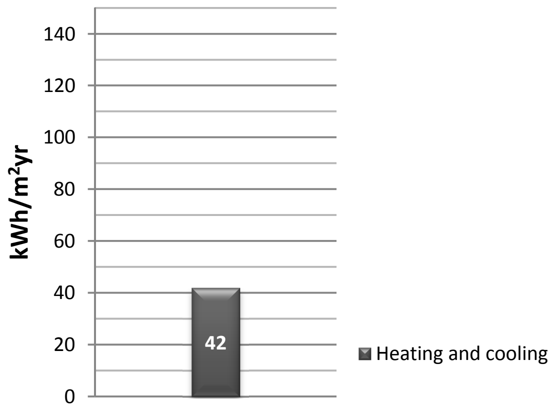


Fig 3.18. End-use energy, heating and cooling only (calculated).

3.2.2 Norway

Aibel, Sandnes

Fig 3.19. No approval from photographer yet

Location	Stavanger (N 58.85˚ E 5.74˚)
Climate	HDD 2663 / CDD 136
Completion year	2006
Client/developer	Seabrokers AS
Architect	Brandsberg-Dahls
Tenant	Aibel AS
Tot. floor area	23 300 m^2 Atemp (office)
Floors	6 + garage
Operation	Office and restaurant
Operation hours	85 h/week
Plan type	30/70 cell/landscape
Space efficiency	20 m^2/employee
References	(Grini, Mathisen et al. 2009)

Building design

Aibel in Sandnes has a compact building shape with an 800 m^2 central atrium partly covered by glass, with a U-value of 1.6 W/m^2K. The façade has a concrete sandwich construction. The windows have a U-value of 1.25 W/m^2K and the g-value is 0.33. For sun shading there are internal Venetian blinds. WWR is 54% but the GFR is only 12%. The average U-value of the envelope is 0.41 W/m^2K and the design value of air-tightness is 1.0 ach at 50 Pa pressure difference.

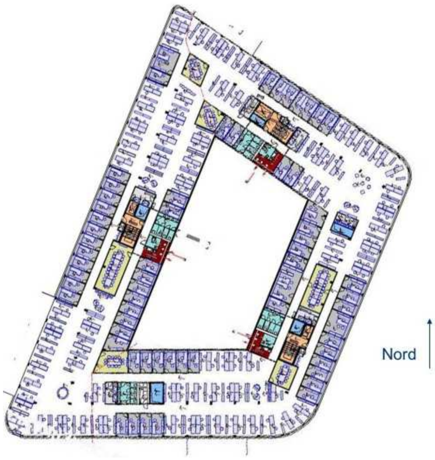


Fig 3.20. Plan (SINTEF Byggforsk)

HVAC+L

The building is connected to district heating and cooling. Heat is distributed by radiators but there are no room units for cooling. The control set-points for indoor air temperature are 20-23˚C. During night, the indoor air temperature is allowed to drop to 19˚C. The ventilation system is a VAV-system, controlled by occupant- and CO2 sensors. The air is distributed via an aluminium "climate ceiling" which cools the air. The maximum air flow is 2.4 l/sm^2 during working hours and 0.24 l/sm^2 at night (as extra cooling). A liquid-coupled heat exchanger with an efficiency of 64% (calculated value) recovers heat from the exhaust air. SFP is 2.0 kW/m^3s^{-1} (design value). Occupant sensors also control the lighting system which has an installed power of 10 W/m^2. Installed power for computers is estimated to 6 W/m^2.

Energy performance

The total end-use energy was **134 kWh/m²** in 2008 (incl. tenant electricity).

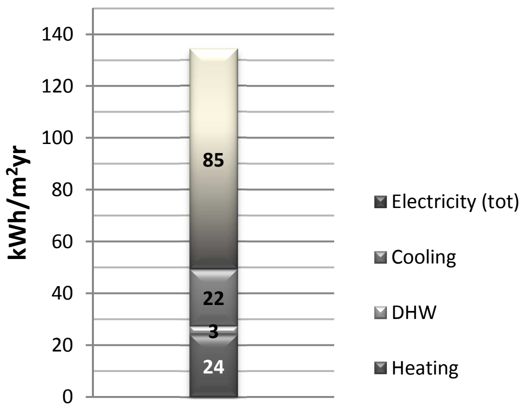


Fig 3.21. End-use energy (monitored 2008).

Bravida, Fredrikstad

Fig 3.22. Photo by SINTEF Byggforsk.

Location	Fredrikstad (N 59.22˚ E 10.93˚)
Climate	HDD 3800 / CDD 182
Completion year	2002
Client/developer	Lillebæk
Architect	Multiconsult AS
Tenant	Bravida and others
Tot. floor area	6038 m^2 Atemp
Floors	3
Operation	Office
Office hours	8-16 weekdays
Plan type	Mostly open
Space efficiency	-
References	(Grini, Mathisen et al. 2009)

Building design

The two rectangular building bodies are connected on the short sides with a glazed communication space, which has an E/W orientation. The concrete joist floor is exposed in the ceilings. External walls are wooden framed with a U-value of 0.2 W/m^2K. The average U-value of the envelope is 0.71 W/m^2K and the design value of air-tightness is 1.5 ach at 50 Pa pressure difference. The windows have a U-value of 1.4-1.6 W/m^2K and the glass g-value is 0.32-0.48. The glass area is small, WWR 36% and WFR 19% including the glass atrium. Sun shading devices are manually controlled, external Venetian blinds to east and internal curtains to west and south.

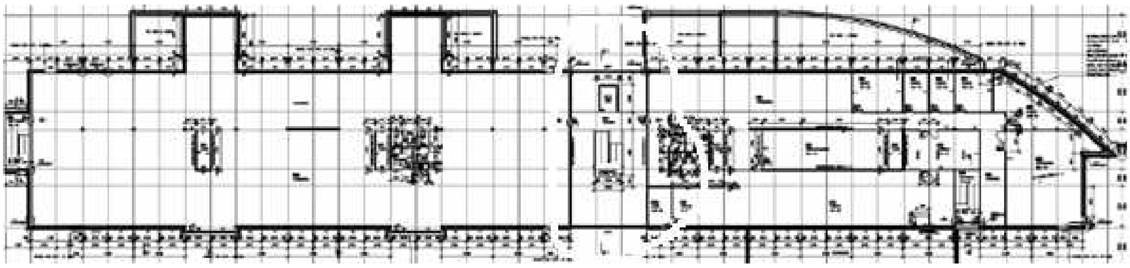


Fig 3.23. Plan by Multiconsult AS.

HVAC+L

Control set-points for indoor temperature are 22-26˚C but at night, the indoor air temperature is allowed to drop to 20˚C. A geothermal heat pump with 15 boreholes produces warm water for heating. Oil is used in a back-up system which also supplies the building with cooling when needed (peak load). In addition, there are 300 m^2 solar thermal collectors on the south façade for extra heat production but these have not been working as planned. Heating and cooling is distributed to the rooms with the ventilation air through a "climate ceiling". The glass atrium is provided with waterborne floor heating. The ventilation system is a VAV-system, controlled by occupant sensors. The maximum air flow is 2 l/sm^2 and SFP is 2.0 kW/m^3s^{-1} (design value). The system operates 85 h/week. A rotating heat exchanger with a measured efficiency of 61% recovers the heat from the exhaust air. Occupant sensors also control the lighting system which has an installed power of 7.1 W/m^2. Installed power for computers is estimated to 2 W/m^2.

Energy performance

The total end-use energy was **135 kWh/m^2** in 2008.

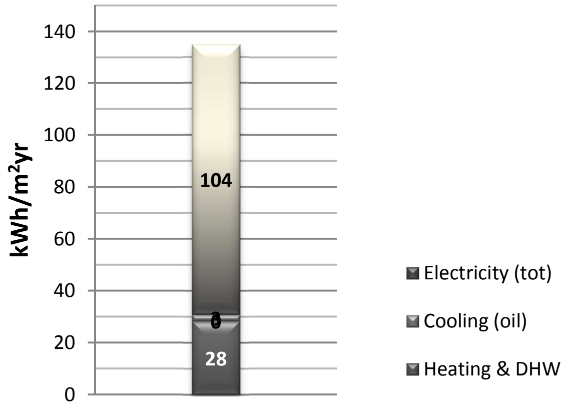


Fig 3.24. End-use energy (monitored 2008).

Stavanger Business Park H5

Fig 3.25. Visualisation by Plank Arkitekter

Location	Stavanger (N 58.96˚ E 5.72˚)
Climate	HDD 2663 / CDD 136
Completion year	2013
Client/developer	NCC PD
Architect	Plank Arkitekter
Contractor	NCC
Tenant	-
Tot. floor area	9203 m^2 (heated BRA)
Floors	5 + garage
Operation	Office, garage
Office hours	-
Plan type	Flexible
Space efficiency	16 m^2/employee
References	(Haugland and Haugstad 2010)

Building design

The two building bodies are connected with a glazed communication space. The Building envelope is a well-insulated and airtight concrete construction. The average U-value is 0.30 W/m^2K and the design value of airtightness is 1.5 ach at 50 Pa pressure difference. The U-value of the walls is 0.18 W/m^2K. The windows have a U-value of 1.1 W/m^2K and the total g-value including exterior solar shading devices is 0.12 (glass 0.35). The glazing area is small, WWR is 32% and WFR is 14%.

Fig 3.26. Plan by Rom & Design.

HVAC+L

The control set-points for indoor temperature are 20-25˚C. The building is provided with district heating and cooling. The heat is distributed via radiators but there are no room units for cooling. Instead there is a cooling battery in the central AHU. At night, the indoor temperature is allowed to drop to 19˚C. The ventilation system is a VAV-system, controlled by occupant sensors and indoor air temperature. The average air flow is 1.9 l/sm^2 during working hours and 0.55 l/sm^2 at night (night ventilation as extra cooling effect). A rotating heat exchanger with an estimated efficiency of 80% recovers the heat from the exhaust air. SFP is 2.0 kW/m^3s^{-1} (design value). Occupancy and daylight sensors control the lighting system with an installed power of 6.4 W/m^2.

Energy performance

The specific end-use energy according to BBR is estimated to **62 kWh/m^2yr** (excl. tenant electricity), calculated with SIMIEN. Stavanger BP is aiming for a certificate according to EU GreenBuilding.

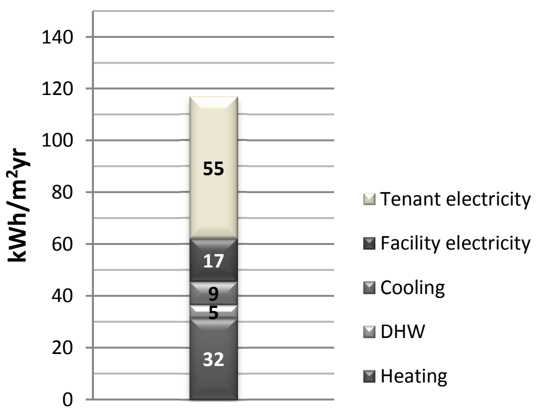


Fig 3.27. End-use energy (calculated).

UN House (renovation), Arendal

Fig 3.28. Photo by SINTEF Byggforsk

Location	Arendal (N 58.46˚ E 8.77˚)
Climate	HDD 3001 / CDD 172
Completion year	1965/2006
Client/developer	GRID-Arendal
Architect	A7 Arkitekter
Contractor	Skanska
Tenant	GRID (UNEP)
Tot. floor area	2391 m^2 Atemp (office 428 m^2)
Floors	5+1
Operation	Office, school, health centre
Operation hours	50 h/week
Plan type	Open/cell
Space efficiency	19.5 m^2/employee (office)
References	(Skanska 2008b; Grini, Mathisen et al. 2009)

Building design

The building was originally constructed in 1965 but completely rebuilt in 2006 with focus on energy efficiency and carbon neutrality. A double skin façade with 40 cm cavity was installed in order to insulate and ventilate the façade. Furthermore, 20-30 cm insulation was added to the roof and the external walls. The envelope's average U-value is 0.66 W/m^2K. The airtightness was improved but because of the exposed position by the sea the design value of airtightness was estimated to 2.0 ach at 50 Pa pressure difference. The windows' total U-value is 1.0 W/m^2K and the g-value is 0.27 (double glass). WWR is 50% and WFR is 25%. Manually controlled solar shading screens are installed in the double skin facade cavity.

Fig 3.29. No approval to publish plan yet

HVAC+L

The target indoor temperature is 21-23˚C. Two new cooling machines, connected to seawater heat pumps with a 1.5 km long pipe system, produce 95% of the building's heating and cooling demand. An electric boiler covers the peak load. New solar thermal collectors (30 m^2) cover 50% of the domestic hot water demand. Radiators are used for space heating and ceiling elements provide both radiant cooling and supply air. The ventilation is a VAV-system controlled by occupant sensors. The airflow rate is 2.4 l/sm^2 and SFP is estimated to 2.9 kW/m^3s^{-1}. The exhaust air is collected at a single point on each floor, to reduce the pressure drop, and a rotating heat exchanger with an estimated efficiency of 65% recovers the heat from the exhaust air. Occupancy sensors control the lighting system with an installed power of 7 W/m^2. Installed power for office equipment is 10.5 W/m^2. The building uses 100% renewable electricity according to the electricity provider.

Energy performance

Before renovation, the end-use energy was approximately 300 kWh/m^2yr. The new specific end-use energy according to BBR was **52 kWh/m²** (excl. tenant electricity) in 2008. The building is now carbon neutral.

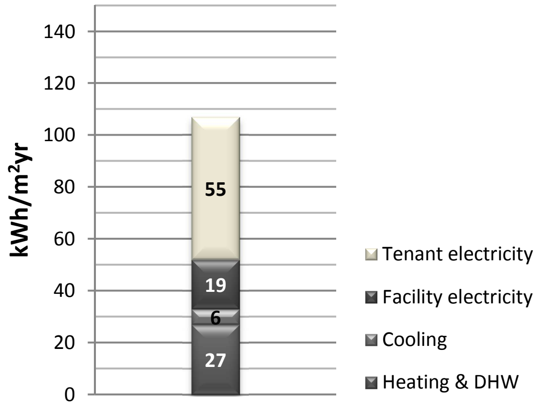


Fig 3.30. End-use energy (monitored 2008).

3.2.3 Denmark

Kolding Company House III

Fig 3.31. Photo NCC Property Development

Location	Kolding (N 55.53˚ E 9.47˚)
Climate	HDD 2415/ CDD 240
Completion year	2009
Client/developer	NCC Property Development
Architect	C. F. Møller Architects
Contractor	NCC Construction
Tenant	Alectia, Hjem-Is, others
Tot. floor area	5147 m^2 Atemp
Floors	2+basement
Operation	Office, restaurant
Operation hours	8-17
Plan type	Flexible
Space efficiency	20 m^2/employee
References	(Ladekjaer 2011; NCC 2011a)

Building design

The building shape is square with a central, uncovered, courtyard for daylight access. The envelope is well insulated and very airtight with a concrete sandwich construction and an average U-value of 0.28 W/m^2K (incl. thermal bridges). WWR is 40% and WFR is 17%. The windows' U-value is 1.0 W/m^2K and the measured airtightness is 0.6 l/sm^2 A_{temp} (w_{50}). Note that the basement area is included in the total heated floor area (~780 m^2).

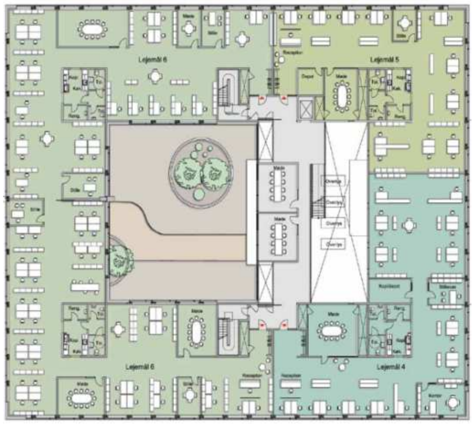


Fig 3.32. Plan by NCC Property Development

HVAC+L

The target indoor temperature is 23˚C and the cooling set-point is 25˚C. The building is connected to district heating and heat is distributed with radiators. There are no room units for cooling but a cooling battery in the AHU cools the supply air. Night ventilation is possible for extra cooling during summer why the bought cooling energy can be set to zero (Danish regulations). The ventilation is a VAV-system (20-100%) with a maximum air flow rate of 1.8 l/sm^2. A rotating heat exchanger with an efficiency of 84% (design value) recovers the heat from exhaust air. The lighting system is according to the GreenLight Standard. It is controlled by occupant- and daylight sensors and the estimated installed power is 4 W/m^2 according to the energy calculation.

Energy performance

The specific end-use energy according to BBR is estimated to **36 kWh/m^{2}yr** (excl. tenant electricity), calculated with Be06. Note that basement area is included in this calculation. The building is certified according to EU GreenBuilding and complies with Danish low energy class 1 (BR08).

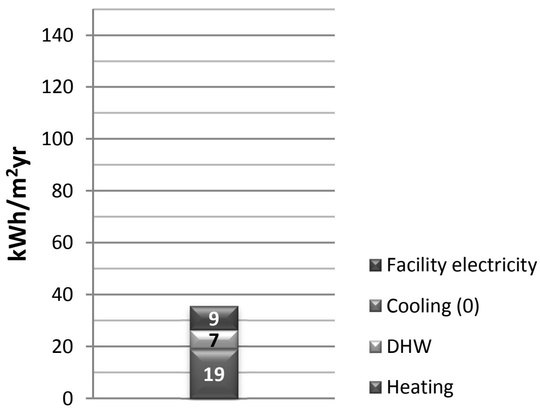


Fig 3.33. End-use energy (calculated).

Skejby Company House III

Fig 3.34. Photo by NCC Property Development

Location	Aarhus (N 56.19˚ E 10.18˚)
Climate	HDD 2786/ CDD 191
Completion year	2011
Client/developer	NCC Property Development
Architect	C. F. Møller Architects
Contractor	NCC
Tenant	-
Tot. floor area	5900 m^2 Atemp (1-3)
Floors	3 + basement
Operation	Office, restaurant
Operation hours	8-17
Plan type	Flexible
Space efficiency	20 m^2/employee
References	(Jensen 2011; NCC 2011a)

Building design

The office will soon be built in Skejby Park next to Aarhus. The building will be well insulated with a quite heavy construction with load bearing internal concrete walls. The exterior walls are wooden wall elements with a U-value of 0.16 W/m^2K. The average U-value of the envelope is 0.29 W/m^2K (incl. thermal bridges). WWR is only 18% and WFR is 15%. The windows will have a U-value of 1.1 W/m^2K and a g-value of 0.36. Manually controlled internal Venetian blinds will reduce solar gains.

Fig 3.35. Plan by NCC Property Development

HVAC+L

Control set-points for indoor temperature are 20-25˚C. The building will be provided with district heating and heat is distributed with radiators. Cooling is provided with cooling machines (COP 3.2) which cool the ventilation air. The ventilation system is a VAV-system with ceiling air diffusers for sub-cooled air (17˚C) and low air-flows (30%). The average air flow is 1.5 l/sm^2 during working hours, otherwise the ventilation is off but night ventilation is possible during summer as extra cooling. A rotating heat exchanger with an efficiency of 80% (design value) recovers the heat from the exhaust air. The lighting system is according to the GreenLight Standard. It is controlled by presence- and daylight sensors and the estimated installed power is 8 W/m^2. Installed power for computers is estimated to 6 W/m^2.

Energy performance

The specific end-use energy according to BBR is estimated to **46 kWh/m^2yr** (excl. tenant electricity), calculated with Be06. The building will be certified according to EU GreenBuilding and has a pre-assessment according to BREEAM (Very Good).

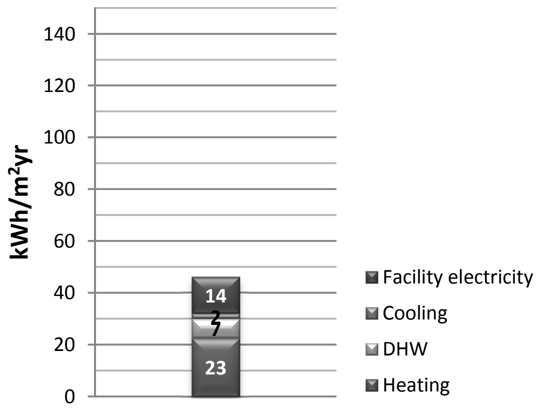


Fig 3.36. End-use energy (calculated).

3.2.4 Finland

Alberga Business Park (building A)

Figure 3.37. Visualization by Arkitekturbyrå Brunow & Maunula.

Location	Espoo (N 60.21˚ E 24.66˚)
Climate	HDD 3921 / CDD 251
Completion year	2012
Client/developer	NCC Proprty Development
Architect	Brunow & Maunula
Contractor	NCC
Tenant	ÅF, SATS
Tot. floor area	8460 m^2 Atemp (office)
Floors	5 + underground garage
Operation	Office, gym, garage
Office hours	Weekdays 8-17
Plan type	Flexible
Space efficiency	18 m^2/employee
References	(Utriainen 2011; NCC 2011b)

Building design

This will be the first building of five separate office blocks in Alberga Business Park. The Building envelope is well insulated with U=0.09 W/m^2K in the roof and U=0.17 W/m^2K in the walls. The average U-value is 0.36 W/m^2K.The windows have a U-value of 1.0 W/m^2K and a g-value of 0.46, WWR is 34%. The design value of air leakage is 0.9 ach at 50 Pa pressure difference.

Fig 3.38. Plan by Arkitekturbyrå Brunow & Maunula.

HVAC+L

The control point for indoor temperature is minimum 21˚C. The building is provided with district heating and a condenser chiller with COP 5. The ventilation system is a VAV-system, controlled by occupant sensors and indoor air temperature. The average air flow is 1.7 l/sm^2 during work hours and the SFP is 2.1 kW/m^3s^{-1} (design value). During summer the Indoor Air Quality class is degraded from the highest class S1 to S2 in order to save cooling and ventilation energy. A rotating heat exchanger with an estimated efficiency of 74% (design value) recovers the heat from exhaust air. Occupancy and daylight sensors control the lighting system with an installed power of 7-15 W/m^2.

Energy performance

The specific end-use energy according to BBR is estimated to **62 kWh/m²yr** (excl. tenant electricity and gym). The office part of the building achieves Finnish Energy Class A according to calculations. The building will be certified according to EU GreenBuilding and BREEAM Very Good (goal).

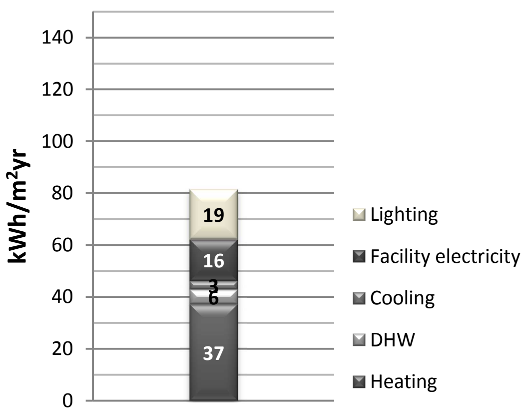


Fig 3.39. End-use energy (calculated).

Plaza Pilke, Vantaa

Fig 3.40. Photo by Sini Pennanen

Location	Vantaa (N 60.29˚ E 25.04˚)
Climate	HDD 3891/ CDD 221
Completion year	2011
Client/developer	NCC Property Development
Architect	Forma-Futura
Contractor	NCC
Tenant	Ramirent among others
Tot. floor area	6882 m^2 Atemp
Floors	7 + garage
Operation	Office, garage
Office hours	Weekdays 8-16
Plan type	Flexible
Space efficiency	20 m^2/employee
References	(Utriainen 2011)

Building design

Plaza Pilke is the first completed building of the third phase in Plaza Business Park near Helsinki Airport. The building shape is rather compact with a large atrium towards the north for daylight penetration. The plan arrangement is flexible and the tenants can choose both open landscape and cell office rooms. Room height is 3.0 m. The Building envelope has an average U-value of 0.36 W/m^2K and the windows are well insulated with a U-value of 1.0 W/m^2K. The glass area is limited and the WWR is 27% and the WFR is 17%. The design target of airtightness is 0.7 ach at 50 Pa pressure difference.

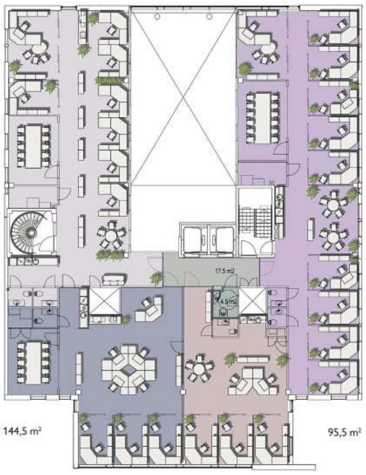


Fig 3.41. Plan from NCC Property Development.

HVAC+L

The control set-points for indoor temperature are 21-25˚C. Heat is provided with district heating and radiators. Cooling is provided with a condenser chiller with COP 5 and distributed with cooling beams. The ventilation is a VAV-system, controlled by occupant sensors and indoor air temperature. The air flow is 1.76 l/sm^2 (1.56 ach) during working hours and SFP is 2.45 kW/m^3s^{-1} (design value). Rotating heat exchangers with estimated efficiencies of approximately 75% recover the heat from outgoing air. Occupancy and daylight sensors control the lighting system with an installed power of 5-15 W/m^2. Heat balance simulations were made with IDA ICE (Equa) for an office room and a meeting room to secure that the cooling system is sufficient during a summer day.

Energy performance

The specific end-use energy is estimated to **82 kWh/m²yr** (excl. office equipment but incl. lighting). Plaza Pilke is the first commercial building complying with the Finnish requirements of Energy Class A. The building will be certified according to EU GreenBuilding and to BREEAM (target Very Good).

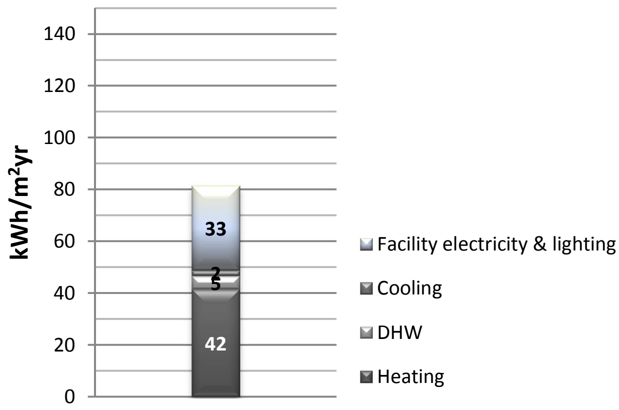


Fig 3.42. End-use energy (calculated).

