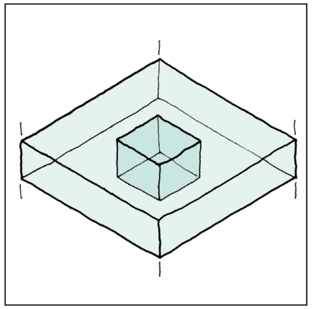
Energy optimisation of office buildings

Introduction

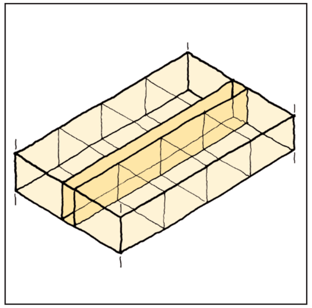
The project "Energy optimisation of office buildings" investigates how the energy consumption of an office building varies accordingly to the building's form and orientation as well as the design