3.2.5 Germany

In German buildings, primary energy is generally declared but sometimes end-use energy is declared in addition. In the cases where primary energy was declared only, these figures have been re-calculated to end-use energy according to German conversion factors (see table X).

Table x: Primary energy conversion factors for Germany according to DIN 4701, 2003, index: p primary energy, e end energy (Voss, Herkel et al. 2007).

Type	Source	Primary energy conversion factor kWh_p/kWh_e
Fuels	Oil, natural gas	1.1
	Wood chips, pellets…	0.2
District heating (heating only)	Fossil fuel	1.3
	Biomass	0.1
District heating (CHP)	Fossil fuel	0.7
	Biomass	0.0
Electricity	German mix	3.0

Barnim Service and Administration Centre, Eberswalde

Fig 3.43. Photo by Martin Duckek, GAP

Location	Eberswalde (N 52.83˚ E 13.83˚)
Climate	HDD 2505/ CDD 514
Completion year	2007
Client/developer	District of Barnim
Architect	GAP Architekten
Tot. floor area	17 131 m^2 NFA
Floors	3-4
Operation	Office + conference
Office hours	Weekdays 7-18
Plan type	Cell rooms
Space efficiency	23 m^2/employee
References	(Bine 2009b; En0B 2011)

Building design

This complex of four compact buildings in the North-east of Germany houses the local authorities of Barnim and the district administration centre. In each building, the office rooms are arranged around an unheated glass-covered interior courtyard. The buildings have skeleton concrete constructions with prefabricated wooden wall elements with cellulose insulation. The U-values of the walls and roof are 0.2 and 0.12 W/m2K respectively. The windows are triple glazed with U-values of 1.0 and 1.4 W/m2K. The solar protection consists of automatically controlled two-section exterior blinds which make it possible for daylight penetration in the upper part of the windows even when they are closed. There are also manually controlled interior glare protections. The buildings' airtightness is estimated to 0.8 ach (n50). Room height is 3 m and there is no suspended ceiling.

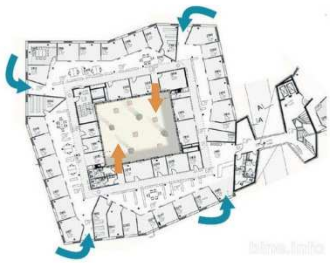


Fig 3.44. Plan by GAP Architekten. 1st floor building D.

HVAC+L

The heating set-point for room air temperature was planned to be 20˚C but during 2008, when the building was monitored, the actual room temperature was around 23-24 ˚C. Heat pumps provide the basic heat supply via absorbers installed in the buildings' 9 m deep foundation piles. The absorbers extract geothermal heat and cold from the ground in a waterborne system with buffer storage tanks. When the ambient air is warmer than 8˚C, the heat pumps use outdoor air as a heat source instead. Heat is distributed with radiators in the office rooms and floor heating in the communication space. In the summer, the reversible heat pumps use the ground as cold source in combination with a water-glycol re-cooler. Additional cooling is provided with automatic night ventilation via windows. Domestic hot water is provided with a decentralised electrical system. The rooms have high thermal inertia and additional phase change materials (PCM). The ventilation is a conventional balanced system with a rotating heat exchanger (estimated efficiency 80%). Daylight- and presence sensors control the electric lighting system and the installed power for lighting is 8-12 W/m2 in office rooms and only 2 W/m2 in corridors.

Energy performance

Building D was monitored the first two years and the systems are still in a trimming phase. Total monitored primary energy in 2008 was 62 kWh/m^2yr (excl. tenant electricity). From this, the specific end-use energy according to BBR was estimated, with German primary conversion factors, to **21 kWh/m2yr** (excl. tenant electricity). In 2009, the District of Barnim received a Golden German quality label for sustainable building.

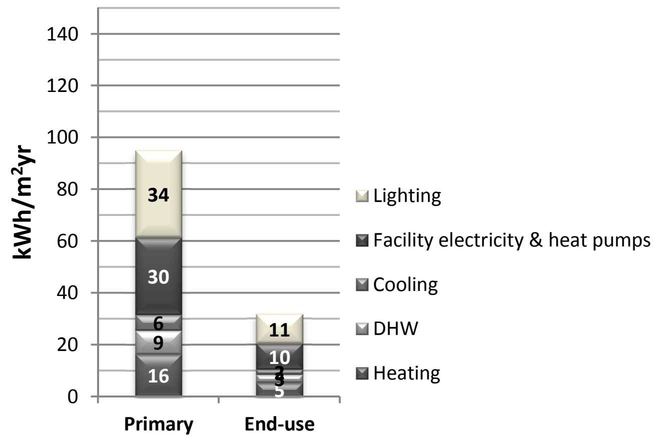


Fig 3.45. Primary and end-use energy (monitored 2008).

BOB, Aachen


Fig 3.46. Photo by Euku, 2011 (Wikimedia Commons)

Location	Aachen (N 50.78˚ E 6.08˚)
Climate	HDD 2156/ CDD 412
Completion year	2002
Client/developer	VIKA Ingenieur
Architect	Hahn Helten
Contractor	B. Walter
Tenant	Vika, Helten, Walter et al
Tot. floor area	2076 m^2 NFA
Floors	4
Operation	Office
Plan type	2-3 pers/room
Space efficiency	22 m^2/employee
References	(Kalz, Herkel et al. 2009; BOB 2011; En0B 2011)

Building design

"Balanced Office Building" (BOB) is a low-energy office concept in Germany. The building has a compact shape and a heavy construction with concrete joist floors, concrete pillars and precast façade panels with concrete interior surface (U=0.17 W/m^2K). There are no load-bearing interior walls, mainly glass walls for daylight penetration. The envelope has an average U-value of 0.48 W/m^2K. The windows are triple glazed with a U-value of 0.8 W/m^2K and a g-value of 0.50. Internal Venetian blinds are controlled by daylight sensors. WWR is 41%. The building is very airtight with a measured airtightness of 0.3 ach (n50). Surface-to-volume ratio is 0.37 m^{-1}.

Fig 3.47. No approval of publishing plan yet

HVAC+L

For generating heat and cold there are 28 boreholes and a heat pump (COP 4.3). Heating and cooling is distributed with concrete core temperature control (CCTC) which means that hot and cold water circulate in the concrete floors. The water supply temperature varies between 19-26 ˚C. The ventilation is a CAV-system with timer. The nominal airflow is only 20 m^3/h and person (0.26 l/sm^2) and in addition, windows are operable. The ventilation heat exchanger has an efficiency of 75% (measured). Daylight sensors control the lighting system. The installed power for lighting is 7.5 W/m^2.

Energy performance

In 2006, the primary energy consumption was 86 kWh/m²yr (incl. lighting), and the specific end-use energy according to BBR was **19 kWh/ m²yr** (excl. tenant electricity). The savings with the heat pump is estimated to 40 kWh/m^{2}yr. BOB is GreenBuilding certified according to DGNB.

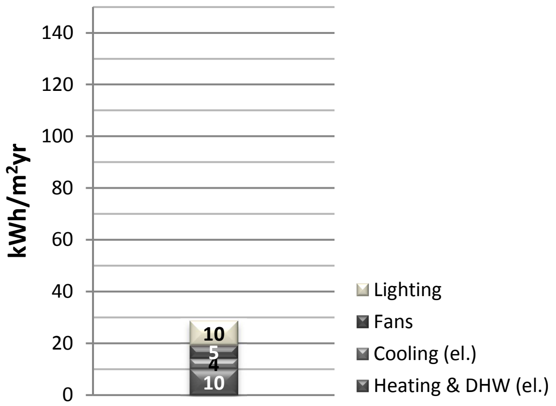


Fig 3.48. End-use energy (monitored 2006).

Energon, Ulm

Fig 3.49. Photo by G8w, 2012 (Wikimedia Commons)

Location	Ulm (N 48.42˚ E 9.94˚)
Climate	HDD 2822/ CDD 413
Completion year	2002
Client/developer	Software AG Foundation
Architect	Oehler Faigle Archkom
Contractor	Freie Planungsgruppe 7
Tenant	Software AG Foundation
Tot. floor area	6911 m^2 NFA
Floors	5
Operation	Office + restaurant
Office hours	Weekdays 7-18
Plan type	3 persons/room
Space efficiency	13 m^2/employee
References	(Kalz, Herkel et al. 2009; En0B 2011; Energon 2011; PHI 2012b)

Building design

This very compact, triangular building with a curved façade has a concrete skeleton construction with prefabricated wooden wall elements. There is a large central atrium with communication space, daylight access and ventilation openings. The envelope is well insulated with 350 mm insulation in the walls (U=0.13 W/m^{2}K), 500 mm in the roof and 200 mm in the slab. The windows are triple glazed with a U-value of 0.84 W/m^{2}K and an effective g-value of 0.17 (because of external blinds, glass g-value is 0.50). The WWR is 44%. The building is very airtight with a measured air-tightness of 0.2 ach at 50 Pa pressure difference. The room height is 2.9 m and surface-to-volume ratio is 0.22 m^{-1}.

Fig 3.50. Plan by Oehler Archkom Solar Architektur.

HVAC+L

For heating and cooling, there are 40 borehole heat exchangers (100 m deep) in the ground but no heat pump. Heating and cooling is distributed with concrete core temperature control, which means plastic tubes for hot and cold water in the concrete floors. Waste heat from compression refrigeration machines in server rooms is gathered and the remaining heat requirement is covered by district heating. The outdoor air is channelled through a 28m long underground duct (earth-to-air heat exchanger) for preheating/cooling the supply air. When needed, the air is further heated/cooled by the borehole heat exchangers and finally by district heating. The airflow is approximately 1.1 l/sm^2 (30 m^3/h and person). The ventilation heat exchanger has an efficiency of 65% but together with the underground channel, the total system efficiency is 80%. There are 328 m^2 of PVs on the building with a power of 15 kW. Occupancy- and daylight sensors control the lighting system. The installed power for lighting is 14 W/m^2 in office rooms and 10 W/m^2 in corridors.

Energy performance

In 2005, the end-use energy according to BBR was **47 kWh/ m^2yr** (excl. tenant electricity) and the total primary energy consumption was 82 kWh/m^2yr. However, the office was not fully occupied that year. Energon is certified as “Quality Approved Passive House”.

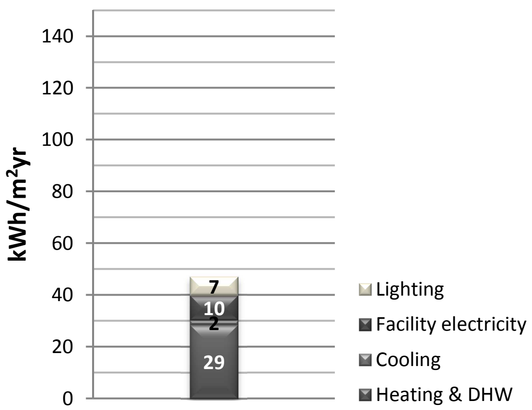


Fig 3.51. End-use energy (monitored 2005).

Lamparter, Weilheim

Fig 3.52. Photo by Menerga, no approval yet

Location	Weilheim (N 48.62˚ E 9.54˚)
Climate	HDD 2563/ CDD 458
Completion year	2000
Client/developer and tenant	Ingenieur- und Vermessungs-büro Hans Lamparter GbR
Architect	weinbrenner.single.arabzadeh
Tot. floor area	1000 m^2 NFA
Floors	3 (+ underground car park)
Operation	Office
Office hours	Weekdays 7-18
Plan type	2 pers/room (flexible)
Space efficiency	29 m^2/employee
References	(Bine 2001; Eicker, Seeberger et al. 2005; Eicker , Huber et al. 2006; En0B 2011)

Building design

Lamparter is one of the first and smallest office building based on the German Passive-house principle and it was built with a cost effective approach. The building has a central open stairwell with a large skylight for natural ventilation and daylight inlet. The building has a skeleton steel/concrete construction with prefabricated wooden wall elements (U=0.14 W/m^2K). The envelope is well insulated with 240-350 mm insulation and an average U-value of 0.3 W/m^2K. The windows are triple glazed with a U-value of 1.1 W/m^2K. The windows are split in two, with an upper part for air- and daylight access. There are external louvres for sun protection. WWR is 44% and the g-value is 0.60. The building is very airtight with a measured airtightness of 0.3 ach (n_{50}). Surface-to-volume ratio is 0.4 m^{-1}.

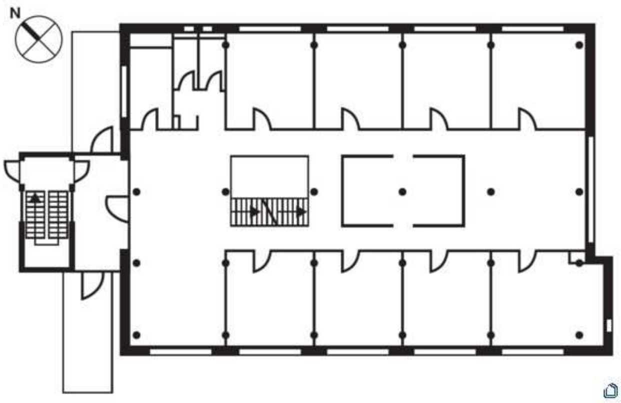


Fig 3.53. Plan by weinbrenner.single.arabzadeh architects.

HVAC+L

The target room temperature is 22˚C. The building uses gas-fired condensing boilers for heating and the cooling system is passive. There are no radiators; heat is provided with the AHU. The supply air is drawn through an earth-to-air heat exchanger for cooling/preheating and is further preheated in the AHU rotating heat exchanger (measured efficiency 80%) if needed. The gas-fired condensing boiler system is used for backup heating. The cooling system is a passive night ventilation concept, based on thermal buoyancy and wind forces only. The workers have to manually open the upper sections of the windows when they leave in the evening. The mechanical airflow during day is 30 m^3/h and person (~0.56 l/sm2) and the pressure loss is small. A small (4m^2) thermal solar system facing S/SW produces hot water (87%) and a PV-system on the roof (70 m^2, 8 kW) covers one third of the electricity demand for lighting and ventilation. Daylight sensors control the lighting system and the installed power for lighting is 11.6 W/m^2 in office rooms and 6.1 W/m^2 in corridors.

Energy performance

The building has been monitored for four years in a research study. Hourly internal loads, temperatures, air change rates, heating and cooling were measured and analysed. In 2000-2003 the average specific end-use energy according to BBR was **23 kWh/ m²yr** (excl. tenant electricity) with a big contribution (37%) from free solar energy. The passive night ventilation system works satisfactorily during a normal central European summer climate but in the hot summer of 2003, office temperature exceeded 25˚C too many hours.

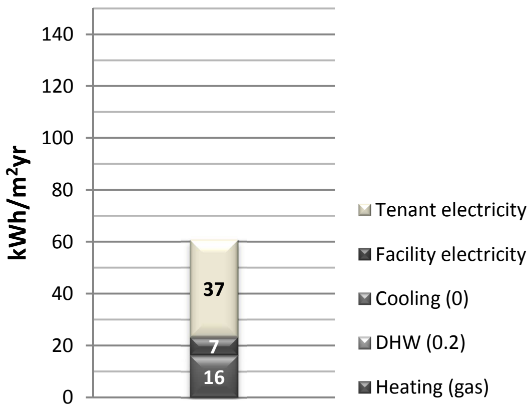


Fig 3.54. End-use energy (monitored 2000-2003, average).

Regionshaus, Hannover

Fig 3.55. Photo by Bilfinger Berger

Location	Hannover (N 52.37˚ E 9.72˚)
Climate	HDD 2497/ CDD 397
Completion year	2007
Client/developer	Hanover Region
Architect	bünemann & collegen
Contractor	Bilfinger Berger
Tenant	Hanover Region
Tot. floor area	7134 m^2 NFA
Floors	6
Operation	Office + hall
Office hours	No information
Plan type	2 persons/room
Space efficiency	12 m^2/employee
References	(Bine 2009a; En0B 2011)

Building design

The new "Regionshaus" is an additional building to a complex of existing buildings. A large hall building for 540 people sticks out from the facade on the first floor. The heavy, L-shaped building has a solid reinforced-concrete construction and exterior walls with 160 mm insulation (U=0.23 W/m^2K). The windows are triple glazed with a U-value of 1.2 W/m^2K and window areas are moderate (WWR is only 30%). Dark anthracite-coloured granite on the facade makes the window openings appear larger. Intermediate sun protection with daylight redirection in the upper part makes it possible for daylight to enter even when the sun protection is closed. In case of strong solar irradiation on the façade, the solar shading is automatically pulled down but it can also be operated manually. The building is airtight with a measured air-tightness of 0.4 ach (n_{50}). The surface-to-volume ratio is 0.3 m^{-1}.

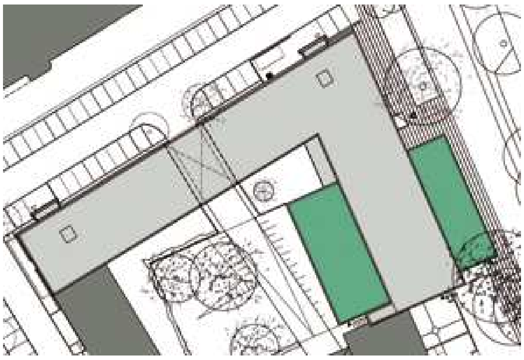


Fig 3.56. Plan by Bilfinger Berger

HVAC+L

Office heating is supplied by district heating and radiators. The cooling system is nearly passive with a concrete core temperature control which means that cold water is pumped through plastic tubes within the concrete joist floors. There are no suspended ceilings. The warm return water is cooled again in a heat sink system with 12 underground boreholes (70 m). A chiller is provided as a reserve. The borehole heat exchanger is also used for pre-heating the supply air in the winter. The hot water production is provided with electricity. A hybrid ventilation system provides the office rooms with natural window ventilation while the hall, the meeting rooms and the sanitary facilities have mechanical ventilation with heat recovery (airflows and efficiency unknown). Presence- and daylight sensors control the lighting system. The power supply to all equipment sockets can easily be switched off on each floor.

Energy performance

In 2008, the primary energy consumption was 81 kWh/m²yr (excl. tenant electricity)**.** From this, the specific end-use energy was estimated, with German primary conversion factors, to **61 kWh/m²yr** (excl. office equipment). Because of the window design, the effective solar protection and the moderate climate, no cooling was needed the monitored years.

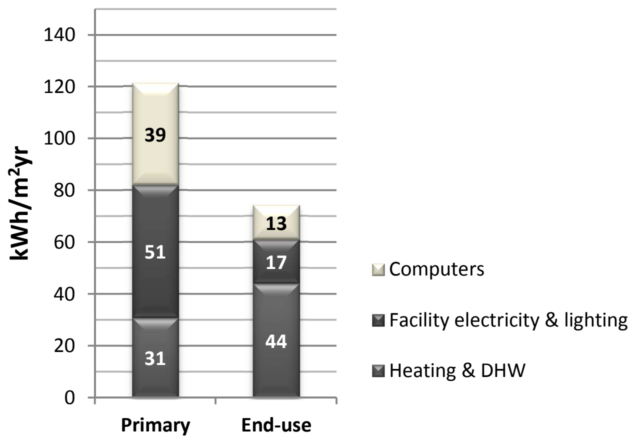


Fig 3.57. Primary and end-use energy (monitored 2008).

Solar Info Center, Freiburg

Fig 3.58. Photo by Architekturbüro Epp.

Location	Freiburg (N 47.98˚ E 7.85˚)
Climate	HDD 2283/ CDD 599
Completion year	2003
Client/developer	PLB
Architect	Architekturbüro Epp
Contractor	No info
Tenant	Provinzial-Leben-Baubetreuung
Tot. floor area	13 822 m^2 NFA
Floors	6 + garage
Operation	Office + conference
Office hours	Weekdays 7-19
Plan type	Office rooms
Space efficiency	22 m^2/employee
References	(Bollin, Fernandes et al. 2008; En0B 2011)

Building design

This large innovation and conference centre lies at the foot of the Schwarzwald mountains in the south of Germany. The U-shaped building has a reinforced-concrete skeleton construction and exposed concrete ceilings with a room height of 2.99 m. The exterior walls are light with 200 mm insulation (U=0.19 W/m^2K). The windows are double glazed with a U-value of 1.3 W/m^2K and the average U-value of the envelope is 0.5 W/m^2K. WWR is approx. 45% and WFR is 23%. Venetian blinds are automatically closed when room temperature exceeds 24˚C and solar irradiation exceeds 130 W/m^2. No information was found regarding the air-tightness. The surface-to-volume ratio is 0.29 m^{-1}.

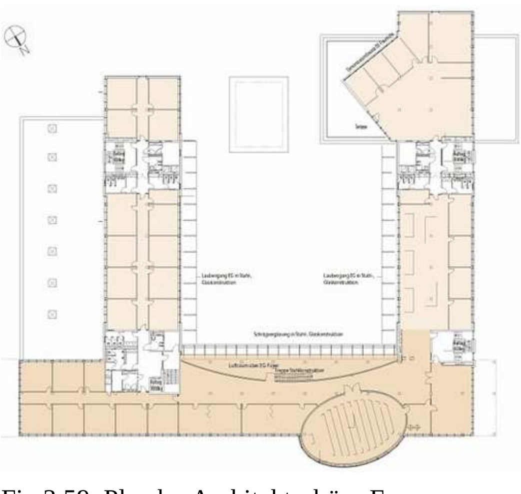


Fig 3.59. Plan by Architekturbüro Epp.

HVAC+L

The building is heated with radiators which are supplied with district heating from a CHP plant at the nearby hospital. Five borehole heat exchangers (80 m deep) are available for cooling the conference area via a floor cooling system. The borehole heat exchangers are also used for pre-heating the supply air in the conference area. The ventilation is a mechanical exhaust air system which secures the necessary hygienic airflow of approximately 7 l/s,person (1-2 ach). Supply air penetrates through window ventilators except for the conference area where there is a balanced supply and exhaust air system with heat recovery. The office rooms are cooled in the summer with mechanical night ventilation (measured to maximum 1.25 ach). An intelligent dynamic operational management concept determines the necessary intensity of night ventilation. The installed power for lighting is 10 W/m^2 in both office rooms and corridors. A PV system (382 m^2) is installed on the roof and facade and contributes to approximately 13 kWh/m²yr of electric energy. The additional bought electric energy is almost 100% CO_2 neutral. Four solar collectors are installed to cover the total hot water demand but due to large distribution losses they only cover 30%. Every tenant can control their own space separately via individual time programs.

Energy performance

In 2007, the specific end-use energy according to BBR was **42 kWh/m²yr** (excl. tenant electricity).

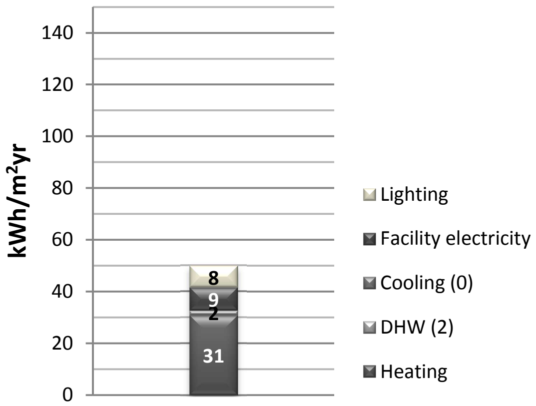


Fig 3.60. End-use energy (monitored 2007).

Wagner & Co, Cölbe

Fig 3.61. Photo by Hydro, 2009 (Wikimedia Commons)

Location	Cölbe (N 50.85˚ E 8.78˚)
Climate	HDD 2277/ CDD 563
Completion year	1998
Client/developer	Wagner & Co Solartechnik
Architect	Architektur Stamm
Contractor	No information
Tenant	Wagner & Co Solartechnik
Tot. floor area	1 948 m² NFA
Floors	3
Operation	Office, seminar, exhibition
Office hours	Weekdays 7-18
Plan type	Open/cell
Space efficiency	35 m²/employee
References	(Schneiders and Feist 2002; Wille, John et al. 2004; En0B 2011)

Building design

Wagner & Co's administration building, in central Germany, was the first office building built according to passive house principles. The building has a rectangular floor plan with a round ending on the west side. The construction is a concrete skeleton with prefabricated wooden wall elements. The envelope is well insulated with 400 mm insulation in the walls (U=0.13 W/m²K) and 240 mm foam-glass under the slab (U=0.17 W/m²K) and the roof U-value is 0.11 W/m²K. The windows are triple glazed (low E with krypton gas fill) with a U-value of 0.8 W/m²K and a g-value of 0.46. The average WWR is 45%. The automatically controlled external blinds have daylight redirection in the upper part, which makes it possible for daylight to enter even when the sun protection is closed. The measured air-tightness is 0.75 ach at 50 Pa pressure difference. The surface-to-volume ratio is 0.36 m^{-1}.

Fig 3.62. Plan, no approval yet

HVAC+L

The control set-point for heating is 21˚C. The building requires heating only from December to February. The small amount of heat is distributed via the supply air and no radiators are needed. The air can be heated to temperatures between 30 and 40˚C. The outdoor air is preheated through four 32 m long underground ducts. The air is further heated with the heat exchanger in the ventilation system, a four-way-cross-flow heat exchanger with 80% efficiency (design value). There are additional small heat exchangers which are supplied with solar heating. The solar heating (64 m^2 collectors on the roof) is collected in the warm months and then stored in a huge seasonal storage tank (87 m^3), placed in the centre of the rotunda. For back-up heating, the gas-driven power plant, mainly providing electric power, can be used as a heat plant as well. The balanced ventilation system has an average airflow of 0.5 ach (~0.5 l/sm^2), which is necessary for hygienic purposes. The cooling system is passive. The supply air is pre-cooled in the ground-coupled ducts with a measured cooling capacity of up to 6K during a warm summer day. The building is also cooled at night using natural night ventilation, driven by thermal buoyancy. The airflow is approximately 4 ach and the measured cooling capacity is about 3K. Daylight sensors control the lighting system with an intensity set point of 500 lx. The installed power for lighting is high with 20 W/m^2.

Energy performance

The office was monitored and analysed in detail for three years by the Passivhaus Institut. In the season 2000/2001, the total end-use energy was **83 kWh/m^2yr (**incl. tenant electricity). The experiences have been very positive so far and the occupants are pleased with the indoor climate.

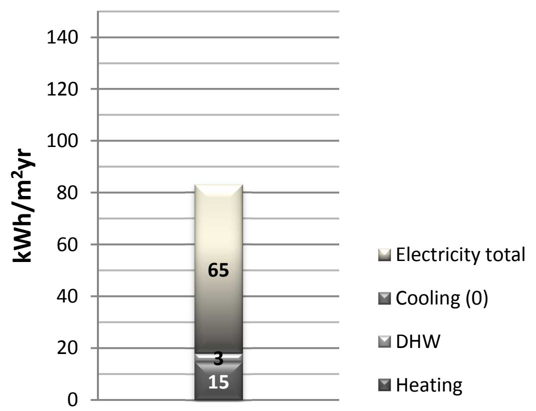


Fig 3.63. End-use energy (monitored season 2000/2001).

3.2.6 Austria

In the office buildings from Austria, information was received on both primary energy and end-use energy. Primary energy conversion factors for Austria are shown in table X.

Table x: Primary energy conversion factors for Austria, index: p primary energy, e end energy (BuildUp 2010).

Type	Source	Primary energy conversion factor kWh_p/kWh_e
Fuels	Gas	1.1
Electricity	“Wienstrom”	2.7

ENERGYbase, Vienna

Fig 3.64. Photo by Hertha Hurnaus

Location	Vienna (N 48.2˚ E 16.37˚)
Climate	HDD 2394/ CDD 623
Completion year	2008
Client/developer and tenant	Vienna Business Agency
Architect	POS architekten
Contractor	Divided contract
Tot. floor area	7500 m^2 lettable area
Floors	5+garage
Operation	Office and research
Office hours	Weekdays 8-18
Plan type	Mixed
Space efficiency	15 m^2/employee
References	(Rauhs, Schneider et al. 2008; ENERGYbase 2009; BuildUp 2010; Greenbuilding 2011; Pos 2011)

Building design

This award-winning office and research centre was built according to the passive-house standard with a great focus on renewable energy and sustainability. The compact and narrow building has a construction of concrete joist floors and prefabricated wooden wall elements with 26 cm insulation (U= 0.22 W/m^2K). The U-value of the roof is 0.13 W/m^2K and the windows are triple glazed with a U-value of 0.9 W/m^2K and a g-value of 0.42. The extraordinary south façade has a saw-tooth shape with integrated PVs and solar panels. These work as effective passive solar and glare protections in summer, but allow direct solar radiation into the building during winter. The conventional windows have light directing Venetian blinds which channel daylight into the depths of the rooms. The WFR is approximately 36%. The plan arrangement is open on the south façade, allowing daylight penetration deep into the building, and contains cell office rooms on the north façade. No information was found regarding the airtightness. The surface-to-volume ratio is 0.29 m^{-1}.

Fig 3.65. Plan by POS architekten

HVAC+L

The control set-points for indoor temperature are 20-26˚C. Geothermal energy and solar energy provide heating and cooling. Ground water heat pumps supply the concrete core temperature control system with warm or cold water, circulating within the concrete floors. Heat is also generated on the south façade when direct solar radiation heats the air, which is transported to colder areas via heat exchangers. For cooling, the air conditioning system has a solar sorption cooling unit supplied with heat from 300 m^2 solar thermal collectors. The balanced mechanical ventilation system has a rotating heat exchanger with 75% efficiency (design value). The airflow is 30 m^3/h and person. Electric lighting is hardly needed but the installed power for lighting is 10 W/m^2 in the north office area and 5 W/m^2 in the south office area. There are 400 m^2 PVs generating about 42 MWh per year (19% of total electricity consumption). For extra user comfort, there is a so-called green buffer zone, containing 500 plants (Cyperus Grass), humidifying the indoor air.

Energy performance

The specific end-use energy according to BBR is estimated to **20 kWh/m²yr** (excl. tenant electricity), with a contribution from the PV system estimated to 5 kWh/m^2yr. Calculations were carried out with TRNSYS and CFD-simulations as part of a research project. The estimated primary energy for heating is 11 kWh/m^2yr and for cooling 15 kWh/m^2yr.

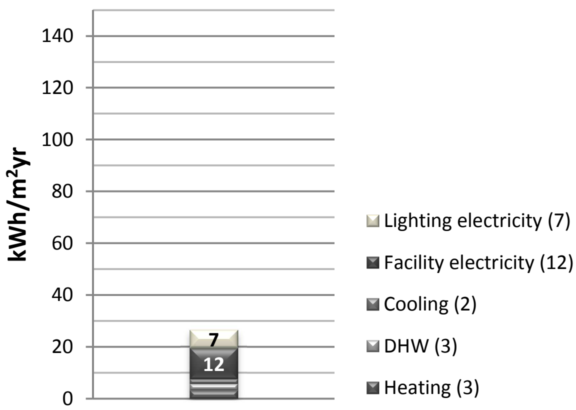


Fig 3.66. End-use energy (calculated).

SOL4, Mödling

Fig 3.67. No approval yet

Location	Mödling (N 48.08˚ E 16.27˚)
Climate	HDD 2394/ CDD 623
Completion year	2005
Client/developer	BM Ing. Klausjürgen Kiessler
Architect	Solar4you Consulting
Contractor	No information
Tenant	Many small companies
Tot. floor area	2 740m^2 gross floor area (BGF)
Floors	4
Operation	Office, fitness centre
Office hours	-
Plan type	Flexible
Space efficiency	8 m^2/person (incl. gym?)
References	(Kiessler, Stockinger et al. 2005; Kornadt and Wallasch 2008)

Building design

This innovative training and business centre is situated in a nature reserve at the foot of the Eich Hill south of Vienna and has a great ecological focus. The building is square and compact with a central atrium for daylight penetration and night ventilation. The load-bearing structure is made of cement-free concrete and brick masonry with optimized storage capacity. The external walls are made of clay blocks insulated with 30 cm mineral foam (U=0.11 W/m^{2}K), except for the walls behind the "clip-on" PV façade system on the top floors which have 36 cm straw insulation (U=0.13 W/m^{2}K). The interior walls are made of unfired brick. The floor has 35cm insulation and the green roof system has 30cm insulation (U=0.10 and 0.11 W/m^2,K). The windows and the glass roof of the atrium are triple glazed with U-values of 0.9-0.97 W/m^{2}K. The windows have an advanced shutter system for solar shading. The measured air-tightness is 0.56 ach at 50 Pa pressure difference.

Fig 3.68. Plan by, no approval yet

HVAC+L

Heating and cooling is supplied with two reversible ground water heat pumps (COP of 4.0) coupled with 7 boreholes, each 80 m deep. A concrete core temperature control system distributes and circulates the warm or cold water within the concrete floors. The building is also cooled at night using natural night ventilation, driven by thermal buoyancy through the atrium. The natural airflow is approximately 6-12 ach in the summer. Half of the large annual hot water demand is covered by 36 m^2 solar thermal collectors on the roof; the rest is covered by an electric heater. The PV system (210 m^2) on the facades produces a rough 6 kWh/m^{2}yr electric power, which covers all the energy needs of fans and pumps. The ventilation is a VAV-system with a rotating heat exchanger with 85% efficiency (design value). The airflow is 0.5-2.5 ach which correspond to approximately 0.4-2.0 l/sm^2 (assuming 3 m room height). Daylight sensors control the lighting system and 80% of all work stations are placed within 5 m of a window.

Energy performance

The specific end-use energy according to BBR is estimated to **37 kWh/m^{2}yr** (excl. tenant electricity). The high domestic hot water demand is due to the gym. No information was found on the tenant electricity. The primary energy for heating and hot water is 19 kWh/m^{2}yr (design value).

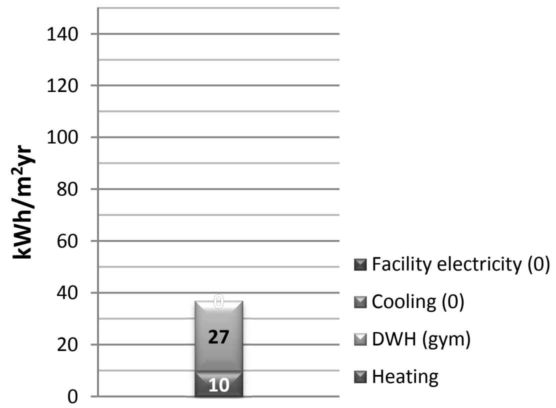


Fig 3.69. End-use energy (calculated).

3.2.7 Switzerland

Primary energy conversion factors for Switzerland are shown in Table X.

Table X. Primary energy conversion factors in Switzerland according to the Minergie standard

Energy source	Primary energy conversion factor kWh_p/kWh_e
Solar and ambient heat	0
Biomass (wood, biogas)	0.7
Waste heat	0.6
Fossil fuels	1.0
Electricity	2.0

Dreieck GHC, Esslingen

Fig 3.70. Visualization by Stücheli Architekten.

Location	Esslingen (N 47.28˚ E 8.72˚)
Climate	HDD 2600/ CDD 471
Completion year	2010
Client/developer	Rehalp Verwaltungs AG
Architect	Stücheli Architekten
Contractor	-
Tenant	Basler & Hofmann et al.
Tot. floor area	2621m^2 heated floor area (EBZ)
Floors	4+basement
Operation	Office+ boutiques
Office hours	-
Plan type	Flexible
Space efficiency	22 m^2/person
References	(Filleux 2009) (Braun, Filleux et al. 2009)

Building design

This is the third out of five office buildings (building C) in Esslinger Dreieck southeast of Zürich. All buildings on the site have a high sustainability focus and are aiming for the Minergie-P-ECO certificate. Building C is rectangular and compact with a load-bearing structure made of recycled concrete and prefabricated concrete elements. The exterior walls are prefabricated wooden wall elements with a U-value of 0.10 W/m^{2}K. The U-value of the roof is 0.11 W/m^{2}K. The windows are very well insulated with a U-value of 0.7 W/m^{2}K (incl. frame) and the g-value is 0.45. The WFR is 27%. The spectacular south façade has a shell with an integrated PV system with a slope designed for excellent solar shading. In addition, the double skin protects the exterior Venetian blinds. No information was found on the building's airtightness but it ought to fulfil the passive house standard (0.6 ach at 50 Pa pressure difference) since it is a Minergie-P certified building.

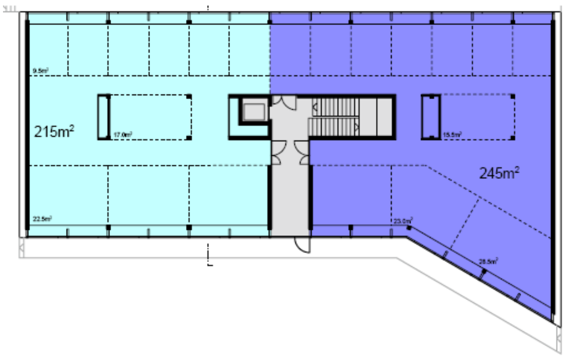


Fig 3.71. Plan by Stücheli Architekten.

HVAC+L

The control set-points for indoor temperature are 20-26˚C. The heating concept is an innovative system completely supplied with solar energy. There are 95 m^2 of thermal solar collectors integrated on the roof, which store heat in the ground in the summer through 33 boreholes (35 m deep) for winter use. In the winter, the solar collectors are used for direct pre-heating of the warm water supply. The heat store in the ground heats the return water in the heating system. The system is new and not yet evaluated. By estimate, it takes about five years to fully load the ground with heat. Heating and cooling is distributed with convectors in the window parapets working with modest supply temperatures (26˚C for heating and 20˚C for cooling). The incoming cold water is used for evaporative cooling of the convector circuit. Heat from the server rack is used for heating the return water both in the heating and cooling seasons with en efficiency of 2K. In addition, the temperature in the server room is reduced. The ventilation system is a VAV-system with CO2 control. No information was found about the airflow rate or the heat exchanger efficiency. LED lighting is installed in the bathrooms. The 200 m^2 PV panels on the south façade produce enough power to cover all lighting and fan electricity demand.

Energy performance

The specific end-use energy for heating is estimated to **9 kWh/m²yr**. No other information was found on the energy consumption so the figures are uncertain. Building C was certified as a Minergie-P-ECO building in December 2010. Thus, the primary energy for heating and hot water should not exceed 15 kWh/m²yr (design value).

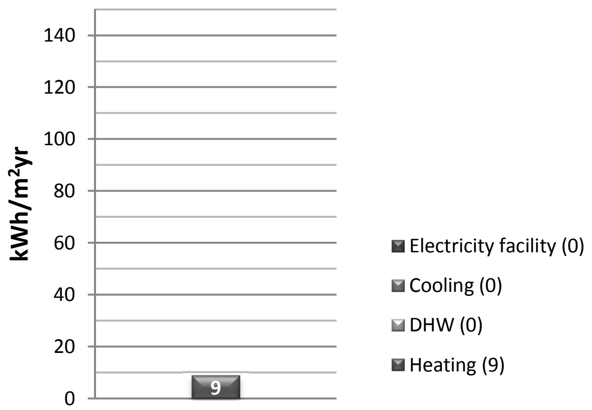


Fig 3.72. End-use energy (calculated).

3.3 Discussion

Detailed information was collected for 14 low energy office buildings in the Nordic countries and 10 office buildings located in other parts of Northern Europe. Although the attempt was to list the most energy-efficient office buildings within this region, with a special focus on the Nordic countries, this study cannot be claimed to be comprehensive. The buildings presented are good examples but there are more buildings which, for different reasons, were difficult to document. There are also energy-efficient buildings currently in the design phase or in the pipeline which have not been studied. Furthermore, the selected buildings are not entirely representative for each country's building standard. For example, the examples from Denmark and Finland all represent the same developer and therefore they exhibit many similarities in the design. In this discussion, an effort is made to illustrate differences and resemblances in building design, HVAC, lighting design, etc., for the described cases.

3.3.1 Building year

The most energy efficient buildings in the Nordic countries are obviously younger than the ones from Germany. All but one of the presented examples from the Nordic countries were constructed after 2006, while many good examples in Germany were built already in 1998-2002. This is likely to depend on the International Passive House programme with its origin in Germany. The Passive House Institute was founded in 1996 (PHI 2012b) and the first passive office building, Wagner & CO, was built shortly afterwards, in 1998. Another strong influence is clearly the demonstration programme EnBau, launched in 1995 by the German Federal Ministry for Economy. EnBau stands for "Forschung für Energieoptimiertes Bauen"(Energy-Optimised New Buildings, En0B) and was initiated in order to gain access to information on energy use in office buildings. For participating and sponsored buildings, the total primary energy limit for heating, lighting, ventilation and air conditioning is 100 kWh/m²yr (heated net floor area, NFA) (Voss, Herkel et al. 2007; En0B 2011). Furthermore, the European Commission initiated the GreenBuilding programme in 2004 (Greenbuilding 2011). In a pilot phase, in the years 2005-2006, the GreenBuilding infrastructure was set up in ten European countries, among them Sweden. It is clear that Sweden began to design GreenBuildings in this pilot phase and that other Nordic countries followed.

3.3.2 Location and climate

In this study, no low-energy office building further north than the 60th degree of latitude (the height of Helsinki and Stockholm) was found (see Figure X). Although the North European region was studied because of the similarities in climate, there are some climate differences within the region. According to heating and cooling degree days (BizEE 2011), Finland has the largest heating demand and Austria has the largest cooling demand while Germany has the smallest heating demand and Norway has the smallest cooling demand (see Figure X.). As an example, Stockholm in Sweden has about 3200 HDD a year and 260 CDD compared to Freiburg in Germany with 2300 HDD and 600 CDD. This means a difference of 900 HDD and 340 CDD. Heating and cooling degree days is a rough tool which should not be used for calculating heating and cooling demand. In his study it is used primary to indicate and compare climate differences.

Figure 3.73. Locations of the 24 studied office buildings (Google 2011).

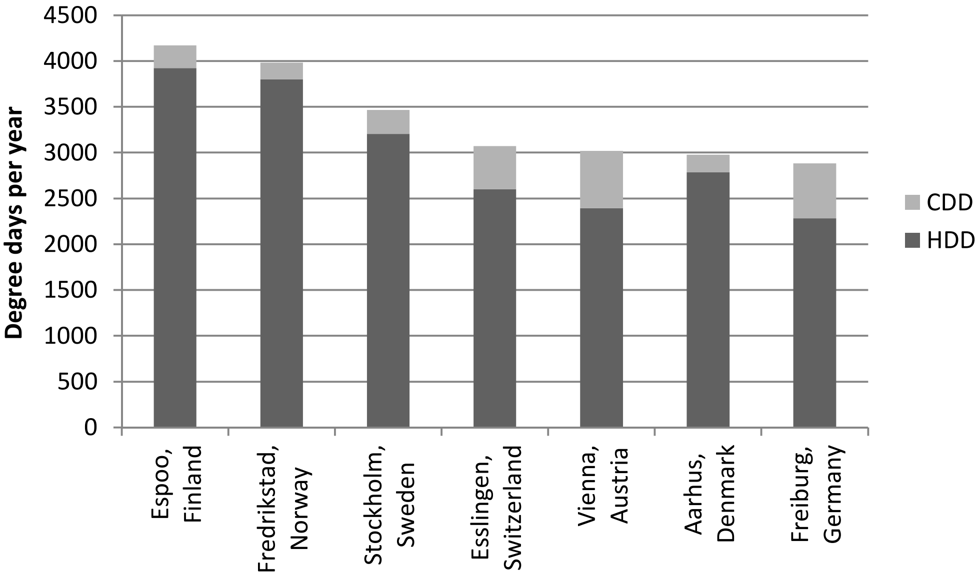


Figure 3.74. Heating and cooling degree days (base temperature 15.5 ˚C) for locations representative for the office buildings studied. An average based on five years of weather data.

3.3.3 Building body design

The Nordic buildings and Swedish in particular, are quite large in comparison to the rest of the studied buildings. The floor area varies mainly from 5 000-30 000 m^2 in the Nordic countries while many of the buildings further south are between 1 000-3 000 m^2. This could be the result of a more experimental and cost-reducing approach when building according to the passive house standard and the EnBau programme. The large buildings in the Nordic countries, with many floors, automatically yield a high compactness. Considering the shape of all the buildings, there are both rectangular/narrow buildings and square/deep ones. More than half of the buildings have a glazed atrium for daylight access and/or as part of a ventilation strategy. Half of the atria are placed along the façade and half have a central location within the building. In the Nordic countries, all the studied office buildings are open plan offices or at least with a degree of flexibility so that the tenant can choose between cell rooms and open plan or a mix of both. In Germany, all buildings are designed with office rooms but it seems to be common with rooms for two or three people which entails rather space-efficient buildings.

Several buildings in the study are designed with a load-bearing concrete skeleton construction with concrete joist floors, concrete columns and prefabricated wooden wall elements. About one third of the buildings have a concrete wall construction in addition and high thermal inertia. Most buildings in the Nordic countries have suspended ceilings, whereas many cases from other countries have exposed concrete floors and ceilings, which are used for heating and cooling distribution and heat storage.

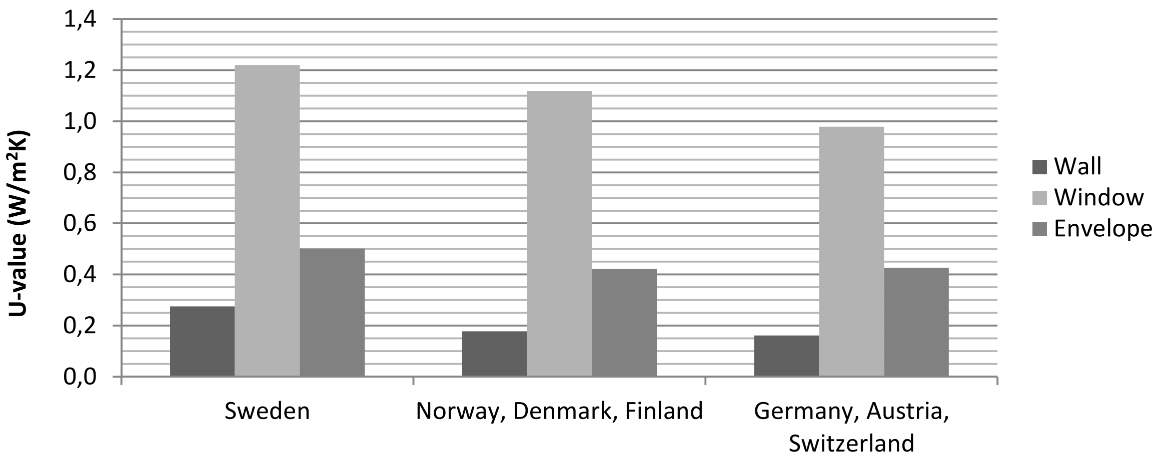


Fig 3.75. Average U-values of walls, windows and building envelopes in the studied office buildings.

The average U-values of the constructions in the Swedish buildings are slightly worse than the average in other regions (se figure X). The walls have U-values between 0.2-0.3 W/m^{2}K and the windows have U-values between 0.8-1.4 W/m^{2}K (frames included). In Germany and the nearby countries, the buildings are better insulated and the U-values of walls are 0.10-0.23 W/m^{2}K and the U-values of windows are 0.7-1.4 W/m^{2}K. Thus, some of these buildings fulfil the basic features of the international passive house guidelines, suggesting that suitable U-values should be maximum 0.8 W/m^{2}K for windows (glazing and frames) and about 0.15 W/m^{2}K for other construction components in the envelope (PHI 2012b). For the cases where the average U-value of the building envelope is declared, it mostly varies between 0.3-0.5 W/m^{2}K. These values fulfil the Swedish GreenBuilding criterion which is 25% under the requirement in BBR which was 0.7 at the time these buildings were designed (Boverket 2011a).

Regarding the airtightness of the envelope, the various countries use diverse quantities and units from the European standard EN 13829 (CEN 2000) and different criteria. For example, the Swedish passive house criterion is 0.3 l/sm^2 (q_{50}) (FEBY 2009) and the international passive house criterion is 0.6 ach (n_{50}) (PHI 2012b). In Sweden, test results were found for three buildings and one of them fulfil the Swedish passive house criterion. In Germany and the nearby countries, six buildings fulfil the international passive house criterion and the best declared airtightness is 0.2 ach (n_{50}). In Norway and Finland, none of the case buildings have been tested and the design values for airtightness are poor; 0.7-2.0 ach (n_{50}).

3.3.4 Solar control

There are relatively great variations in window amount and solar heat gain coefficients in the study (see figure X).

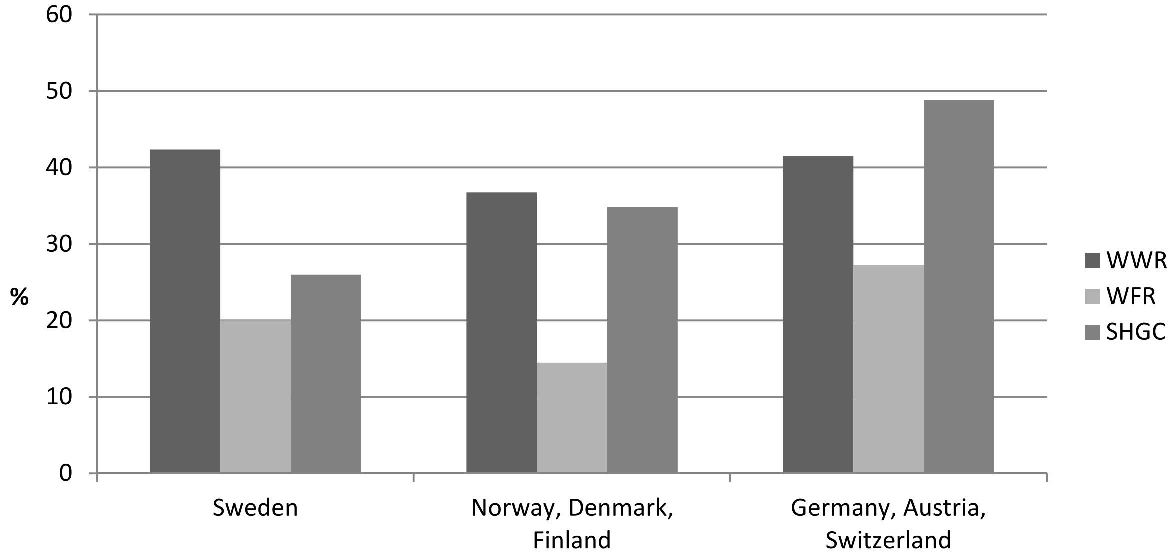


Fig 3.76. Average window-to-wall ratio (WWR), window-to-floor ratio (WFR) and solar heat gain coefficient (SHGC).

The window-to-wall-ratio (WWR) is quite small in the Nordic countries, often 20-40%. In Germany, the WWR is just below 45% in most cases. It was hard to find information about window-to-floor-ratios (WFR) but the declared values range between 12-36% with values below 20% in the Nordic buildings. The SHGC is difficult to analyse since in some cases the glazing SHGC is declared, and in other cases the total effective g-value inclusive solar shading is declared. Most buildings have both solar control glazing and solar shading devices. The SHGC in the Scandinavian cases is often 30-35%. In Germany and nearby countries, the studied SHGC vary between 42-60%. The best SHGC of the whole study is 27% and the best effective g-value (inclusive shading devices) declared is 12%. The international passive house criterion suggests a SGHC around 50% (PHI 2012b).

In the Nordic countries, all types of solar shading devices are represented; external blinds, internal blinds and tinted glass. In Germany and nearby countries, solar shading devices are almost exclusively external, which is the most efficient placement for reducing cooling loads. In some buildings, the shading devices are integrated in the façade as permanent passive devices, designed to let the low winter sun in but to prevent solar radiation from the high standing summer sun. Another characteristic in these countries are solar shadings with daylight redirection, i.e. the blinds consist of two parts which can be adjusted separately to permit daylight to enter through the upper part even when the blinds are closed. Combined with a high reflective ceiling, the natural light can be distributed deeper into the room. Many of the studied buildings are designed with glazed atria for daylight access. These atria are not equipped with solar shading devices in general.

3.3.5 HVAC

Design set-points for indoor air temperatures are 21-25˚C in the Nordic countries in general, or 20-25˚C in some cases, while other countries allow 20-26˚C and often without an upper limit. For comparison, in Swedish guidelines for indoor climate, R1 (Ekberg 2006), the next most stringent classification, TQ2, requires operative temperatures of 20-26˚C which is supposed to correspond to a PPD (Predicted Percentage Dissatisfied) index of 10%. The most stringent classification, TQ1, also requires operative temperatures of 20-26˚C but in addition, an individual temperature control must be possible. The temperature control set-points are not always equal to real temperatures though. From experience, target temperatures in Sweden often lies within 22-23˚C throughout the year which, of course, increases the heating and cooling load.

In Sweden, Denmark and Finland, heating demand is exclusively provided by district heating. In Norway, half of the buildings have electric heat pumps. Heating is mainly distributed with radiators/convectors and cooling is mainly distributed with ventilation air. In Germany and the nearby countries, geothermal boreholes with or without reversible heat pumps are very common for heating and cooling. Heating and cooling is often distributed with a concrete core temperature control (CCTC) which is a water-borne floor heating and cooling system with moderate temperature range. In addition, underground ducts (earth-to-air heat exchangers) are used for preheating and precooling the supply air. There are two example buildings in which solar heat is stored over the year in the ground and in large accumulator tanks.

In the Nordic countries, most air handling strategies are demand controlled VAV systems with airflows changing with temperature and CO_2. The airflows vary from 0.35 to 2.4 l/sm^2 for buildings with large cooling demands. According to Swedish guidelines R1 (Ekberg 2006), the minimum hygienic airflow should be 0.35 l/sm^2 and the minimum person based airflow should be 7 l/s and person. The normal person based airflow is often larger though, 15-20 l/s and person, due to internal gains (Enberg 2009). There are two Swedish buildings with CAV systems, characterized by low air velocity and low pressure drop. In both cases, the constant airflow is 1.5 l/sm^2 during office hours. A couple of Swedish buildings have special air diffusers with built-in occupancy sensors for optimal demand control. These air diffusers operate on an average 30% of maximum capacity on a yearly basis. None of the Swedish buildings have natural ventilation and this is representative for the building stock in general. A recent report (Boverket 2010) presents the state of building technique in existing buildings in Sweden. According to this report, 95% of the existing non-residential buildings in Sweden have a mechanical balanced ventilation system and 63% have additional heat recovery. In Germany, Austria and Switzerland, CAV systems with rather low airflows are most common. Only two buildings have VAV systems. The airflows vary from 0.26 to 1.1 l/sm^2. A couple of buildings have hybrid ventilation with operable windows combined with exhaust fans securing minimum hygienic airflow. There is no studied building with entirely natural ventilation.

Total Specific Fan Power (SFP) varies from 1.0-1.9 kW/m^3s^{-1} in Sweden and Denmark. In Norway and Finland SFP is higher, 2.0-2.9 kW/m^3s^{-1}. No information was found about the fan efficiency in Germany and the nearby countries. The Swedish building code recommends an SFP of maximum 2.0 kW/m^3s^{-1} for mechanical balanced ventilation with heat recovery (Boverket 2011a), but other voluntary guidelines recommend SFP 1.3 kW/m^3s^{-1} in low-energy non-residential buildings (BELOK 2011). Regarding heat recovery, almost all buildings recover heat from the exhaust air, except the ones with hybrid ventilation. Most air handling units have rotating heat exchangers with efficiencies of 75-85% on a yearly basis. In Norway, the efficiency is generally lower, i.e. around 65%.

Night ventilation for passive cooling is used in half of the studied office buildings in Germany and the nearby countries. Night ventilation is used also in buildings without heavy walls but where thermal mass is high because of the exposed concrete ceilings for heating and cooling distribution. Only a couple of Swedish office buildings use night ventilation. In Denmark and Norway, half of the studied building use night ventilation. Most of the buildings with night ventilation use the existing mechanical air handling unit at night, but some German offices have natural night ventilation, driven by thermal buoyancy forces only.

3.3.6 Lighting, equipment and internal heat gains

Almost all of the presented office buildings have some sort of lighting control strategy in order to avoid excessive electricity for lighting. In Sweden, the most common control strategy is having occupancy sensors and there are only two examples with daylight control. There has been no clear focus in limiting the installed power for lighting in Sweden. Best practice is Pennfäktaren with 7.2 W/m^2 installed power and daylight control in addition. The Swedish guideline for lighting (Ljuskultur 2010) recommends a minimum illuminance of 500 lux on the task area in office rooms. The requirement for installed power is 10 W/m^2 in individual office rooms, 12 W/m^2 in landscape offices and about 8 W/m^2 in other spaces. In the studied Norwegian buildings, the installed power lies within 6.4-10 W/m^2 and is mostly controlled by occupancy sensors. In the two Danish buildings, the control strategy is daylight control and the installed power is 8 W/m^2. In Finland, the installed power is high, 15 W/m^2, but in return, the control strategy is daylight dimming. In Germany and the nearby countries, there is a great variety in installed power for lighting, from 2 W/m^2 in communication areas and up to 20 W/m^2 in office spaces. Almost every building has a daylight control strategy.

The study reveals no information on installed power for electric office equipment. This is understandable for recently completed buildings since the equipment is highly user-related and not the designer’s responsibility, unlike the general lighting design. However, not even the older buildings, which have been monitored for a couple of years, show much focus in equipment operation and limiting the internal heat gains.

3.3.7 Energy performance

The primary energy use, declared in some of the buildings in Germany, Austria and Switzerland, has been translated into end-use energy via primary energy conversion factors in order to be able to present all buildings together in one chart (see figure X). Note that most of the Nordic buildings are newly built and have not been monitored yet. These design values are marked with an asterisk (*). The first two bars are fictive and represent the existing office building stock in Sweden (Energimyndigheten 2007) together with a typical office building just fulfilling the requirement in the Swedish building code BBR 18 (Boverket 2011a). The Swedish building code treats the specific end-use energy for heating, cooling and facility electricity and thus, all the buildings are sorted and presented in descending order according to this specific end-use energy. For buildings where tenant electricity is available, this is presented in white stacks and in case tenant electricity is inseparable from facility electricity, the total electricity is shown in grey-to-white toned stacks.

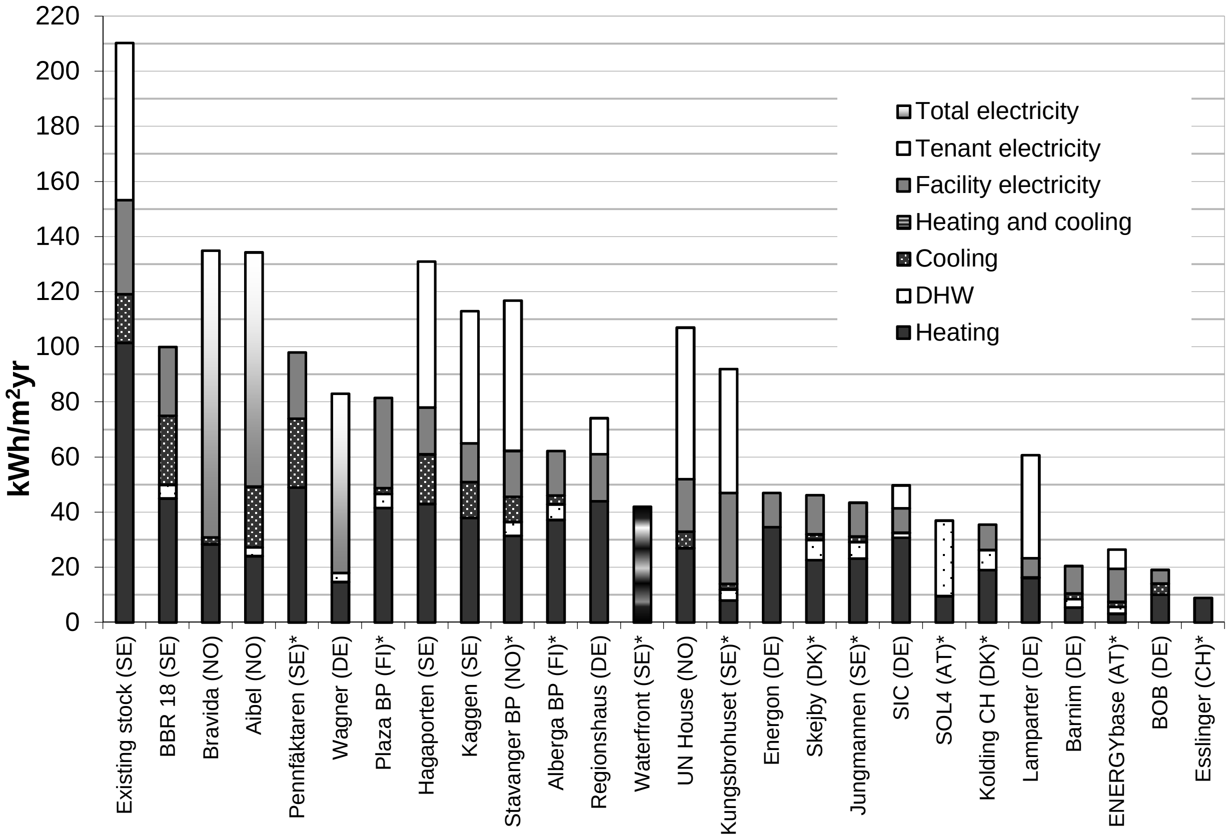


*Figure 3.77. Monitored and calculated end-use energy for the studied office buildings. *Design value (not monitored)*

The energy use in the Swedish buildings (SE) is well below the average of the existing office building stock in Sweden. Except for one renovation project, the Swedish buildings are at least 25% better compared to the regulations in BBR 18 and the GreenBuilding effect is clear. Best practice in Sweden is Jungmannen 3 in Malmö with a total end-use energy for heating, cooling and facility energy of 43 kWh/m^{2}yr (design value). Kungsbrohuset in Stockholm has a very low demand for heating and cooling but, on the other hand, large facility electricity (design value). These energy demands have not been verified though, and best monitored building in Sweden is Kaggen in Malmö with a total end-use energy for heating, cooling and facility energy of 65 kWh/m^{2}yr.

The Norwegian buildings (NO) have moderate heating and cooling demands but in return some of them use much pump electricity. Best practice is the renovation project, the UN House in Arendal, with a total delivered energy for heating, cooling and facility energy of 52 kWh/m^{2}yr (monitored). The two similar Danish office buildings (DK) are both energy-efficient. Best practice is Kolding Company House with a total end-use energy for heating, cooling and facility energy of 36 kWh/m^{2}yr (design value). The two Finnish buildings (FI) have low cooling demand and high heating demand. Best practice is Alberga Business Park with a total end-use energy for heating, cooling and facility energy of 62 kWh/m^{2}yr (design value).

There is a great variety in end-use energy in the office buildings in Germany (DE), Austria (AT) and Switzerland (CH). A large share of the energy is provided with “free” energy from solar thermal collectors, photovoltaic systems and earth-to-air heat exchangers which is not shown in the chart. Most buildings do not have to buy any cooling energy at all. Best practice is BOB in Germany, ENERGYbase in Austria and Esslinger Dreieck in Switzerland. The total end-use energy for heating, cooling and facility energy is 19 kWh/m^{2}yr for BOB (monitored), 30 kWh/m^{2}yr for ENERGYbase (design value) and only 9 kWh/m^{2}yr for Esslinger Dreieck (design value).

The GreenBuilding label is the most frequent energy assessment in the Nordic countries. 10 out of 14 buildings are, or are about to become, certified GreenBuilding partners. Two buildings are classified (or pre-classified) according to Miljöbyggnad, two according to LEED, and three according to BREEAM (SGBC 2012). In Germany, Austria and Switzerland, three of the studied buildings are Quality Approved Passive Houses (PHI 2012b), two are classified according to GreenBuilding and one has a Golden German quality label for sustainable buildings (DGNB 2012). Generally, this region focuses more on sustainability and ecological issues than the Nordic region.

4. Parametric study

4.1 Method

This method section describes in detail the dynamic simulations carried out with IDA ICE 4 on a model of a typical office building with perimeter cell rooms. First, a reference building was modelled as a base case, designed to correspond to the current energy regulations in the Swedish building code. Then, different design features were studied in a parametric study and the results were analysed and compared to the base case. The evaluation was performed on the result of the entire building and on a whole year basis (annual energy balance). The parameters which were analysed were airtightness, insulation levels and thermal mass of the building envelope, glazing and solar control, cooling and ventilation strategies as well as control and installed power of lighting and electric equipment. The impact of climate, occupancy rate and room design was also studied in a sensitivity analysis. Finally, the most effective design features were combined as a best case solution and simulated in order to obtain the maximum energy saving potential with proven and cost effective technique.

4.1.1 The simulation software

The simulations were carried out with IDA ICE (version 4). IDA ICE is a dynamic multi-zone simulation program for study of indoor climate of individual zones within a building, as well as whole-year energy consumption for an entire building. It is written in the neutral model format (NMF) which is program-independent and uses differential-algebraic equations for modelling dynamical systems (Kalamees 2008). This enables the user to change and write new models. IDA ICE was developed in the mid-eighties at the Royal Institute of Technology (KTH) in Stockholm and is now launched in a global market with focus in Sweden, Finland, Germany, Switzerland and the UK. The simulation tool is provided by EQUA Solutions AB and it has been validated according to CEN 13791, ASHRAE 140-2004, CEN 15255, CEN 15265, CIBSE TM33, RADTEST and Envelope BESTEST (EQUA 2012).

In the simulation process of IDA ICE, one or more zones are modelled and together they define a building. The zones can be modelled manually or being imported from common 2D and 3D CAD files and to some extent even BIM models (Building Information Modeling) (EQUA 2012). The construction parts (walls, roof and floor) separate the zones from each other and the building from the ambient climate. Various heating and cooling devices, ventilation systems, lighting systems, building materials, windows and shading devices and controller set-points can be chosen from a library and be attached to each zone. The climate model is an algorithmic model that, from a given weather file and location data, calculates air temperature, sky temperature, ground temperature, air humidity ratio, air pressure, CO_2 fraction, direct and diffuse horizontal solar radiation, wind direction, wind velocity and the elevation angle and azimuth angle of the sun. The zone model calculates the indoor climate and energy consumption in each zone and IDA ICE can provide output files for any data object in any system with high time resolution. IDA ICE 4 handles a number of different features and can be used for calculation of (Kalamees 2008):

- Full zone heat and moisture balance with contributions from solar radiation, occupants, equipment, lighting, ventilation, heating and cooling devices, heat transmissions, thermal mass effects, air leakage, cold bridges and furniture
- Wind and buoyancy driven airflows through leaks and openings
- Air and surface temperatures and operative temperature at any occupant location

• Temperature, CO_2 and moisture levels which can be used for controlling the air handling system
• Solar influx thorough windows and the influence of local shading devices and surrounding buildings
• Daylight level at any room location
• Comfort indices (PPD and PMV)
• Energy cost (based on time-dependent prices)

IDA ICE is the probably the most frequently used tool for energy simulations of non-residential buildings and low-energy houses in Sweden today. Thus, the program was selected for this study even though it is rather complex and not considered optimal for multi-zone parametric studies.

4.1.2 The reference building

The virtual reference building, which was defined previously by Poirazis (2008), is a typical large office building with peripheral individual office rooms and a central core with stairways, elevators and other facilities. The office block is a six storey building with a narrow shape (approximately 66 m x 16 m) with the short sides orientated to east and west. The room height is 3.2 m and the floor height is 3.5 m with 0.3 m concrete intermediate floors and a thin ceiling. Each floor is 1030 m^2 with a total heated floor area (A_{temp}) of 6180 m^2 (internal constructions included). More building data is presented in Table 4.1 in section 4.1.3. In IDA ICE, the building was modelled with as few thermal zones as possible in order to reduce the simulation time. Identical floors and identical office rooms within the floors, with the same amount and orientation of external envelope surface, were therefore modelled once and multiplied several times in the simulation (see Figure X and X). This is current practice for speeding up the simulation and has a negligible effect on the result.

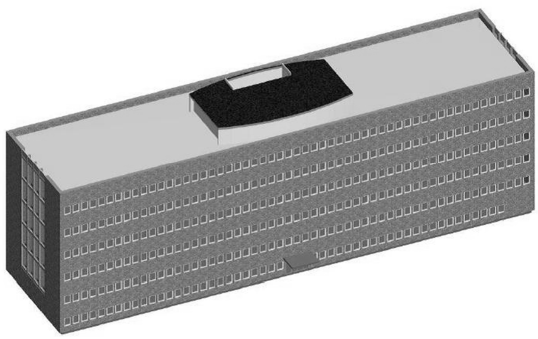


Figure 4.1. Visualization of the reference building (reconstruction)

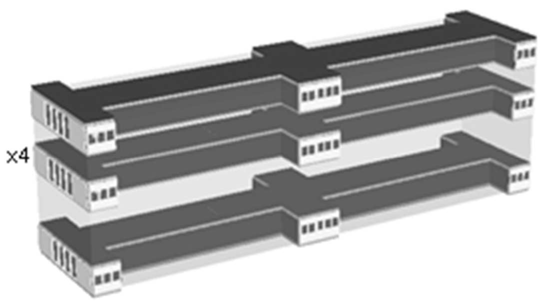


Figure 4.2. Model in IDA ICE of ground floor, 3rd and 5th floor. 3rd floor was muliplied four times in the simulation.

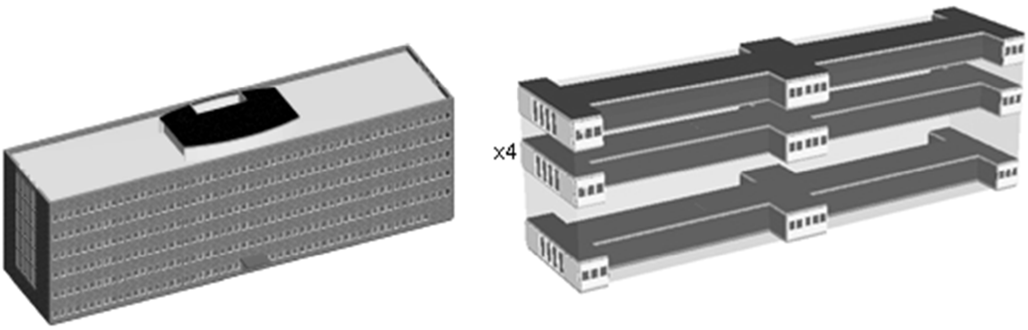


Figure X. Visualization of the reference building (reconstruction)

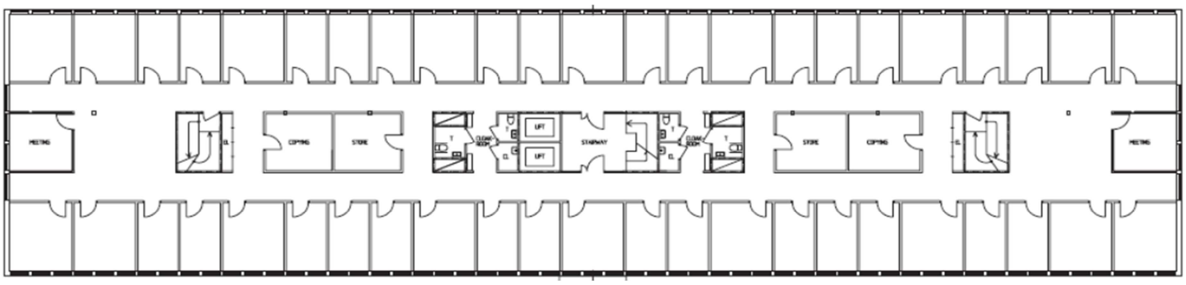


Figure X. Typical floor plan in the reference building.

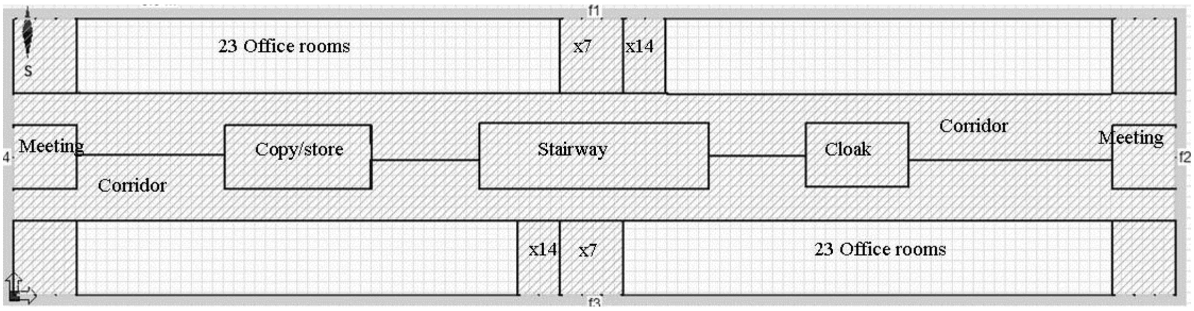


Figure X. Typical floor plan in IDA ICE.

Figure X shows the distribution of office space in the reference building. The individual office rooms and the meeting rooms correspond to 56% of the floor space (office rooms 54%). The corridors answer to as 34% and the remaining space consists of stairways and other facilities (10% in total).

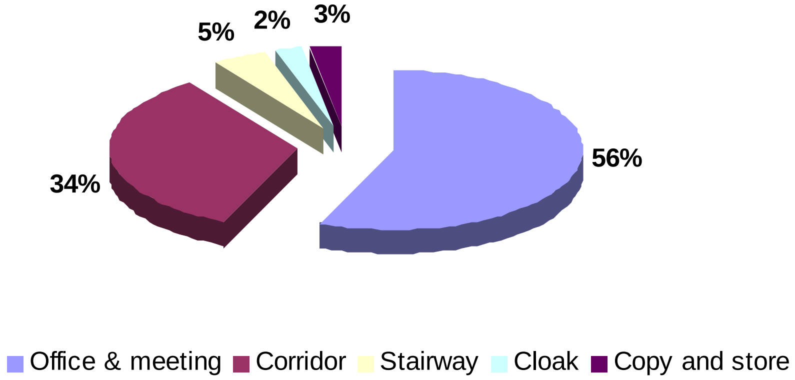


Figure X. Distribution of office space in the reference building.

4.1.3 Input for parametric study

Base case

The base case input was chosen in order to correspond to normal praxis and regulations in the recent Swedish building code BBR18. In addition, the input is to a great extent in line with the standardized input parameters for energy calculations in office buildings (SVEBY 2010) provided by the SVEBY programme which stands for "Standardize and verify the energy performance of buildings" (SVEBY 2012). The SVEBY standard is the Swedish building industry's interpretation and clarifying of the energy regulations in the building code BBR. The SVEBY standard was developed with the intention to agree on a common building praxis and to prevent disputes between different actors in the industry. Remaining input are values experienced by members of the project and reference group. The base case input is presented in Table 4.1 and further described in text in the following sections.

Table 4.1 Base case simulation input

Parameter		Simulation input	Comment
Climate conditions	Location	Stockholm 59.35N, 17.95E	
	Temperature Dry-bulb min/mean/max	-18.3 / 6.5 / 26.1 ˚C	ASHRAE Fundamentals 2001
	Horizon angle	15˚	EN ISO 13790:2008
Dimensions	Heated floor area (A_{temp})	6 180 m^2	BBR definition
	Air volume	19 776 m^3	
	Envelope surface	5 193 m^2	
	Surface-to-volume ratio	0.26 $^{-1}$	
	Façade surface	3 133 m^2	
	Window-to-wall ratio (WWR)	35%	(glazing-to-wall-ratio 31%)
	Window-to-floor ratio (WFR)	18%	
Building elements	External wall U-value	0.20 W/m^2 ˚C	170+50 mm mineral wool
	External roof U-value	0.11 W/m^2 ˚C	300 mm mineral wool
	External floor U-value (excluding ground resistance)	0.17 W/m^2˚C	200 mm EPS
	Windows U-value (including frames)	1.4 W/m^2 ˚C	Pilkington Suncool 2-glass
	Glazing	LT 72%, SHGC 43%	Pilkington Suncool 70/40
	Internal blinds	0.83 x SHGC	SHGC multiplier
	Total UA transmission	2119 W/˚C	
	Thermal bridges	445 W/˚C 21% of total UA	Calculated in HEAT2 (BuildingPhysics 2011)
	Air leakage rate	1.5 ach (n_{50})	EN 13829:2000
Heating/cooling efficiency	Boiler COP	0.9	Total heat supply
	Heating coil COP	0.9	In air handling unit
	Domestic hot water COP	0.9	
	Domestic hot water use	2.0 kWh/m^2yr	SVEBY standard
	Chiller COP	0.9	Total cooling supply
	Cooling coil COP	0.9	In air handling unit
Thermal climate	Set-points for mean air temperature	22-23˚C	Normal target values
Ventilation	Ventilation operating hours	Weekdays 7:00-19:00	

	Constant Air Volume	1.5 l/s,m^2	SVEBY Standard
	Heat exchanger efficiency	70%	Yearly average
	Total Specific Fan Power, SFP	2.0 kW/m^3s^{-1}	BBR18
	Supply air temperature	17 ˚C	
Office operation	Office hours	Weekdays 8:00-18:00	1 hour lunch break
	Occupant space	20 m^2/person	SVEBY standard
	Activity level	1 met, 108 W	Sensible and latent heat
	Occupancy rate	0.7	SVEBY standard
Lighting	Installed power in office rooms and other spaces	10 and 6 W/m^2	Blomsterberg [13]
	Control	Manual switch on/off	
Computers and office equipment	Power on/standby	140/10 W/person	Blomsterberg [13]

Building envelope

The base case construction is typical with heavy concrete joist floors and light curtain wall elements. The U-values are given in Table 4.1 and the average U-value of the envelope is 0.5 W/m^2°C (including thermal bridges). In the parametric study, the roof and floor components were kept intact since these constructions only have a small impact on the total transmission losses in a multi-storey building with a comparatively large façade area. External walls and windows, on the other hand, have a larger impact and the different constructions studied in the parametric study were walls with a U-value of 0.1 and windows with U-values of 0.7, 0.9 and 1.1 W/m^2°C. The wall U-value was achieved with a wooden construction with 80+195+70 mm mineral wool. Walls with U-value 0.1 and windows with U-value 0.9 W/m^2°C correspond to the guidelines in the Swedish passive house standard.

Heavier constructions with more internal thermal inertia were simulated next. A medium heavy version with exposed concrete walls in stairway and cloak rooms, and a heavy version with additional concrete sandwich walls in the facade were performed. U-values were kept the same. In order to optimize the conditions for heat storage, larger temperature variations were allowed and simulations were performed with mean air temperature set-points of 21-24˚C.

The base case air leakage rate was set to 1.5 ach (n_{50}) which corresponds to the former Swedish regulation of 1.6 l/sm^2 (q_{50}). A wind driven flow was specified in IDA ICE, based on wind pressure, fan pressure and thermal buoyancy effects. The wind profile was based on a suburban location. Pressure coefficients depend on form factors and wind direction. The chosen pressure coefficients are a common handbook data set (from the Air Infiltration and Ventilation Centre) based on a semi-exposed building. In the parametric study, two airtight models were evaluated as well, one with an airtightness level according to the international passive house standard (0.6 ach, n_{50}) and the other according to the Swedish passive house standard (0.3 l/sm^2 envelope surface, q_{50}). 0.3 l/sm^2 correspond to 0.28 ach in the reference building.

The initial window-to-wall ratio (WWR) in the reference building was 35%. In the parametric study, WWR 60% was simulated which is a common ratio in modern office buildings. WWR 35% and WWR 60% are equivalent to glazing-to-wall ratios GWR 31% and GWR 54%

(frames excluded). The base case glazing has a solar heat gain coefficient (SHGC) of 43%. Together with internal venetian blinds, SHGC is reduced to $SHGC_{tot}$ 36%. The window integrated shading device is controlled by the amount of solar radiation that penetrates the glazing. As default in IDA ICE, the blinds are drawn when solar radiation level on the inside of the glass exceeds 100 W/m^2. In the parametric study, intermediate blinds ($SHGC_{tot}$ 17%) and external blinds ($SHGC_{tot}$ 6%) were analysed as well as a more efficient glazing with a SHGC of 27% together with internal blinds ($SHGC_{tot}$ 22%). In addition, all models in the study have a fixed horizontal shading of 15˚ (from the middle of the façade height) representing surrounding buildings and other shading objects.

Studied parameters of the building envelope:

- Wall U=0.1 W/m^2˚C
- Window U=1.1 W/m^2˚C
- Window U=0.9 W/m^2˚C
- Window U=0.7 W/m^2˚C
- Wall U=0.1 W/m^2˚C and Window U=0.9 W/m^2˚C
- Medium heavy construction
- Medium heavy with set-points 21-24˚C
- Heavy construction
- Heavy with set-points 21-24˚C
- Airtightness 0.6 ach (n_{50})
- Airtightness 0.3 l/sm^2 (q_{50})
- WWR 60%
- SHGC 27% and internal blinds ($SHGC_{tot}$ 22%)
- Intermediate blinds ($SHGC_{tot}$ 17%)
- External blinds ($SHGC_{tot}$ 6%)

Thermal bridges for the different constructions in the parametric study were calculated with HEAT2 version 6.0. HEAT2 is a two-dimensional heat transfer software provided by Blocon (BuildingPhysics 2011). For the base case, total thermal bridges are 445 W/˚C which corresponds to 21% of the total transmission losses through the envelope (UA-value). The calculated thermal bridges for other constructions in the parametric study are shown in Table 4.2. When constructions are improved and transmission losses are reduced, the total share from thermal bridges naturally increases if nothing is done to time improve also the thermal bridges.

Table 4.2 Total thermal bridges calculated with HEAT2

	Total thermal bridges (W/˚C)	Share of total UA-value
Base case	445	21%
External walls U=0.1	437	22%
Windows U=1.1	445	24%
Windows U=0.9	445	27%
Windows U=0.7	445	32%
WWR 60%	430	14%

HVAC strategies

This parametric study does not include the study of different heating and cooling supply or distribution systems. Thus, only the building's actual heating and cooling consumption was calculated and district heating and cooling with COP 1.0 was assumed. In the IDA ICE model, each zone is equipped with its own ideal heater (radiator) and ideal cooler (cooling beam). In addition, heating and cooling is distributed via heating and cooling coils in the central air handling unit. In order to compensate for distribution losses in pipes and ducts, the total performance of the heating and cooling system was reduced with 10% (COP 0.9) and the air-side efficiency of the heating and cooling coils in the air handling unit was reduced with another 10% (COP 0.9). A standard air handling unit with mechanical supply and return air and an air-to-air heat exchanger with effectiveness (eta) 70% was applied in the base case. Set-point for supply air temperature was 17˚C (after a temperature rise in the fans by 0.5˚C). The pressure rise in the fans was set to 600 Pa and electricity-to-air efficiency was set to 0.6 which gives a specific fan power (SFP) of 1.0 kW/m^3s^{-1} per fan and a total 2.0 kW/m^3s^{-1} for the whole system. Furthermore, the air handling unit was set to operate weekdays from 7:00 to 19:00 and otherwise shut off. The base case ventilation strategy was a constant air volume (CAV) system with a constant airflow during operating hours of 1.5 l/sm^2.

In the base case, control set-points for indoor air temperature were 22-23˚C during working hours, which is a realistic target value for a modern office building in Sweden. However, since a larger temperature range is allowed according to Swedish guidelines (Ekberg 2006), the impact of temperature set-points were studied in the parametric study. In one simulation, the mean air temperature was allowed to drop to 21˚C outside working hours and in another simulation, control set-points during office hours were changed to 21-24°C. IDA ICE controls the indoor thermal conditions with strict set-points for mean air temperature and unlimited heating and cooling supply. In order to make sure that also operative temperatures are acceptable, temperatures were controlled in the most exposed rooms during the warmest summer day and the coldest winter day. Summer comfort was checked in the corner room towards SW on the 5th floor on the warmest work day which happens to be the 24th of June. Winter comfort was checked for a room towards N on the ground floor the 31th of January. Some of these controls are displayed in the result section.

In the parametric study the heat exchanger's effectiveness was changed from 70% to 60%, 80% and 85%, where 60% represents a plate heat exchanger and 85% represents the best available rotating heat exchanger on the market. Furthermore, the air handling unit was studied with improved fan efficiencies of SFP 1.5 kW/m^3s^{-1}.

In the next simulation setup, a variable air volume (VAV) system with airflows of minimum 7 l/s and person, and maximum 100 l/s and person was studied. These airflows correspond to 0.8 and 6.7 l/sm^2 and the actual flow is controlled by both mean air temperature (22-23°C) and CO_2 level (maximum 800 ppm) even though it usually is the temperature requirement that determines the airflows rather than the CO_2 limit in office buildings (Jardeby, Soleimani-Mohseni et al. 2009). The supply air temperature set-points were changed in order to optimise the cooling and heating efficiency. Set-points were defined as a function of outdoor temperature with a linearly variety between 15.5-19.5°C from summer to winter. When the airflow is variable, rated SFP is customary set at an estimated rated flow corresponding to an average airflow during operation. However, this estimated rated airflow differs in different guidelines. In the Swedish Ventilation Industry's guideline (Backström 2003) and in the

SVEBY programme (SVEBY 2009), 65% of maximum airflow is recommended. According to BELOK's guideline (Organization for Commercial Building Owners) rated flow is 70% (BELOK 2011). In this simulation study, SFP was determined at 70% of maximum airflow.

Finally, the cooling potential with mechanical night ventilation was investigated. In order to make the most of the night ventilation concept, the building was designed with high internal thermal inertia and the night temperature set-point was lowered to 18°C. The night flush ventilation was activated when the following conditions were all fulfilled:

- Cooling season (May - September)
- Sunday - Thursday night, between 22:00 and 07:00
- Outdoor temperature warmer than 12°C
- Outdoor air at least 2°C colder than return air
- Return air warmer than 20°C

Night ventilation was simulated with both variable and constant flow rates. For night ventilation in combination with VAV, the same air handling unit as mentioned above in the VAV study was used with airflows varying between 0.8-6.7 l/sm^2. For night ventilation in combination with CAV, a constant night flush of 4 ach was studied. 4 ach is considered by many researchers as the minimum airflow for achieving a good cooling effect with night ventilation. The daytime airflow was still kept constant at 1.5 l/sm^2 though, as in the base case. A two-speed motor was assumed in the fans, with a rated flow of 4 ach (3.6 l/sm^2) and a reduced flow of 1.5 l/sm^2. SFP was determined at the rated flow of 4 ach which make the fan electricity during normal day operation much lower than the base case. Hence, in order make the comparison reasonable, both night ventilation simulations were compared to similar models without night flush.

Studied parameters of the HVAC systems:

- 21˚C (nights and weekends)
- 21-24˚C (day and night)
- eta 60%
- eta 80%
- eta 85%
- SFP 1.5 kW/m^3s^{-1}
- VAV 0.8-6.7 l/sm^2
- Night ventilation with VAV 0.8-6.7 l/sm^2
- Night ventilation with CAV (4 ach)

User related electricity and internal gains

In the simulations, office hours were defined as weekdays 8:00-18:00 with one hour lunch break. No summer vacation or other holidays were considered. The degree of automatic schedule smoothing was set to ± 1h in IDA ICE, which means that people were assumed arriving between 7:00-9:00 and leaving between 17:00-19:00 (see Figure 4.X). The occupancy factor was set to 70% (SVEBY 2010). For a building with individual office room, this assumption might be a source of error. In reality, there are of course not 70% persons in each room, rather 7 out of 10 rooms are occupied which means that some rooms can be heated and some rooms cooled at the same time and this was not regarded in the simulation study. Meeting rooms were presumed occupied 4h per day while other spaces were presumed not occupied. The office workers were assumed having an activity level of 1 met (reading, seated) with an emission of 108 W per person in sensible and latent heat. The amount of clothing was assumed 0.85 ± 0.25 clo (ASHRAE????). User related electricity was in this study defined as office lighting and office equipment in terms of computers, printers and copy machines, projectors, chargers, adjustable desks, office kitchens, servers and more. The frequency of both lighting and equipment was in the base case set to 70% during office hours and to 15% otherwise due to standby losses and power left on by mistake (SVEBY 2010). Additionally facility energy included pumps (8.9 kWh/m^{2}yr), elevators (11 MWh/yr) and entrance heaters (4 MWh/yr) but these were not studied further (Energimyndigheten 2007; SVEBY 2010).

Figure 4.X Occupant schedule

The power input for office equipment in the base case and in the parametric study (see "best practice") is presented in Table 4.3. Each office room was equipped with a computer, a charger and an adjustable desk (electric). In the "best practice" simulation, the stationary PC was exchanged for a laptop computer with an efficient LCD screen. The power to each office room was also completely shut off outside office hours, resulting in no "off mode" power.

Table 4.3 Power input for office equipment for base case and best practice. Numbers from SVEBY (2010) and EnergyStar (2012).

Tenant equipment	On (W)		Off mode (W)		Per area
	Base case	Best practice	Base case	Best practice	
Computer	125	50	5	0	Office room
Charger	10	5	1	0	Office room
Adjustable desk	4	0,5	4	0	Office room
Copy/printer	560		8.5	2.5	Floor
Fax	4	0	4	0	Floor
Projector	375	213	30	0.4	Meeting room
Pentry (20W/person)	1020		30		Floor
Server (150 kWh/person)	0,9		0,9		1 m^2
Engine warmers 1.5 kWh/m^{2}yr					

The base case installed power for lighting was set to10 W/m^2 in office rooms and 6 W/m^2 in other spaces which are realistic design values today (SVEBY 2010). In IDA ICE, all installed power is converted to heat (Johnsson 2011). Fluorescent tubes were assumed and the luminous efficacy was set to 60 lm/W. The lighting control was manual on/off switch by the door, reflecting the occupant schedule. In the parametric study, the lighting concept was improved with daylight control (photo electric dimming) with a minimum required light intensity of 500 lux at the desk (Dubois and Flodberg 2012). The installed power was reduced to 8 W/m^2 in office rooms and 4 W/m^2 in other spaces, which can be considered best practise today (BELOK 2011). However, standby losses of 2 W per room and ballast losses of 15% during office hours were added for the dimming system. Furthermore, the electric lighting was shut off completely during night, without standby losses.

Studied parameters of the lighting and office equipment design:

- Improved equipment (55 W/room)
- Improved equipment and lighting (LPD 8 and 4 W/m^2, daylight control)

Best case

The most effective design features in the parametric study were combined as a best case solution and simulated in order to obtain the maximum energy saving potential with existing and cost effective technique.

Design features in best case simulation (based on the results of the parametric study):

- Wall U=0.1 W/m^2°C
- Window U=0.9 W/m^2°C
- Airtightness 0.3 l/sm^2
- External blinds ($SHGC_{tot}$ 6%)
- Temperature set-points 21-24˚C
- Heat exchanger eta 80%
- SFP 1.5 kW/m^3s^{-1}
- VAV 0.8-6.7 l/sm^2
- Improved equipment (55 W/room)
- Improved lighting (LPD 8 / 4 W/m^2, daylight control)

Sensitivity analysis

In a final sensitivity analysis, the reference building was studied regarding aspects which are not likely to be able to influence when designing a building, such as the actual building site and climate and the user related operation of the building. The impact of building shape and interior planning was also analysed.

There are three different climate zones in the Swedish building code. Stockholm (base case) is situated in the north part of the south zone (zone III). Other big Swedish cities simulated in the sensitivity analysis were Malmö in the south part of the south zone (zone III), Karlstad in the middle zone (zone II), Östersund in the south part of the north zone (zone I) and finally Kiruna in the north part of the north zone (see Figure 4.X). Frankfurt am Main in Germany was also studied as a reference. Frankfurt is close to Darmstadt where the International Passive House Institute originated. Climate data is presented in Table 4.4.

Figure 4.X Climate zones in BBR. (www.rockwool.se)

Table 4.4 Location and climate. Climate files in IDA ICE

Location	**Latitude / Longitude**	**Temperature Dry-bulb mean ˚C**	**Temperature Dry-bulb min /max ˚C**
Kiruna	67.82N / 20.33E	-1.1	-30.2 / 21.0
Östersund	63.18N / 14.50E	3.1	-25.8 / 23.2
Karlstad	59.37N / 13.47E	5.9	-20.6 / 25.1
Stockholm	59.35N / 17.95E	6.5	-18.3 / 26.1
Malmö	55.55N / 13.37E	8.3	-13.9 / 25.0
Frankfurt	50.05N / 8.60E	10.1	-11.0 / 30.3

The impact of occupancy attendance was investigated since this parameter is difficult to predict, and since it affects both heating, cooling and electricity. The base case occupancy rate was set to an average 70% during office hours which is recommended in the SVEBY programme. However, a study by Maripuu (2009) argues that 70% might be too high since different monitoring studies have shown that the actual occupancy attendance is closer to 50% or even 40%. Two simulations were performed, one with a low occupancy factor (50%) and one with the highest possible occupancy factor (100%) as reference. The occupancy rate influences both the number of people and the power for computers and lighting in the simulation model.

The impact of building shape and interior planning was analysed at last. Interior planning is often is optional an can be changed with time. A square model with open landscape offices and an atrium was simulated. The building measures and interior zones were obtained from the Kaggen office in Malmö (see figure 4.X and 4.x and Table 4.X). Kaggen is a six storey building approximately 48 m x 37 m with the atrium at the south facade. The atrium is not used for natural ventilation, solely for daylight distribution. The room height is 3.4 m and the floor height is 3.7 m Otherwise, same input as in the reference building were used in the base case model, and the same design features were studied in a parametric study.

Figure 4.X South and East façades of Kaggen in Malmö (photo: Rafael Palomo).

Figure 4.X Kaggen interior, 2nd floor (visualization: Metro Arkitekter)

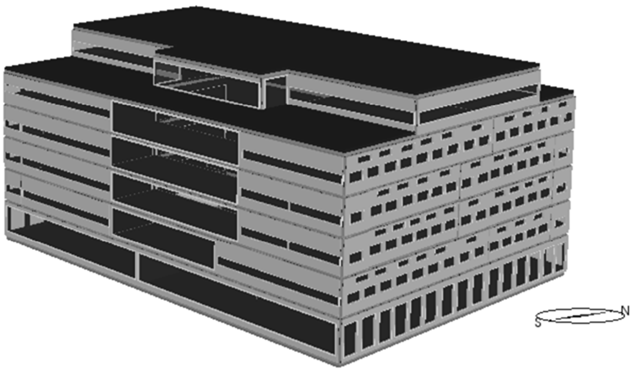


Figure 4.X IDA ICE model of Kaggen.

Table 4.X Kaggen building data

Dimensions	Heated floor area (A_{temp})	9 083 m^2
	Air volume	34 911 m^3
	Envelope surface	7 092 m^2
	Surface-to-volume ratio	0.20^{-1}
	Façade surface	3 539 m^2
	Window-to-wall ratio (WWR)	43% (GWR 38%)
	Window-to-floor ratio (WFR)	17%
	Occupant space	20 m^2/person (incl. ground floor) 13 m^2/person (office space only)

4.2 Results

This section presents the results from the base case simulation, the parametric study, the best case simulation and the sensitivity analysis. Results are displayed as annual delivered energy for heating, domestic hot water, cooling, fan electricity, additional facility electricity as well as tenant's electricity for lighting and office equipment. Results from the parametric study are presented as total heating, cooling and electricity deviation from the base case.

4.2.1 Base case

The total delivered energy for the base case is 139 kWh/m^2yr including user related electricity for lighting and equipment (see Figure 4.X). Excluding the user related energy, the specific end-use energy is 92 kWh/m^2yr. This is below the requirement in BBR 18 of 100 kWh/m^2yr plus addition for large airflows (Boverket 2011a). Hence, the base case achieves the regulation with a small margin, just as anticipated. The most dominating posts are heating energy (48 kWh/m^2yr) and user related electricity for lighting and equipment (48 kWh/m^2yr). Even though internal heat gains from lights and equipment are quite large, and the cooling set-point is strict (23°C), it is clear that the heating load dominates at this high latitude. The heating demand is mainly covered by zone heating (radiators) and the contribution from the heating coils in air handling unit is small.

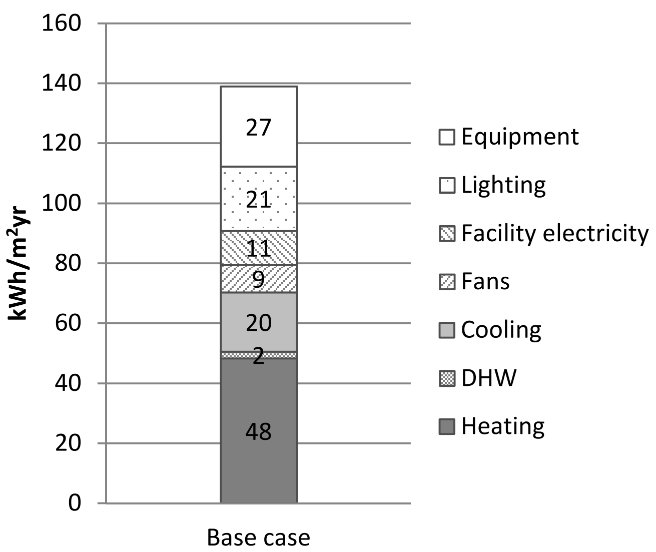


Figure 4.X Total end-use energy for the base case.

Thermal conditions the warmest and the coldest days are displayed in Figure 4.X. In summer, the operative temperature deviates at most 1.3°C from the set-point temperature and in winter, the operative temperature hardly deviates at all from the set-point temperature during working hours.

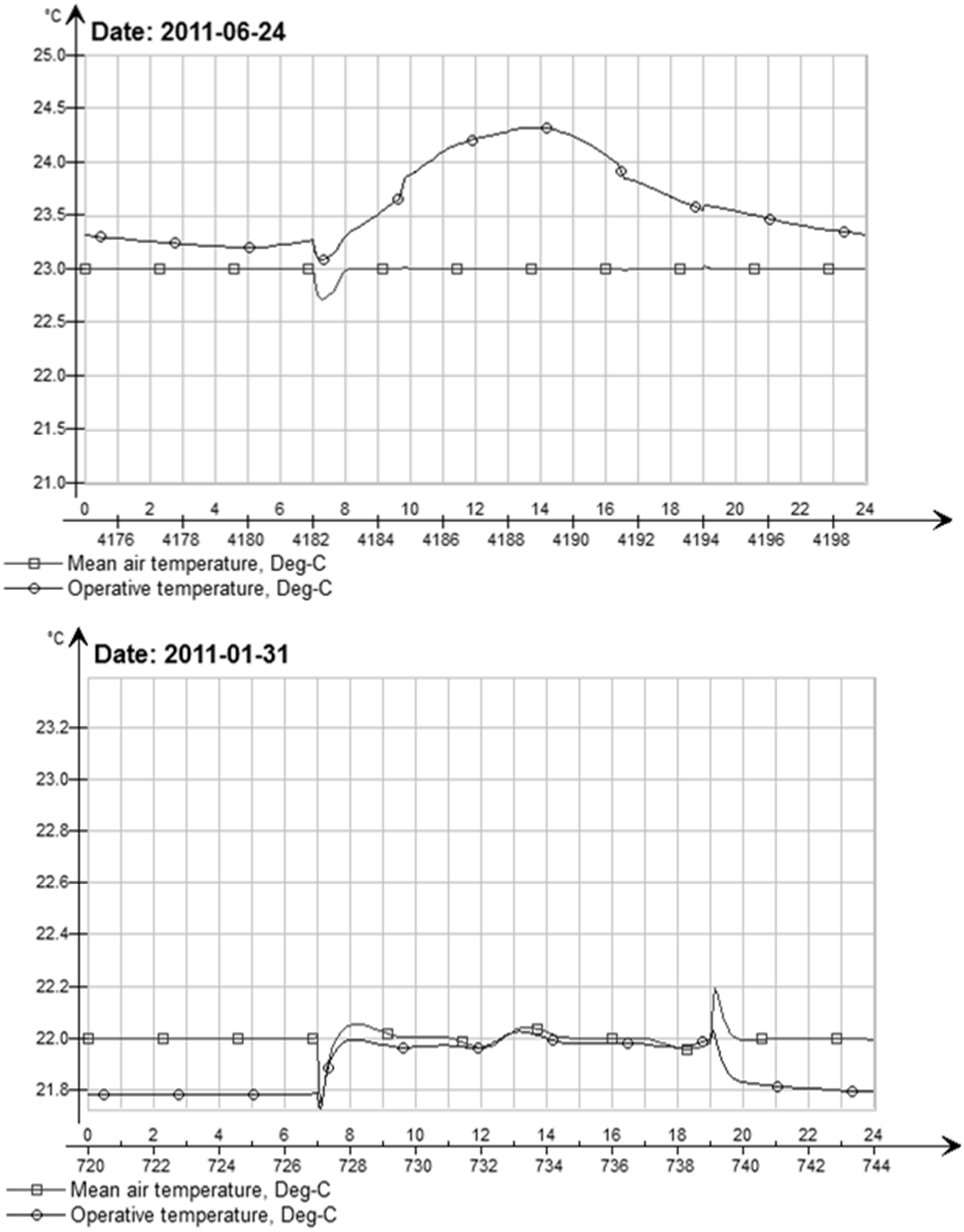


Figure 4.X Indoor air temperatures and operative temperatures for the base case. Above: the warmest room the warmest day. Below: the coldest room the coldest day.

4.2.2 Building envelope design

In the first parametric setup, the building envelope was studied. Thermal mass, insulation levels, airtightness, window-to-wall ratio, orientation and solar shades were varied. The results are presented in Figure 4.X and Figure 4.X. It can be added that the design features only affected the zone heating and zone cooling, the energy for the air handling unit was not affected.

The results in Figure 4.X show that thermal mass and thermal inertia have rather small impact on heating and cooling demand and that the saving potential for a heavy construction can save 2.5 kWh/m^{2}yr compared to the base case. A larger range in indoor air temperature actually decreases the impact of thermal mass. Regarding insulation levels and U-values, it is more effective choosing passive house windows (U=0.9) than passive house walls (U=0.1), despite the rather modest window-to-wall ratio. The result depends on the base case starting points which provided an improvement of 0.5 W/m^2°C for the windows (from 1.4 to 0.9) and only 0.1 W/m^2°C for the wall elements (from 0.2 to 0.1). The negative aspect with improved U-values is the increased cooling demand, but this is compensated by the even larger decrease in heating demand. With a combination of passive house windows and passive house walls, the total energy saving potential is 11 kWh/m^{2}yr compared to the base case. Finally, an improved airtightness turns out to have a large impact on the building's heating demand. The result is not surprising since the base case has a particularly leaky building envelope (1.5 ach or 1.6 l/sm^2 envelope area at 50 Pa). According to the simulations, the Swedish passive house criterion for airtightness is sharper than the international criterion, at least for the shape of the reference building.

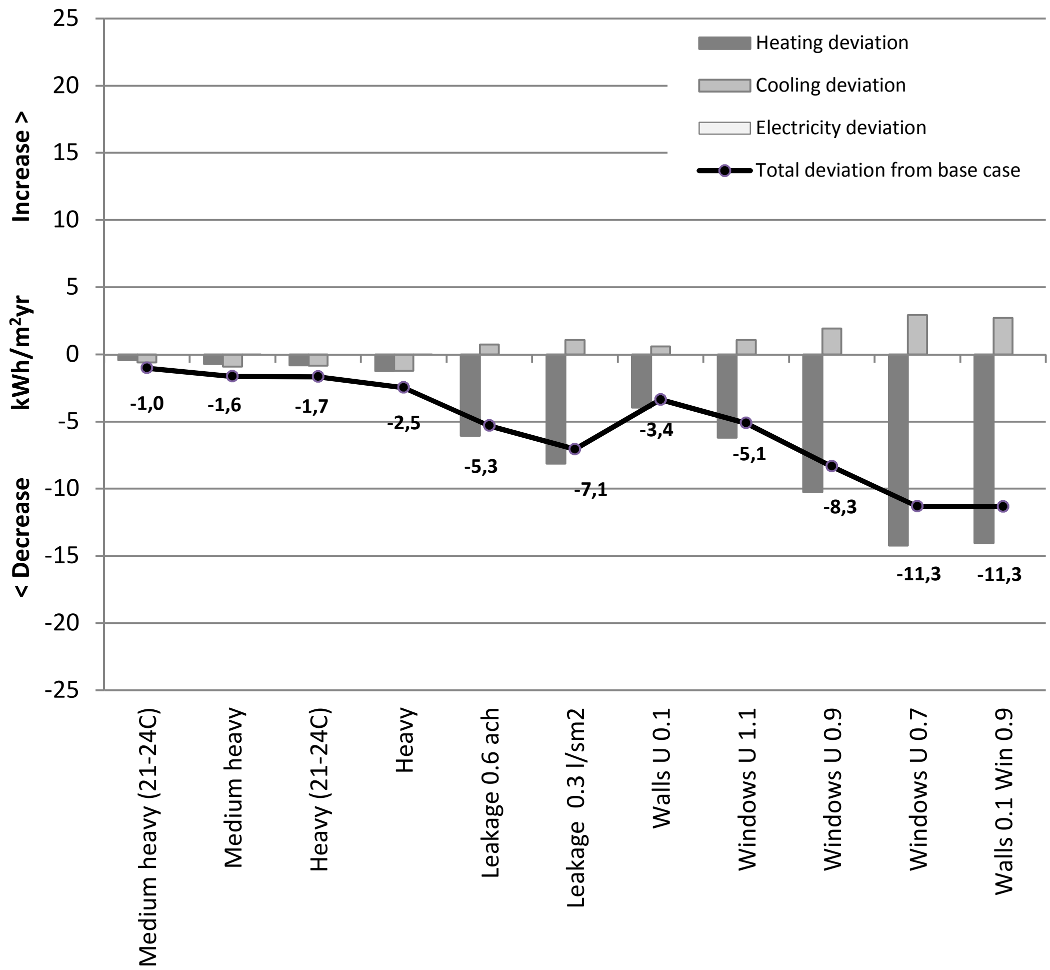


Figure 4.X Impact of insulation, thermal inertia and airtightness on end-use energy for total heating, cooling and electricity.

Figure 4.X shows the impact of a larger window area and different solar shading systems. The presented result indicates that a larger WWR has an indisputably negative effect on energy saving, both for the heating and cooling demand. In total, an extra 25 kWh/m^{2}yr is needed for this case with WWR 60% compared to the base case with WWR 35%. The building orientation, on the other hand, does not affect the energy consumption. Regarding solar shadings, cooling energy is saved when the blinds are moved further out in the façade as expected. However, the heating energy increases at the same time and the difference in total energy demand between the external and the intermediate blinds is small. The case with improved glazing (SHGC 27%) and internal blinds has the least saving potential since it increases the heating demand during winter when blinds are not used.

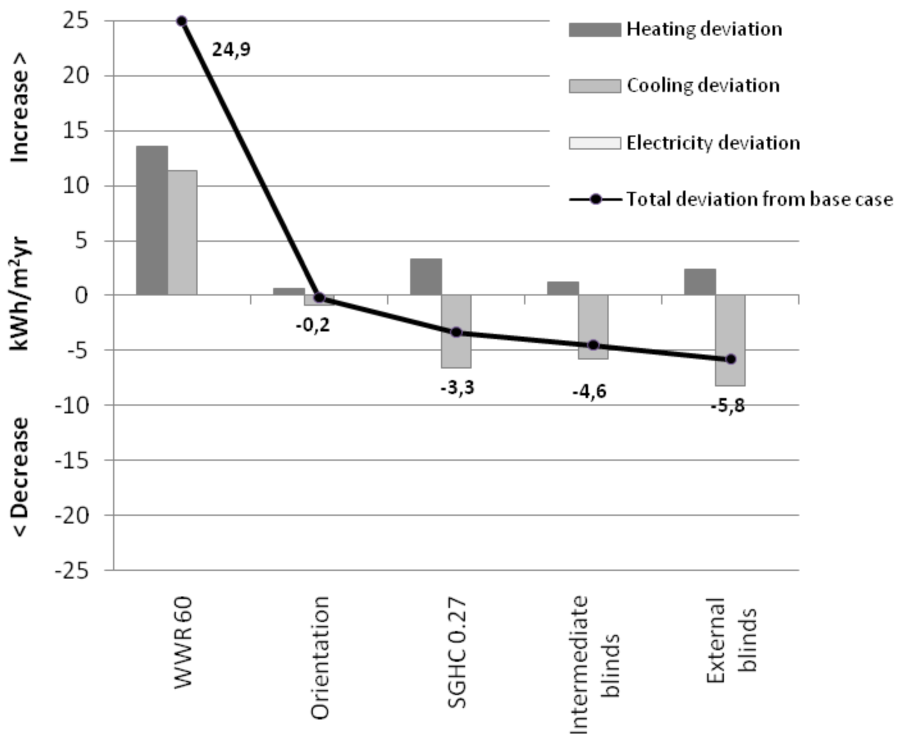


Figure 5. Impact of window area and solar shading systems on delivered energy for heating and cooling.

4.2.3 HVAC strategies

Figure 4.X. 4.X and 4.X show the results from the study of temperature set-points, heat exchangers, fan power and ventilation strategies. The energy-saving potential when allowing a larger temperature range is far from negligible (see Figure 4.X). According to this study, up to 7 kWh/m^{2}yr heating energy and 5 kWh/m^{2}yr cooling energy can be saved by accepting 1˚C colder in winter and 1˚C warmer in summer.

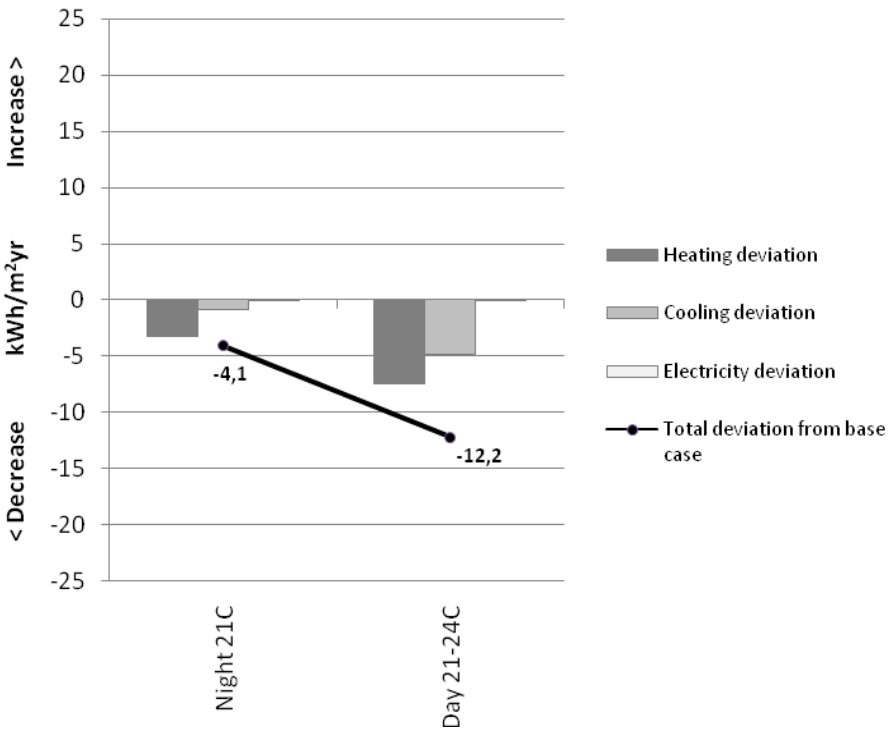


Figure 4.X. Impact of indoor temperature on delivered energy for heating and cooling.

Figure 4.X shows the results for different air handling units and strategies. The impact of the heat exchanger efficiency (compared to base case, eta 70%) is larger when the eta is reduced with 10% than when it is improved with 10%. Another 5% improvement makes no difference at all. A total saving potential of 3 kWh/m^{2}yr is possible (mainly in the heating coil in the air handling unit). The specific fan power (SFP) was also improved in the parametric study. The base case fan efficiencies with an SFP of 2.0 kW/ m^{3}s^{-1} for both fans were improved to 1.5 kW/m^{3}s^{-1}. However, this only decreased the electric energy with 2 kWh/m^{2}yr. The greatest saving potential according to the parametric study occurs when changing the CAV system into a VAV system with airflows depending on indoor temperatures and CO_2 levels. For the reference building, a total of 21 kWh/m^{2}yr can be saved which is 15% of the total energy demand. The airflows per hour are shown in Figure 4.X and 4.X. The average airflow over the year is actually the same, 3200 l/s, for both strategies but the demand controlled ventilation distributes the airflow in a more efficient way, saving both zone heating and zone cooling energy. The fact that fan electricity is saved for the VAV system even though the average airflow is the same, indicates that 70% rated flow might be too high.

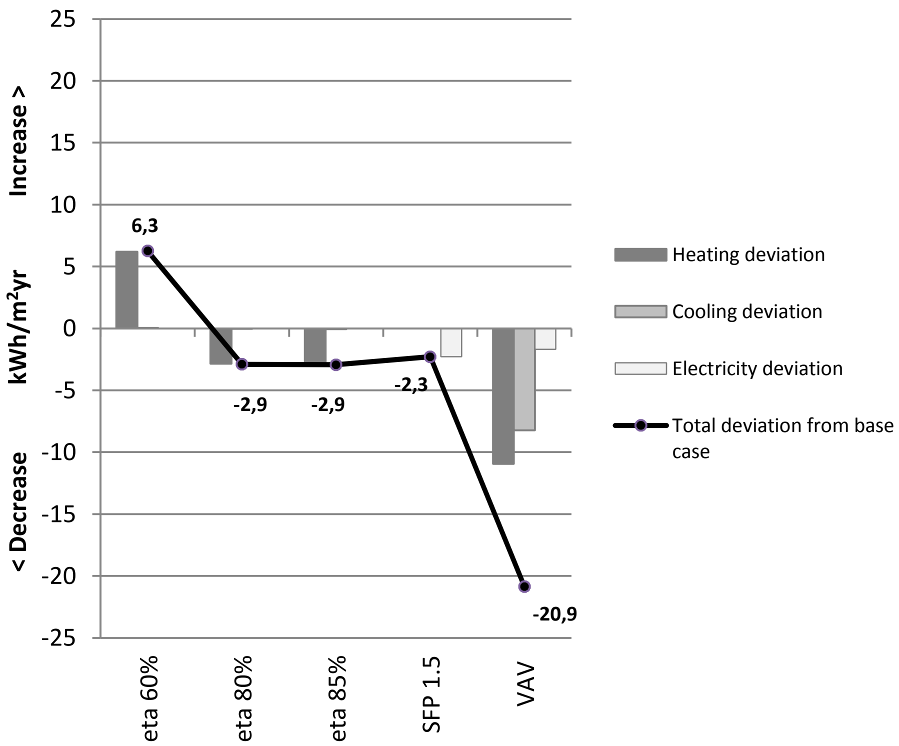
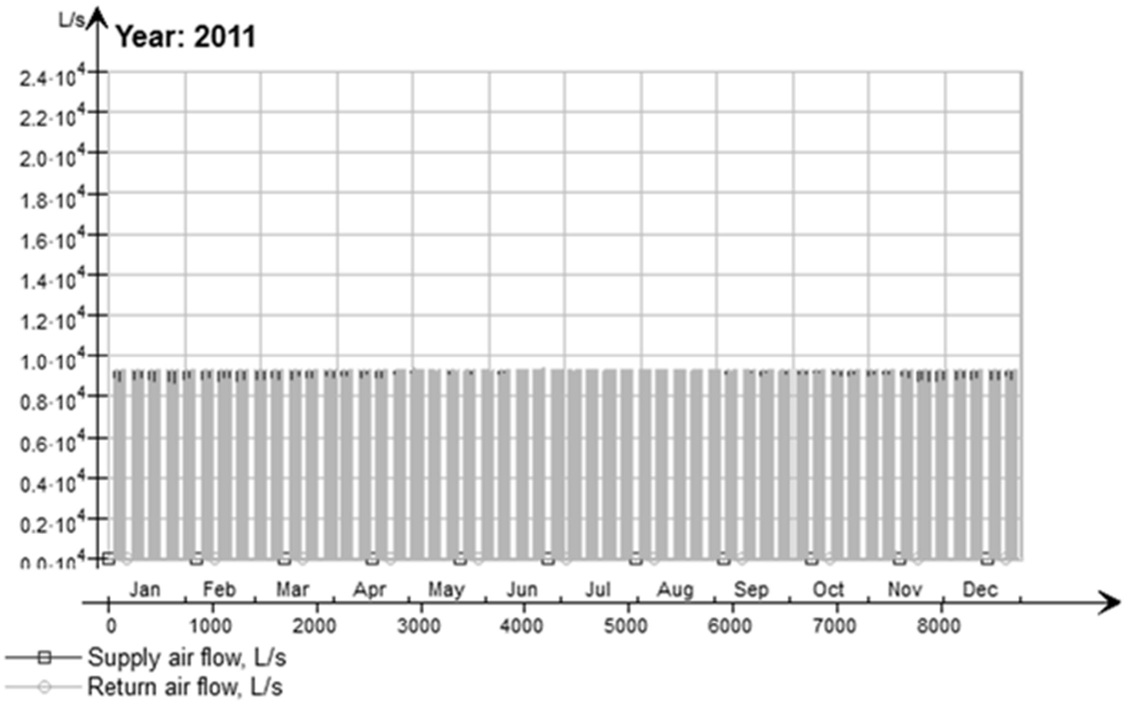


Figure 4.X Impact of air handling equipment on delivered energy for heating, cooling and electricity.



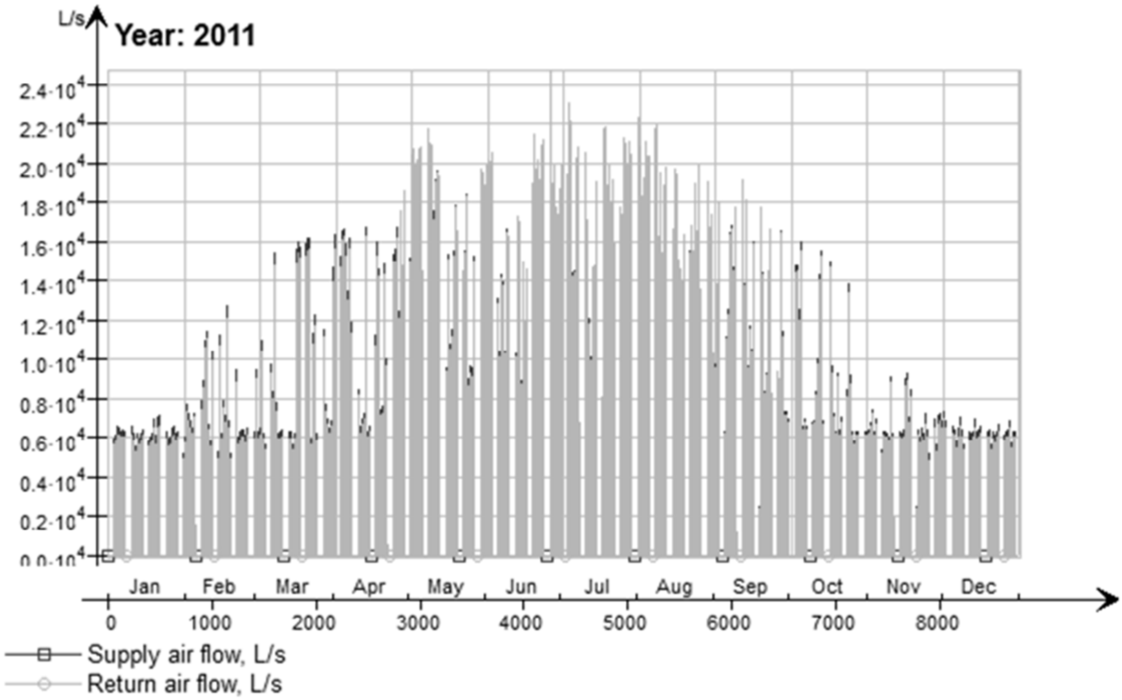


Figure 4.X Annual airflow per hour for CAV and VAV.

Figure 4.X shows the potential cooling effect from mechanical night ventilation with variable respectively constant airflows during night. For the VAV case, the energy saving potential is negligible (< 2 kWh/m^{2}yr) compared to a similar model without night ventilation. For the CAV case with a constant night flow of 4 ach, the savings in cooling energy does not weigh up to the extra energy gains for fans and radiators. The total increase compared to a similar model without night ventilation is almost 5 kWh/m^{2}yr.

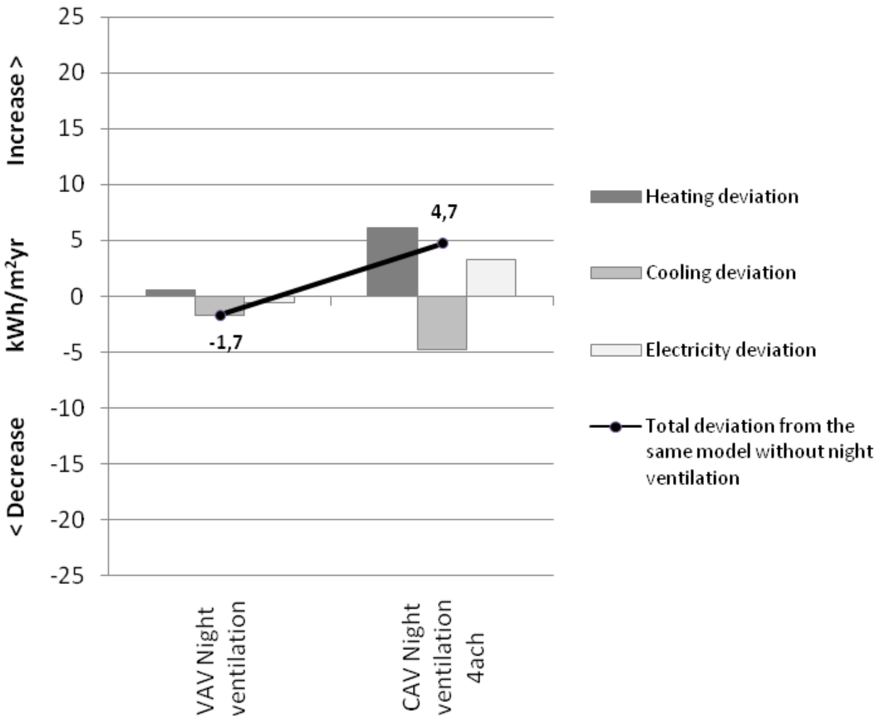


Figure 8. Impact of night ventilation on delivered energy for heating, cooling and electricity.

In a closer study of the night ventilation results, it is revealed that the improvement in thermal comfort is negligible for the two night ventilation concepts. Figure 4.X shows the operative temperatures during the warmest day for the VAV system with and without night ventilation. Note that set-point temperatures are 21-24˚C in these simulations. The operative temperature peaks at 14.00 in both cases and is only a few tenths of a degree cooler for the case with night ventilation.

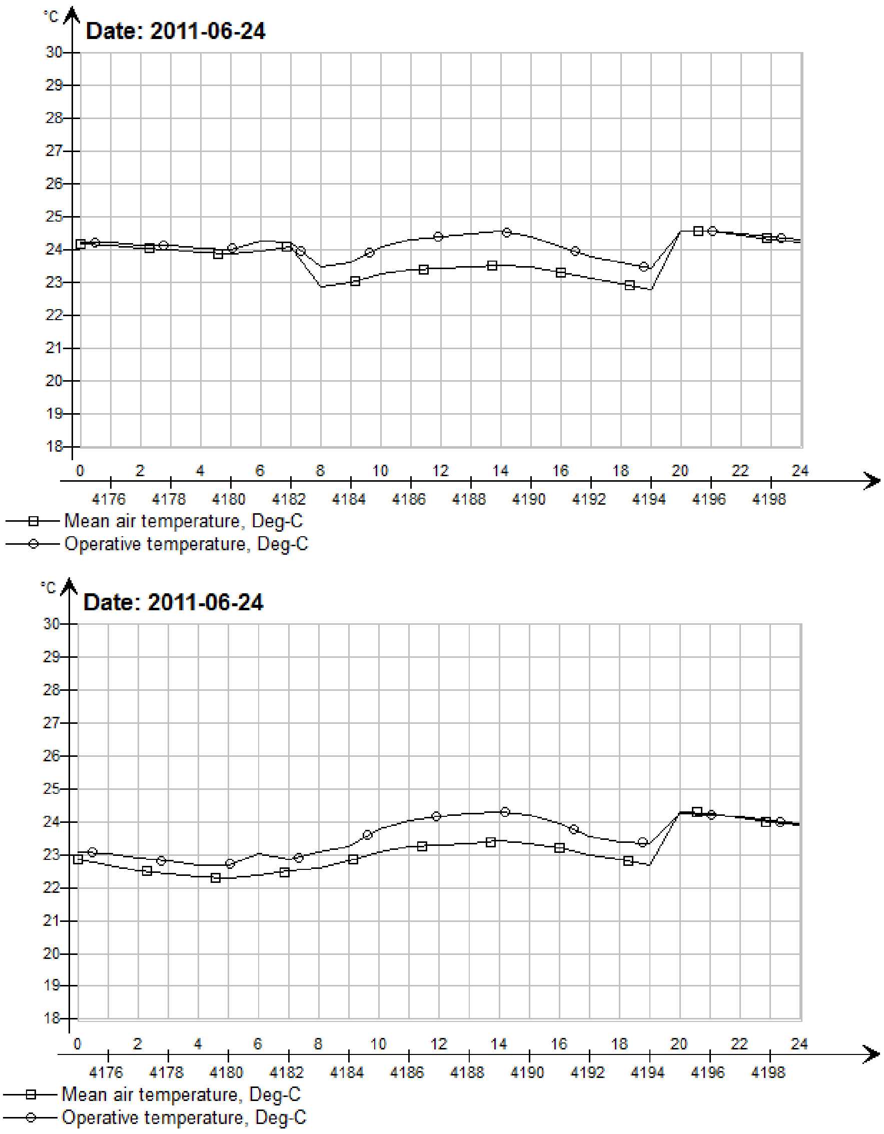


Figure 4.X Indoor temperatures and operative temperatures for the warmest room during the warmest day (a Friday). Above: VAV without night ventilation, Below: VAV with night ventilation.

Figure 4.X shows the operative temperatures during the warmest day for the CAV system with and without night ventilation. Note that set-point temperatures are 21-24˚C in these simulations. Just as for the VAV system, the operative temperature peaks at 14.00 in both cases and is only a few tenths of a degree cooler for the case with night ventilation.

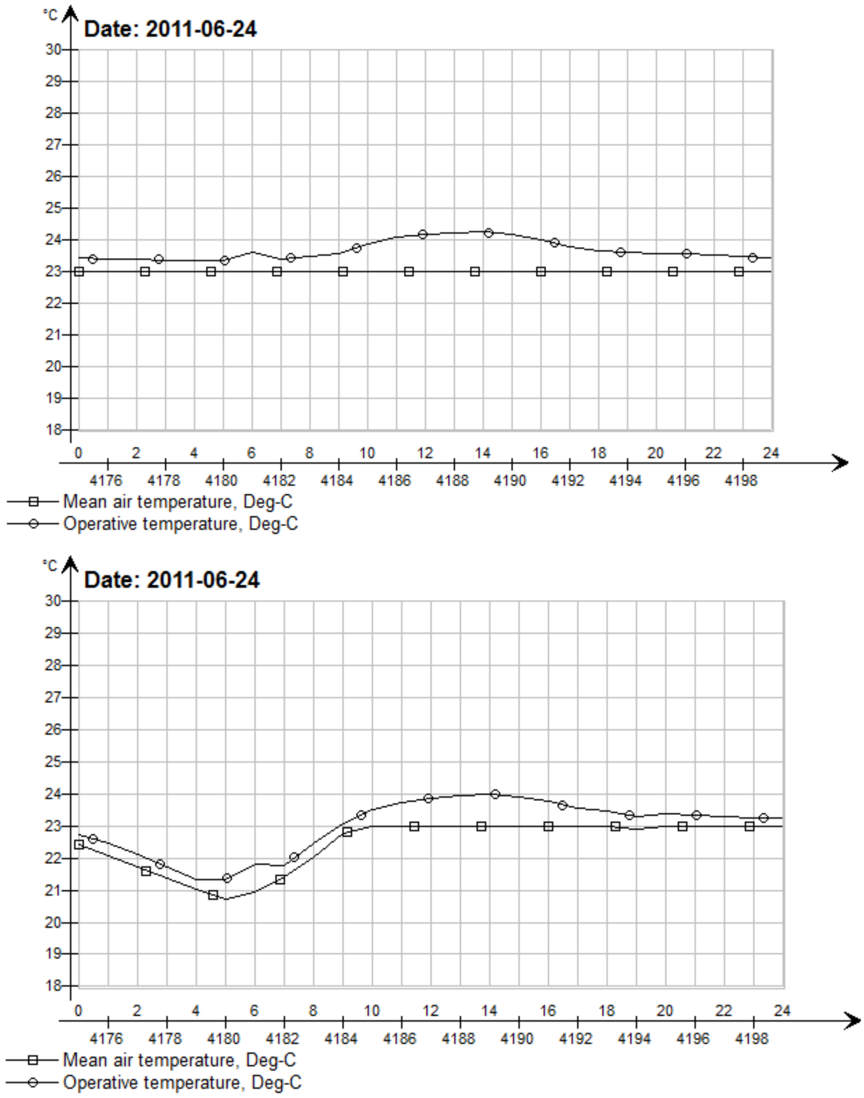


Figure 4.X Indoor temperatures and operative temperatures for the warmest room during the warmest day (a Friday). Above: CAV without night ventilation.. Below: CAV with night ventilation.

Figure 4.X presents the airflows the warmest week for the VAV case (above) and the CAV case (below). For the VAV case, the night time airflows are smaller than the day time airflows. The day time airflows are actually smaller than the airflows in the similar model without night ventilation. This explains why the fan electricity is not increased when having night ventilation. For the CAV case, the night time air flows are more than twice the size of the day time airflows.

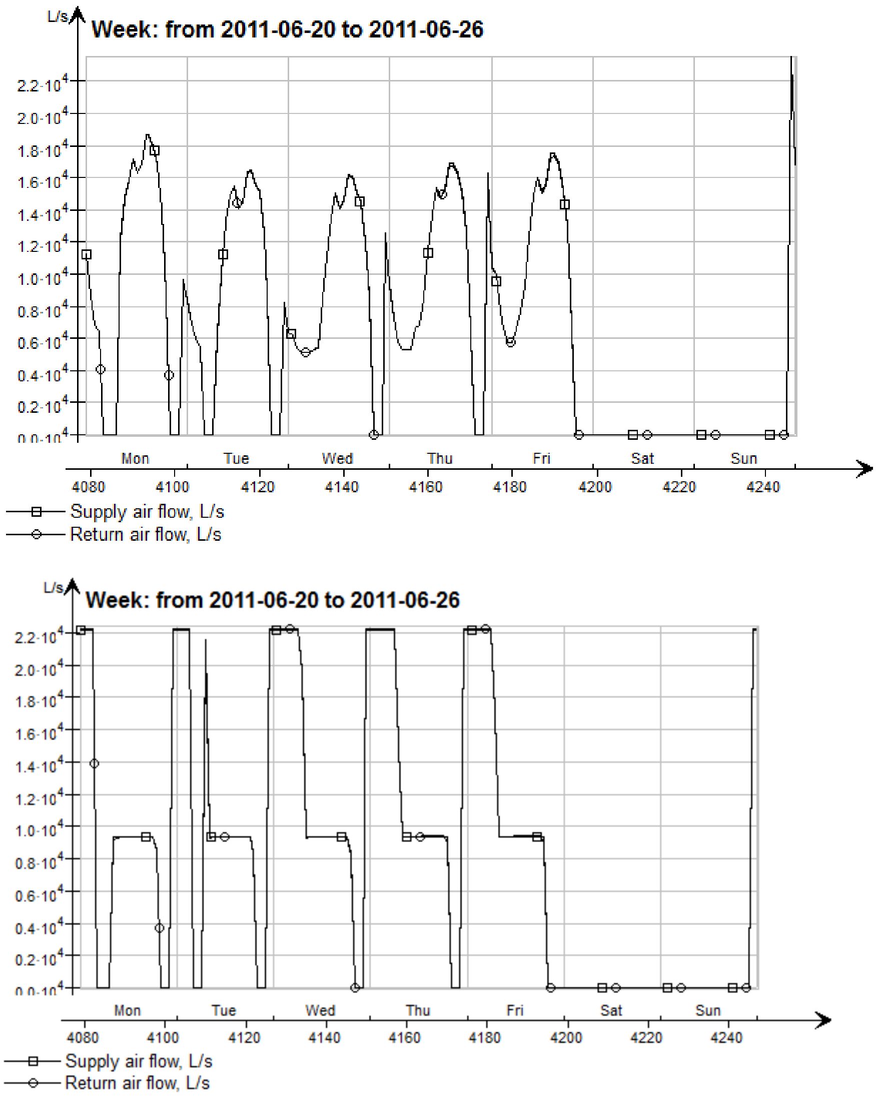


Figure 4.X Night time and day time airflows during the warmest week. Above: VAV system. Below: CAV system.

4.2.4 Lighting and electric equipment

Figure 4.X presents the results from the parametric study when using more efficient office equipment and lighting, with reduced installed powers and improved control. Compared to the base case, approximately 10 kWh/m^{2}yr of electric energy is saved when improving the office equipment and another 10 kWh/m^{2}yr is saved when improving the lighting system. Meanwhile, the cooling energy decreases and the heating energy increases due to reduced internal heat gains. The total energy saving potential, compared to the base case, is 12 kWh/m^{2}yr when both office equipment and lighting is improved.

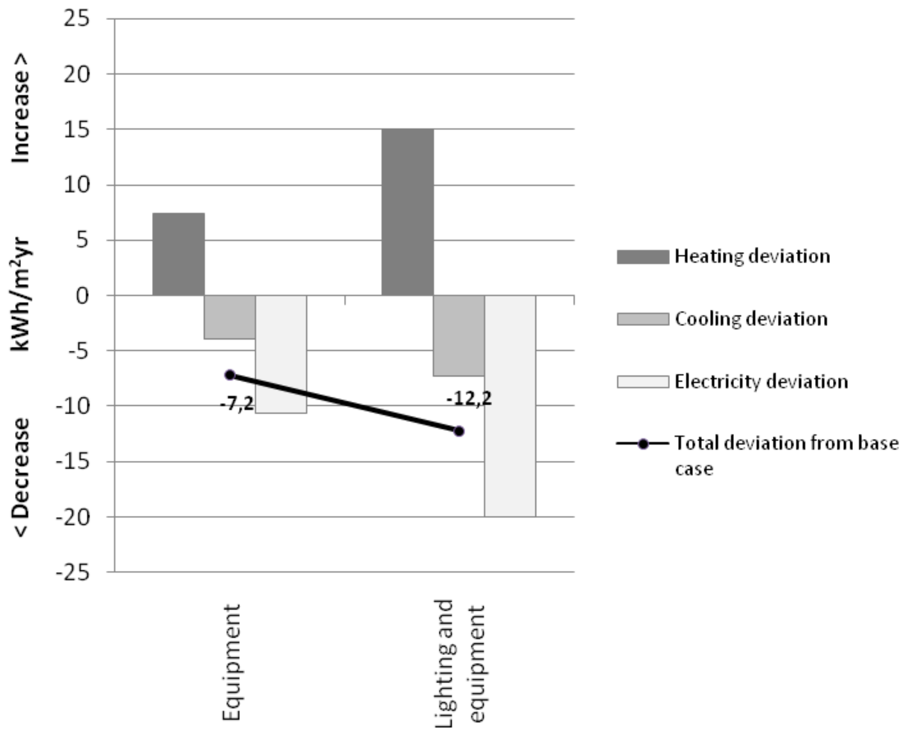


Figure 9. Impact of equipment and lighting on delivered energy for heating, cooling and electricity.

4.2.5 The best case scenario

Figure 4.X presents the most efficient design features from the parametric study, combined into a "best case" with the intension to reach a low-energy solution. The best case solution shows a great improvement in especially heating and electricity. The space heating energy is reduced with 25 kWh/m^{2}yr (36% heating energy saved and 18% total energy saved) and the total electricity is reduced with 26 kWh/m^{2}yr (54% electricity saved and 19% total energy saved). The reduction in cooling energy is 15 kWh/m^{2}yr (77% cooling energy saved and 11% total energy saved). The total saving potential is 66 kWh/m^{2}yr (49%). This total energy use can probably be further reduced if an effort is made to reduce remaining facility electricity, in particular energy for pumps which in this study was set to almost 9 kWh/m^{2}yr.

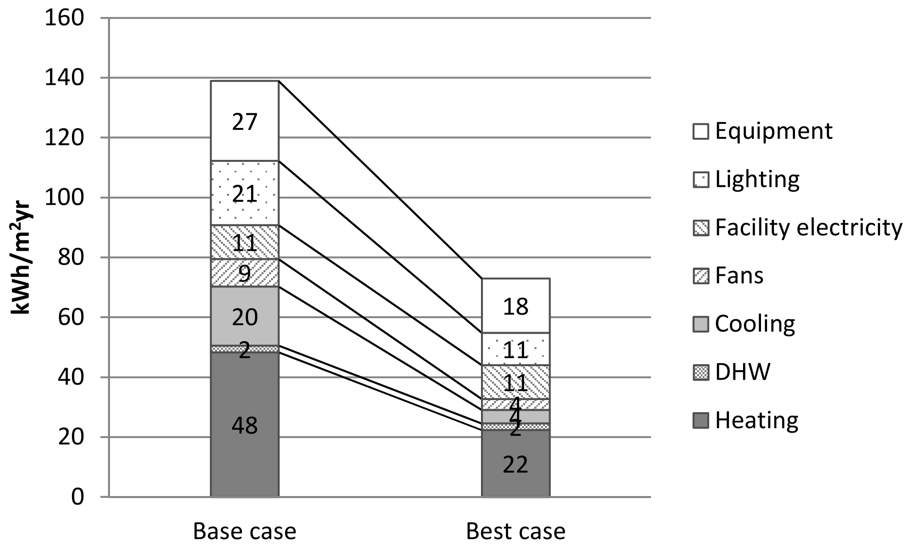
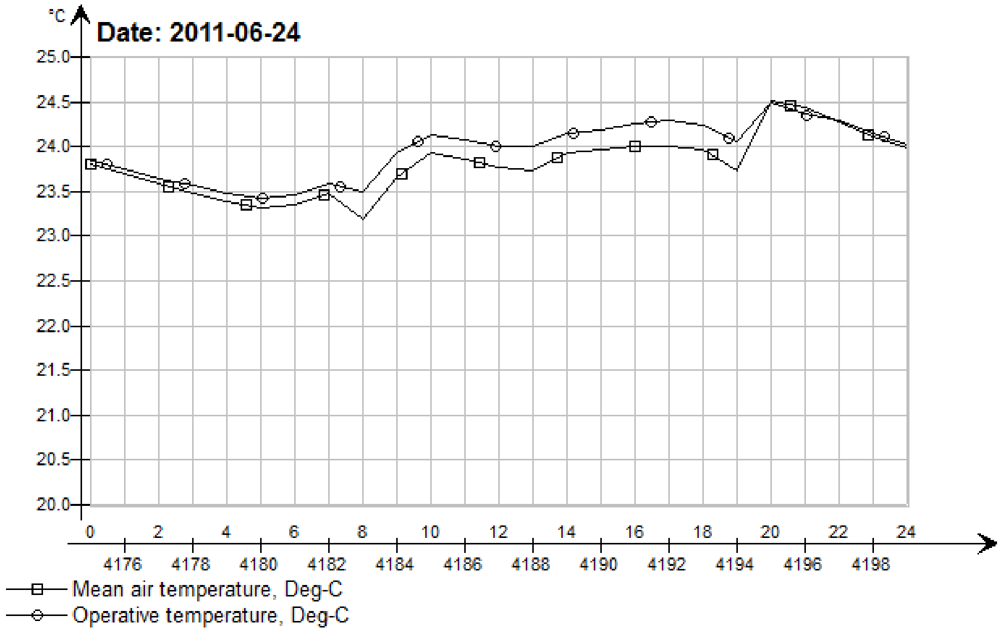


Figure 4.X Energy saving potential for the best case solution.

Thermal conditions the warmest and the coldest days are displayed in Figure 4.X. Even though indoor air temperature is allowed to range between 21-24˚C, the operative temperature stays between 20.5˚C and 24.5˚C during office hours. The maximum operative temperature does not even exceed the peak in the base case (see Figure 4.X). However, the room is constantly warm during the entire working day.



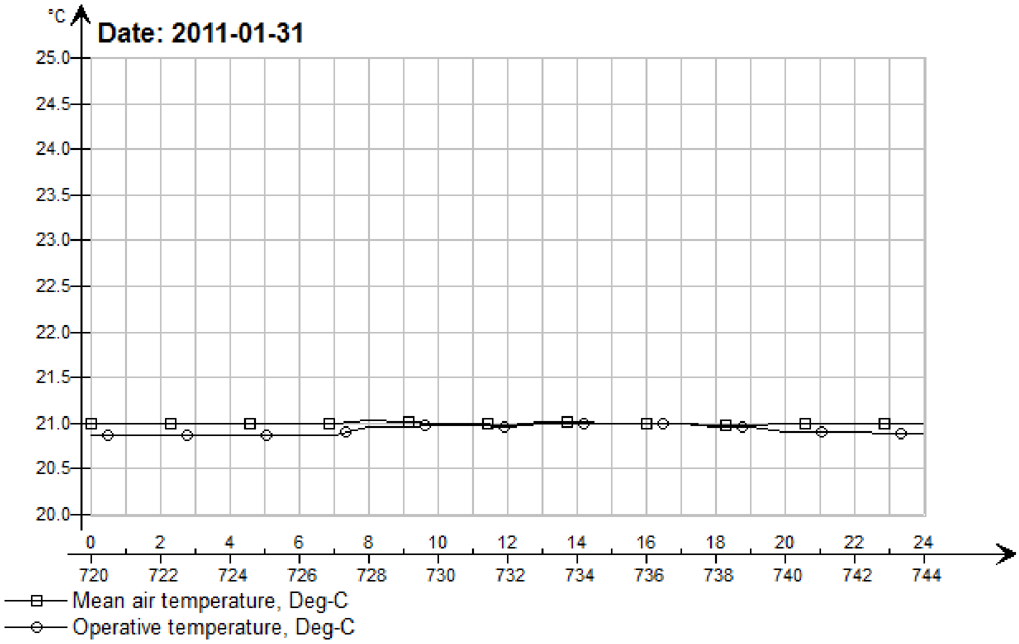


Figure 4.X Indoor air temperatures and operative temperatures for the best case. Above: the warmest room the warmest day. Below: the coldest room the coldest day.

4.2.6 Sensitivity analysis

This section presents the results from the sensitivity analysis concerning the impact of climate, occupant attendance and building shape and interior planning.

Figure 4.X illustrates the climate's impact on heating and cooling energy from room units and the air handling unit. The difference in delivered energy between the coldest (Kiruna) and the warmest city (Frankfurt) is 39 kWh/m^{2}yr. Placed in Kiruna, the reference building requires 58 kWh/m^{2}yr more delivered heating energy than in Frankfurt, but placed in Frankfurt it requires 18 kWh/m^{2}yr more cooling energy on the other hand. One interesting result, regarding the Swedish building code, is the fact that the difference between Stockholm and Karlstad only is 3 kWh/m^{2}yr. Nevertheless, the cities represent different climate zones, and office buildings in Karlstad are allowed to use 20 kWh/m^{2}yr more energy than Stockholm (Boverket 2011a). Likewise, Kiruna and Östersund both represent the north climate zone, although the difference in total delivered energy is 24 kWh/m^{2}yr. Furthermore, which is not obvious in the graph, the ventilation cooling battery is hardly used in Kiruna (0.5 kWh/m^{2}yr) while the ventilation heating battery hardly is used in Frankfurt (1.3 kWh/m^{2}yr). This indicates that the supply air temperature of 17˚C can be met almost by free cooling and heating in the ambient air combined with the recovered air in the heat exchanger. This indicates the importance of considering the climate when designing efficient HVAC systems.

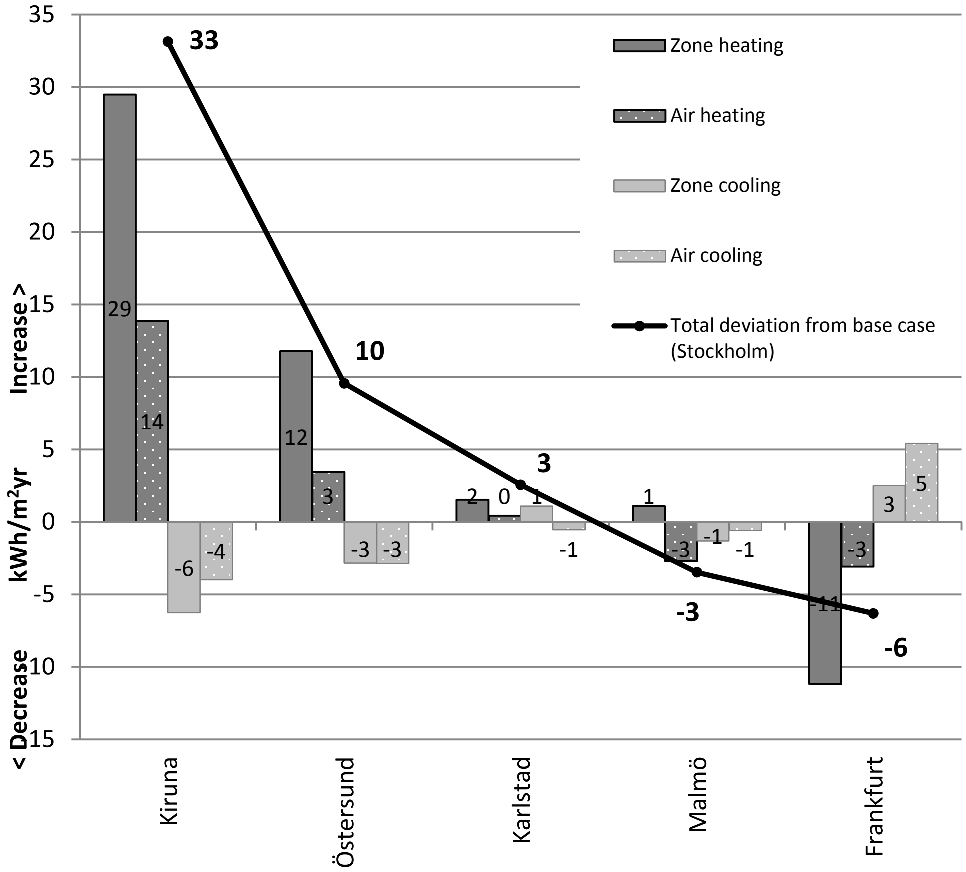


Figure 4.X Impact of climate on heating and cooling energy. Note that the axes have been changed

The presence of occupants varies over the day and over the year and is difficult to predict. Figure 4.X shows what happens with the energy use when the average occupancy rate is high and low compared to the base case (70%). The heating energy increases when the building is less occupied but meanwhile, the cooling energy decreases to some extent. As long as the equipment and the lights are turned off in un-occupied rooms, the electricity decreases as well and the total energy demand is reduced. The total end-use energy is reduced with 3 kWh/m^{2}yr

(3%) when the occupancy rate is reduced from 70% to 50%. Hence, if the normal occupancy rate is as low as 50% this only has a positive effect on the delivered energy. It is not very space-efficient though. The positive effect might be smaller in landscape office buildings since the lighting is fully on even though the occupancy rate is 50%.

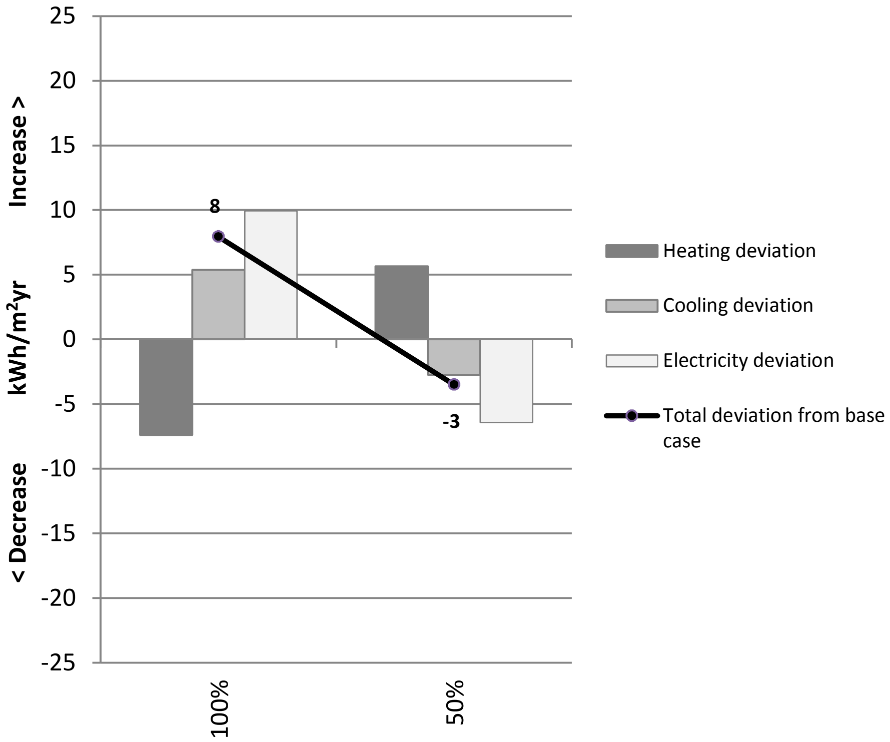


Figure 4.X Impact of occupancy rate on delivered energy.

The total end-use energy for the Kaggen building, with an open landscape design, compared to the reference building with individual rooms is presented in Figure 4.X. The result indicates that impact of building shape and interior planning is negligible. However, the two buildings are not strictly comparable since the floor heights and window-to-wall ratios are different. Kaggen yields a little bit more heating and less cooling energy. The specific energy for lighting is a little bit larger since Kaggen has much office space and hardly any corridors with reduced installed lighting power.

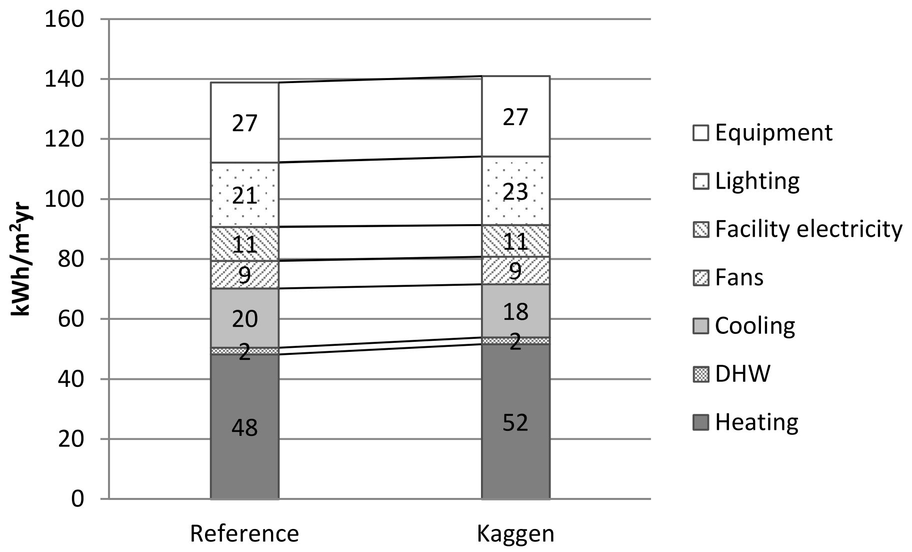


Figure 4.X Total end-use energy for Kaggen and the reference building. Base case input.

Instead, it is more interesting to compare the impact of the different design features in the parametric study (see Figure 4.X). The figure shows the total deviation (%) from the base case simulation for each parameter for the two building types. The impact of thermal mass, heat exchanger efficiency, specific fan power, insulation levels, solar control and electric equipment is basically the same for the two building types. The impact of VAV system is smaller for Kaggen compared to base case but the negative impact of mechanical night ventilation and the impact of occupancy rate are larger. The most significant differences between the two building types are the effects of changing window-to-wall ratio and airtightness. Kaggen can actually benefit from more windows and save energy. The saving potential for improving the airtightness is also greater for Kaggen compared to the reference building.

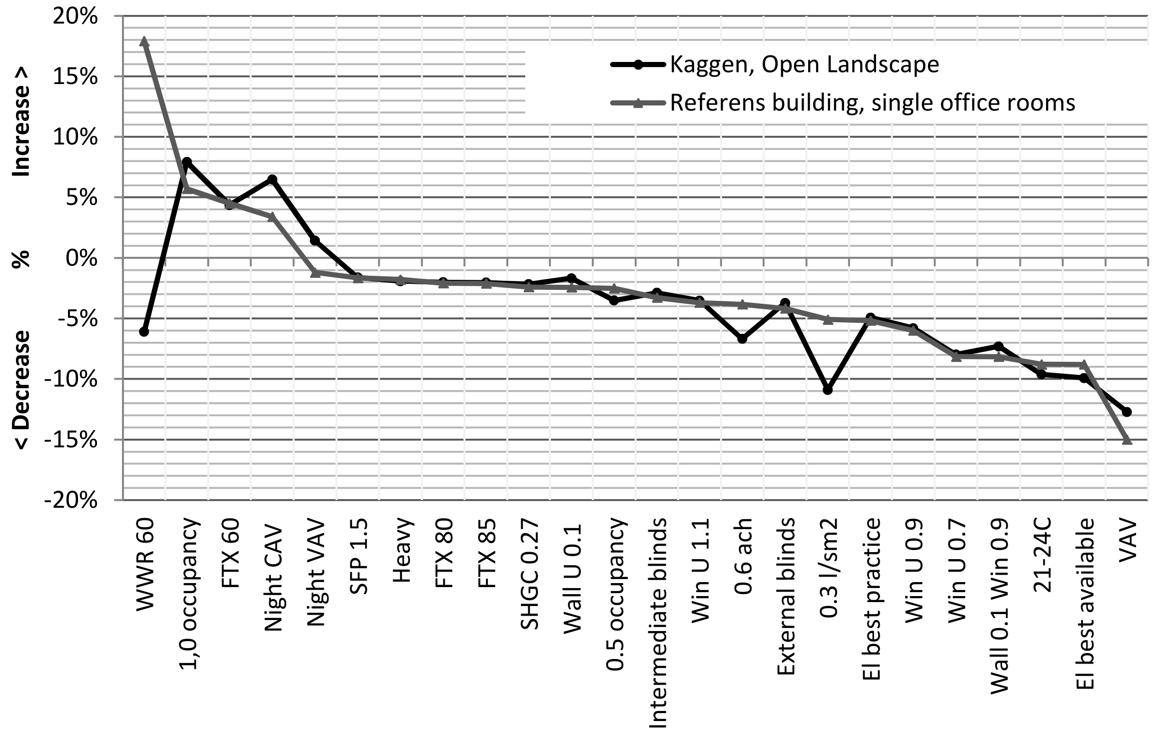


Figure X. Results from parametric study, comparsion of impact from parameters between the reference building and the open landscape building. Deviation from total base case energy use (%). el best available equipment and lighting

4.3 Discussion

Dynamic simulations were carried out with IDA ICE 4 on a typical narrow office building with peripheral individual office rooms in Sweden. As expected, air-tightness, insulation and solar shades are important design features in order to decrease heating and cooling loads. However, the most crucial design features turned out to be glazing sizes relative to the facade and ventilation strategy. The least crucial features turned out to be building orientation, thermal inertia and cooling with mechanical night ventilation. The most important results from the parametric study are discussed in the following text.

An increase in glazing-to-wall ratio, from 31% to 54%, has indisputable great negative effect on the building's energy demand. Heating increases with 14 kWh/ m²yr (28%) and cooling with 11 kWh/m²yr (57%) compared to the base case. Beside the additional energy demand, large glazing amounts increase the risk of glare. According to a recent daylight study on a similar building, the optimal glazing-to-wall ratio in Sweden is 20-40%, with the lower value preferable on the south façade where the risk of glare is higher (Dubois and Flodberg 2012). Furthermore, the study shows that increasing the glazing-to-wall ratio to more than 40% has a negligible effect on available daylight inside the building, and no electric lighting will therefore be saved. Hence, the results presented in this article are supported by Dubois' study, and it can be concluded that the glazing amount shall be kept as small as possible in order to save energy and to avoid glare, but not less than 20% in order to secure enough daylight and view out. However, the sensitivity analysis revealed that the phenomena might be different in a deep building with open landscape design. Kaggen can benefit from increased solar gains thanks to open building and perfect mixture of air.

The study of solar control indicated that the further out in the façade the solar shades are placed, the more cooling energy can be saved but in return more heating energy will be needed. Therefore, climate and the amount of heating and cooling hours must be considered when selecting solar shading strategy. One possible but rather expensive solution is to have both internal and external solar shades in order to optimize the solar heat gains in different seasons. It could also be an alternative to improve the glazing performance and select a glass with low solar heat gain coefficient but not too low since there is a risk the solar heat gains will be reduced more than needed. Another risk with efficient glazing is if the visual transmittance and window view are degraded.

Regarding ventilation, the simulations showed that having demand-controlled ventilation with combined temperature and CO_2 control is the most energy efficient feature in terms of heating, cooling and fan electricity. Compared to the base case with constant airflow, a total 26 kWh/m²yr can be saved (heating 28%, cooling 42% and electricity 41%). This result is in line with recommendations from the Passive House Institute, which states that comfort and a good indoor air quality should be ensured and provided by using just the necessary air quantities. On the other hand, this simulation study showed that the efficiency of the heat exchanger in the air handling unit is not as important as expected. Improving the efficiency from 70% to 80% saves only 3 kWh/m² yr in heating energy and improving from 80% to 85%

efficiency saves no heat at all. This is most likely due to the way a normal office is operated: the ventilation operates during day while solar gains and internal heat gains from people, lights and equipment occur. The heating demand is therefore lowor non-existing while the ventilation is on and the heat exchanger will be bypassed. The recommendation based on this study is therefore to have a rotating heat exchanger and the required efficiency should be determined with a sensitivity analysis.

Other important findings deal with passive design features that are common in many German low-energy office buildings, such as high thermal inertia for heat storage or passive cooling with night ventilation which are not necessarily interesting for other countries. According to this parametric study, a mechanical night ventilation strategy actually has a rather small effect on energy savings. The cooling energy decreases with less than 2 kWh/m^{2}yr (8%) and the total energy saving is 2% compared to the base case. It would probably be more suitable to use the night ventilation strategy in combination with a natural ventilation strategy which does not use any fan electricity. However, a natural ventilation strategy demands a carefully planned building design, based on current conditions in the surroundings, and was therefore not investigated in this study. Furthermore, regarding the result from the thermal inertia study, a heavy building with concrete floors, concrete sandwich walls and various internal walls in concrete has a negligible impact on the heating and cooling loads. This result indicates that the cooling load, due to solar gains and internal heat gains, is not large enough in countries at high latitudes to take advantage of thermal inertia. Another explanation can be the strict temperature range used in Sweden, not allowing as big variations in the indoor air temperature as in Germany and hence activating heating and cooling systems too soon.

Modern Swedish office buildings often have a very strict indoor temperature target at about 22-23˚C during working hours. The energy-saving potential when allowing a larger temperature range, for example 21-24˚C, is far from negligible. According to this study, 7 kWh/m^{2}yr (14%) heating energy and 5 kWh/m^{2}yr (25%) cooling energy can be saved by accepting a larger range in indoor temperatures. To avoid complains and dissatisfaction, it is important to keep the operative temperature close to the mean air temperature by avoiding, for example, solar radiation impinging on the occupants. It could also be a good idea to inform the workers of the underlying reasons for temperature variations.

In a final best case simulation, the most effective design features were combined to see the lowest reachable energy use in the reference building. The simulation result is promising and shows that 49% energy can be saved compared to a new office building designed according to the current Swedish building code, which means that the initial goal of this project was reached. By improving walls and windows, reducing window-to-wall ratios, introducing demand-controlled ventilation and lighting, allowing a larger range in temperature, and by installing more efficient equipment which is completely turned off outside office hours, the heating, cooling and electricity can decrease significantly. One aim was to completely remove the cooling energy but this was not fully achieved. This goal might however be possible to achieve if, for example, the air handling system is combined with an earth-to-air heat exchanger for pre-cooling the ambient air during the cooling season, but this has not been evaluated. If other renewable energy sources, such as solar energy and wind power, also are added to this best case scenario, there is a chance that the yearly produced energy will exceed the yearly consumed energy and a net zero-energy building will be accomplished, but this must be further investigated.

5 Summary and conclusions

The state-of-the-art indicates that Germany, Austria and Switzerland might be ahead of Sweden when it comes to designing very low-energy office buildings. Improvements should be possible in Sweden when it comes to insulation levels, airtightness, solar shading devices together with heating, cooling, ventilation and lighting strategies. In Germany and nearby countries, a number of extraordinary solutions have been applied and tested. Some of these particular solutions could be tested in a Swedish office building as well, for instance earth-to-air heat exchangers, cooling with solar energy, hybrid ventilation and more sophisticated night ventilation concepts. One barrier in Sweden could have been the large size of the Swedish office buildings which may have prevented some of these more experimental techniques due to higher costs and risks.

Popular environmental classification systems seem to have a great impact on building design and energy performance. In the Nordic countries, where the GreenBuilding standard is rather common for office buildings, small improvements in design have been made just to fulfil the standard and meet the building code regulation with a 25% margin. The GreenBuildings in this region have more insulation, better airtightness, less glazing and more efficient heat recovery than other recent buildings, but apart from this and from demand controlled ventilation and lighting, the building techniques are the same as in regular buildings. In Germany and nearby countries, where the Passive House standard is often used, more experimental office buildings were designed in order to fulfil the rigorous standard. Some sort of new incentive could be necessary in Sweden in order to further develop the office buildings. In general, Sweden is also in need of well documented examples of low energy office buildings as demonstration projects, reliably performance-monitored and evaluated. Some of the Swedish examples in this study are promising but they have not been evaluated yet and they are not well documented.

The outdoor climate has less effect on heating and cooling demand than expected. Despite more significant cooling degree days in Germany and nearby countries, the purchased energy for cooling is almost negligible. This is possible due to more sophisticated cooling strategies, using free cooling from the ground and from the ambient air to a greater extent, but also because of a larger range of acceptable temperatures. The effect from the climate is more obvious when it comes to heating demand. The Finnish buildings have the largest heating demand even though the building envelopes are well insulated. These climate differences ought to be reflected either in building design or in heating and cooling demand but this is apparently not the case. Germany and nearby countries have a lower demand of *both* heating and cooling energy. One consequence might be seen in the use of free cooling, where the Nordic countries can benefit from cooling with ambient air while the Southern countries use the ground as a cooling source instead.

Another conclusion from the study is the indication that national building guidelines and traditions can affect and make it difficult to build low-energy buildings. In Sweden for instance, generally stricter requirements for indoor air quality, hygienic airflows, control temperatures and lighting intensity might result in more heating, cooling and facility energy than in countries with less demanding requirements.

Finally, the study shows no general consideration regarding the often high internal gains from office equipment and lighting. From experience, internal gains are seldom in focus in the design phase. When designing future very low-energy office buildings, internal gains will probably have a greater focus since the benefit is multi-dimensional. Beside a reduction in installed electric power for equipment and lighting, less cooling and ventilation energy will be needed to keep the indoor temperature at acceptable levels.

Dynamic simulations were carried out with IDA ICE 4 on a typical narrow office building with perimeter cell rooms in Sweden. The most effective design features were combined to see the lowest reachable energy use in the reference building. The simulation result is promising and shows that 48% energy can be saved compared to a new office building designed according to the current Swedish building code, which means that the initial goal of this project was reached. By improving walls and windows, reducing window-to-wall ratios, introducing demand-controlled ventilation and lighting, allowing a larger range in temperature, and by installing more efficient equipment which is completely turned off outside office hours, the heating, cooling and electricity can decrease significantly.

Both the parametric study on energy-efficient equipment and lighting as well as the sensitivity analysis on occupancy rate, indicate that it is crucial to decrease the user related electricity and thus the internal heat gains. A common perception in the building industry is that low-energy buildings suffer when the internal gains are lowered, but this does not apply on office buildings with an active cooling system. This is one of the reasons that tenants' electricity must be regulated in the building code in a soon future. Not only is the user related electricity diminished, but the cooling energy is also reduced and it will be easier to remain a stable operative temperature.

One aim with this study was to completely remove the cooling energy, but this was not fully achieved. This goal might however be possible to achieve if, for example, the air handling system is combined with an earth-to-air heat exchanger for pre-cooling the ambient air during the cooling season, but this has not been evaluated. If other renewable energy sources, such as solar energy and wind power, also are added to this best case scenario, there is a chance that the yearly produced energy will exceed the yearly consumed energy and a net zero-energy building will be accomplished, but this must be further investigated.

References

Artmann, N., H. Manz, et al. (2008). "Parameter study on performance of building cooling by night-time ventilation." Renewable Energy **33**: 2589-2598.

ASHRAE (????). ASHRAE Fundamentals.

Aste, N., A. Angelotti, et al. (2009). "The influence of the external walls thermal inertia on the energy performance of well insulated buildings." Energy and Buildings **41**(11): 1181-1187.

Backström, C. (2003). Kalkylera med LCCenergi: Riktlinjer för val av indata. Luftbehandlingssystem. V-skrift 2003:1. http://www.svenskventilation.se, Svensk Ventilation.

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

Barlow, S. and D. Fiala (2007). "Occupant comfort in UK office: How adaptive comfort theories might influence future low energy office refurbishment strategies." Energy and Buildings **39**: 837-846.

BELOK (2011). Energikrav för lokalbyggnader. Version 3. http://belok.se/docs/kravspec/Energikrav-11-09-06.pdf.

Berggren, B., H. Stenström, et al. (2011). A parametric study of the energy and moisture performance in passive house exterior walls. The 4th Nordic Passive House Conference. Helsinki, Finland.

Berglund, T. (2010). Visit Waterfront, 2010-09-08, Project Manager, Stockholm Waterfront.

Bine (2001). Projektinfo 8/01. http://www.bine.info/en/, Bine Informationsdienst.

Bine (2007). Thermo-active building systems: High-comfort, energy-efficient heating and cooling of non-residential buildings. http://www.bine.info/en/, Bine Informationsdienst.

Bine (2009a). Projektinfo 06/09. http://www.bine.info/en/, Bine Informationsdienst.

Bine (2009b). Projektinfo 16/09. http://www.bine.info/en/, Bine Informationsdienst.

BizEE. (2011). "Heating and Cooling Degree Days." Retrieved 2011-06-10 from http://www.degreedays.net/.

Blomsterberg, Å. (2009). Lufttäthet i kontorsbyggnader: mätningar och beräkningar. Malmö, WSP Environmental.

BOB. (2011). "Balanced Office Building." Retrieved 2012-03-04, from http://www.bob-x.de/.

Bollin, E., J. d. C. Fernandes, et al. (2008). Energie optimiertes Bauen, Teilkonzept 3: Langzeitmonitoring des Neubauvorhabens Solar Info Center Freiburg. Offenburg, Germany, Hochschule Offenburg - Institute of Applied Research.

Boverket. (2010). "Teknisk status i den svenska bebyggelsen - resultat från projektet BETSI."

Boverket (2011a). Boverkets byggregler, BBR 18. BFS 2011:6. BBR 18. B. författningssamling. Karlskrona.
Boverket (2011b). Regelsamling för byggande, BBR 2012. BFS 2011:6 med ändringar t.o.m. BFS 2011:26. Boverket. Karlskrona.
Braun, D., C. Filleux, et al. (2009). Die sonne als einzige energiequelle. www.baslerhofmann.ch.
Breesch, H., A. Bossaer, et al. (2005). "Passive cooling in low-energy office building." Solar Energy **79**: 682-696.
BuildingPhysics. (2011). "HEAT2." Retrieved 2011-12-29, from http://www.buildingphysics.com.
BuildUp. (2010). "GreenBuilding Partner WWFF - ENERGYbase." Retrieved 2011-02-23.
CEN (2000). EN 13829: Thermal performance of buildings - Determination of air
permeability of buildings - Fan pressurization method (ISO
9972:1996, modified), CEN.
CEN (2007). EN 15251: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics, CEN.
Depecker, P., C. Menezo, et al. (2001). "Design of buildings shape and energetic consumption." Building and Environment **36**(5): 627-635.
DGNB. (2012). "German Sustainable Building Council." Retrieved 2012-03-18, from http://dgnb.de/_en/index.php.
Di Perna, C., F. Stazi, et al. (2011). "Influence of the internal inertia of the building envelope on summertime comfort in buildings with high internal heat loads." Energy and Buildings **43**(1): 200-206.
Dodoo, A., L. Gustavsson, et al. (2012). "Effect of thermal mass on life cycle primary energy balances of a concrete- and a wood-frame building." Applied Energy **92**(0): 462-472.
Dubois, M.-C. and Å. Blomsterberg (2011). "Energy saving potential and strategies for electric lighting in future North European, low energy office buildings: A literature review." Energy and Buildings **43**(10): 2572-2582.
Dubois, M.-C. and J. Du (2012). Landscape offices at high latitude: Daylight autonomy and electric lighting savings in relation to key design features. Improving Energy Efficiency in Commercial Buildings Conference, IEECB'12. Frankfurt, Germany.
Dubois, M.-C. and K. Flodberg (2012). "Daylight utilisation in perimeter office rooms at high latitudes: Investigation by computer simulation." Lighting Research and Technology **0**: 1-24.
Eicker , U., M. Huber, et al. (2006). "Limits and potential of office building climatisation with ambient air." Energy and Buildings **38**: 574-581.
Eicker, U., P. Seeberger, et al. (2005). Evaluierung Passiv-Bürohaus Lamparter. Stuttgart, FH Stuttgart-HFT, Stuttgart University of applied sciences.
Ekberg, L. (2006). R1 - Riktlinjer för specifikation av inneklimatkrav. Kristianstad, VVS Tekniska föreningen.

En0B. (2011). "Research for energy-optimised construction." Retrieved 2011-02-15.
Enberg, H. (2009). Minimikrav på luftväxling. Lilla Edet, Håkan Enberg. **Utgåva 8**.
Energimyndigheten (2007). Förbättrad energistatistik för lokaler - "Stegvis STIL" Rapport för år 1, Swedish Energy Agency.
Energon. (2011). "Energon Ulm." Retrieved 2012-03-04, from http://www.energon-ulm.de/.
ENERGYbase. (2009). "Office complex of the future." Retrieved 2009-10-21.
EnergyStar. (2012). "Find Energy Star Products." Retrieved 2012-03-25, from http://www.energystar.gov.
EQUA. (2012). "Equa Solutions." Retrieved 2012-03-20, from http://www.equa-solutions.co.uk.
Europa. (2012). "Summaries of EU legislation: Strategy on climate change for 2020 and beyond." Retrieved 2012-04-01, from http://europa.eu/legislation_summaries/environment/tackling_climate_change/l28188_en.htm.
European_Parliament (2010). "DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings (recast)." Official Journal of the European Union **53 (2010)**.
FEBY (2009). FEBY Kravspecifikation för Passivhus.
Filleux, C. (2009). 09-09-22 fachbeitrag GHC. Å. Blomsterberg.
Geving, S. and J. Holme (2010). Increased insulation thickness and moisture. 3rd Nordic Passive House Conference. Aalborg, Denmark.
Goethals, K., H. Breesch, et al. (2011). "Sensitivity analysis of predicted night cooling performance to internal convective heat transfer modelling." Energy and Buildings **43**: 2429-2441.
Google. (2011). "Google Maps." Retrieved 2011-04-13, from http://maps.google.se/.
Gratia, E., I. Bruyère, et al. (2004). "How to use ventilation to cool narrow office building " Building and Environment **39**: 1158-1170.
Gratia, E. and A. De Herde (2003). "Design low energy office buildings." Energy and Buildings **35**: 473-491.
Greenbuilding. (2011). "Best practise example." Retrieved 2011-02-24.
Grini, C., H.-M. Mathisen, et al. (2009). LECO - Energibruk i fem kontorbygg i Norge: Befaring og rapportering, SINTEF Byggforsk, Prosjektrapport 48.
Gräslund, J. (2010). Information about Hagaporten, Technical Director, Skanska.
Haase, M., K. Buvik, et al. (2010). Project report no 56 - Guidelines for energy efficiency concepts in office buildings in Norway. Oslo, SINTEF Building and Infrastructure.
Haugland, L. and K. Haugstad (2010). Information about Stavanger BP, NCC Property Development.

Haves, P., P. F. Linden, et al. (2007). "Use simulation in the design of a large, naturally ventilated office building." Building Services Engineering Research and Technology **28**: 223-235.
Henze, G. P., C. Felsmann, et al. (2008). "Primary energy and comfort performance of ventilation assisted thermo-active building systems in continental climates." Energy and Buildings **40**(2): 99-111.
Hernandez, P. and P. Kenny (2010). "From net energy to zero energy buildings: Defining life cycle zero energy buildings (LC-ZEB)." Energy and Buildings **42**(6): 815-821.
Herneheim, B. (2011). Design values Jungmannen 3, Project leader, Ramböll.
Hummelgaard, J., P. Juhl, et al. (2007). "Indoor air quality and occupant satisfaction in five mechanically and four naturally ventilated open-plan office buildings." Building and Environment **42**: 4051-4058.
Humphreys, M. A. and M. Hancock (2007). "Do people like to feel 'neutral'?: Exploring the variation of the desired thermal sensation on the ASHRAE scale." Energy and Buildings **39**(7): 867-874.
Høseggen, R., H. M. Mathisen, et al. (2009). "The effect of suspended ceilings on energy performance and thermal comfort." Energy and Buildings **41**(2): 234-245.
Jaboyedoff, P., C.-A. Roulet, et al. (2004). "Energy in air-handling units: results of the AIRLESS European Project." Energy and Buildings **36**: 391-399.
Jagemar, L. and D. Olsson (2004). Användarprofiler för hyresgästel i kontorsbyggnader - mätningar från tre moderna kontorshus, CIT Energy Management AB.
Jansson, U. (2010). Passive houses in Sweden: From design to evaluation of four demonstration projects Doctoral Thesis, Lund University, EBD-T--10/12.
Jardeby, Å., M. Soleimani-Mohseni, et al. (2009). Distribution av kyla och värme i bostäder och lokaler, SP Rapport 2009:31.
Jensen, F. S. (2011). Information about Skejby CH, NCC Property Development.
Johansson, P., A. Nylander, et al. (2007). "Primary energy use for heating in the Swedish building sector—Current trends and proposed target." Energy Policy **35**(2): 1386-1404.
Johnsson, H. (2011). IDA ICE Support. Email conversation 2011-05-06.
Kalamees, T. (2008). "IDA ICE: the simulation tool for making the whole building energy and HAM analysis." MOIST-ENG **Annex 41**: 1-6.
Kalema, T., G. Jóhannesson, et al. (2008). "Accuracy of Energy Analysis of Buildings: A Comparsion of a Monthly Energy Balance Method and Simulation Methods in Calculating the Energy Consumption and the Effect of Thermal Mass." Journal of Building Physics **32**(2).
Kalz, D. E., S. Herkel, et al. (2009). "The impact of auxiliary energy on the efficiency of the heating and cooling system: Monitoring of low-energy buildings." Energy and Buildings **41**(10): 1019-1030.
Kiessler, K., J. Stockinger, et al. (2005). SOL4 Business and training center Eichkogel. http://www.sol4.info/English-Presentation.pdf, SOL4 Info.

Kolokotroni, M. and A. Aronis (1999). "Cooling-energy reduction in air-conditioned offices by using night ventilation." Applied Energy **63**: 241-253.
Kornadt, O. and K. Wallasch (2008). Building Assessment Report for Office and Seminar Building SOL4 in Mödling, Austria. http://www.lensebuildings.com/downloads/projects/11_AT_KO_LEnSE_Building_Report.pdf, LEnSE Test Pilots.
Källman, O., P. Hindersson, et al. (2004). Effektivare distribution av fjärrkyla, Svensk Fjärrvärme FOU 2004:11.
Ladekjaer, B. (2011). Information about Kolding CH, NCC Property Development.
Larsson, L. (2010). Information about Kungsbrohuset HVAC, P O Andersson Konstruktionsbyrå.
Leroux, M. (2010). Information about review search terms and electronic data bases.
Leslie, R., R. Raghavan, et al. (2005). "The potential of simplified concepts for daylight harvesting." Lighting Research and Technology **37**(1): 21-40.
Levin, P. (2010). Energieffektiva byggnader - Kretsloppsrådets översikt, CERBOF.
Ljuskultur (2010). Ljus & rum Planeringsguide för belysning inomhus. Stockholm, Ljuskultur.
Maripuu, M.-L. (2009). Demand controlled ventilation (DCV) systems in commercial buildings: functional requirements on systems and components. Dissertation Thesis, Chalmers University of Technology, Göteborg.
Marszal, A. J., P. Heiselberg, et al. (2011). "Zero Energy Building – A review of definitions and calculation methodologies." Energy and Buildings **43**(4): 971-979.
MINERGIE (2010). The MINERGIE - Standard for buildings: Information for architects. Bern.
Morgan, S. and M. Krarti (2007). "Impact of electricity rate structures on energy cost savings of pre-cooling controls for office buildings." Building and Environment **42**(8): 2810-2818.
NCC. (2011a). "Commercial Space." Retrieved 2012-03-04, from http://www.ncc.dk/en/Commercial-Space/Offices/.
NCC. (2011b). "Commercial Premises." Retrieved 2012-03-04, from http://www.ncc.fi/en/commercial_premises/offices.
Nì Riain, C., M. Kolokotroni, et al. (1999). "Cooling Effectiveness of South Façade Passive Stacks in a Naturally Ventilated Office Building: Case Study." Indoor and Built Environment **8**: 309-321.
Nollenergihus, S. C. f. (2012). FEBY 12.
OSRAM. (2012). "OSRAM." Retrieved 2012-03-07, from http://www.osram.se/osram_se.
Ourghi, R., A. Al-Anzi, et al. (2007). "A simplified analysis method to predict the impact of shape on annual energy use for office buildings." Energy Conversion and Management **48**(1): 300-305.

Persson, A., C. Rydstrand, et al. (2005). Allt eller inget - Systemgränser för byggnaders uppvärmning. Stockholm, ÅF Energi & miljö AB.
Persson, J. and H. Arvidsson (2010). Visit Hagaporten, 2010-09-08, Consultant, ÅF.
Pessenlehner, W. and A. Mahdavi (2003). Building morphology, transparence, and energy performance. Eighth International IBPSA Conference. Eindhoven, Netherlands.
Pfafferott, J., S. Herkel , et al. (2003). "Design of passive cooling by night ventilation: evaluation of a parametric model and building simulation with measurements." Energy and Buildings **35**: 1129-1143.
Pfafferott, J., S. Herkel , et al. (2004). "Design, monitoring and evaluation of a low energy office building with passive cooling by night ventilation." Energy and Buildings **36**: 455-465.
Pfafferott, J., S. Herkel, et al. (2005). "Thermal building behaviour in summer: long-term data evaluation using simplified models." Energy and Buildings **37**(8): 844-852.
Pfafferott, J., Ü. Herkel, et al. (2007). "Comparison of low-energy office buildings in summer using different thermal comfort criteria." Energy and Buildings **39**: 750-757.
PHI. (2012a). "Passive House Checklist." Retrieved February 27th, 2012, from http://www.passiv.de/.
PHI. (2012b). "Passive House Institute." Retrieved 2012-03-04, from http://passiv.de/07_eng/index_e.html.
Poirazis, H. (2008). Single and double skin glazed office buildings: analyses of energy and indoor climate. PhD, Lund Institute of Technology.
Poirazis, H., Å. Blomsterberg, et al. (2008). "Energy simulations for glazed office buildings in Sweden." Energy and Buildings **40**: 1161-1170.
Pos. (2011). "ENERGYbase - Passive house office building, Vienna." Retrieved 2011-02-23.
Rauhs, G., U. Schneider, et al. (2008). Sunny Energy Building: ENERGYbase - Bürohaus der Zukunft. Vienna, Haus der Zukunft.
Samuelsson, I. (2008). Ökar risken för fuktskador i passivhus? Bygg & Teknik 5/08. Växjö**:** 12-15.
Sartori, I. and A. G. Hestnes (2007). "Energy use in the life cycle of conventional and low-energy buildings: A review article." Energy and Buildings **39**(3): 249-257.
Schiller, G. (1988). "A comparsion of measured and predicted comfort in office buildings." ASHRAE Transactions **94**: 609-622.
Schimschar, S., K. Blok, et al. (2011). "Germany's path towards nearly zero-energy buildings—Enabling the greenhouse gas mitigation potential in the building stock." Energy Policy **39**(6): 3346-3360.
Schneiders, J. and W. Feist (2002). Passiv-Verwaltungsgebäude Wagner & Co. in Cölbe. Darmstadt, Germany, Passivhaus Institut.
SCNH (2012). Kravspecifikation för nollenergihus, passivhus och minienergihus - Lokaler FEBY 12, Sveriges centrum för nollergihus.

SGBC. (2012). "Certifieringssystem." Retrieved 2012-03-19, from http://www.sgbc.se/index.php/certifieringssystem.
Sjöqvist, R. (2010). Visit Jungmannen 3, 2010-03-24, Project Manager, Midroc Engineering.
Skanska (2008a). Case Study 32: Hagaporten 3, Sweden. http://www.skanska-sustainability-case-studies.com.
Skanska (2008b). Case Study 48: UN House, Norway. http://www.skanska-sustainability-case-studies.com.
Sundholm, K. (2010). Information about Kungsbrohuset, Project Accountant, Jernhusen.
SVEBY (2009). Särskilda mätföreskrifter för energikrav 2009. SVEBY http://www.sveby.org/.
SVEBY (2010). Brukarindata för energiberäkningar i kontor - vägledning. Stockholm, Sweden, SVEBY http://www.sveby.org/.
SVEBY. (2012). "Branschstandard för energi i byggnader." Retrieved 2012-03-23, from http://www.sveby.org/.
Söderling, H. (2010). Energiberäkning och uppmätta värden för Kaggen, NCC.
UNFCCC. (2012). "United Nations Framework Convention on Climate Change." Retrieved 2012-04-01, from http://unfccc.int/2860.php.
Utriainen, I. (2011). Information about Alberga BP and Plaza Pilke, Project Manager, NCC Property Development.
Uvslökk, S., H. B. Skogstad, et al. (2010). How to prevent natural convection causing extra heat loss and moisture problems in thick insulation layers. 3rd Nordic Passive House Conference. Aalborg, Denmark.
Wagner, A., E. Gossauer, et al. (2007). "Thermal comfort and workplace occupant satisfaction: Results of field studies in German low energy office buildings." Energy and Buildings **39**: 758-769.
van Moeseke, G., I. Bruyère, et al. (2007). "Impact of control rules on the efficiency of shading devices and free cooling for office buildings." Building and Environment **42**(2): 784-793.
Waterfront, S. (2009). Energilösning i världsklass. http://www.waterfrontbuilding.se/pdf/stockholmwaterfront.pdf.
Wille, A., R. John, et al. (2004). Passiv-Verwaltungsgebäude Cölbe: Messtechnische Begleitung und systemtechnische Untersuchungen. Kassel, Germany, Institut für Thermische Energietechnik, Universität Kassel.
Voss, K., S. Herkel, et al. (2007). "Energy efficiency office buildings with passive cooling: Results and experiences from a research and demonstration program." Solar Energy **81**: 424-434.
Zettergren, T. (2010). Visit Pennfäktaren 2010-09-08, Project Manager, Vasakronan.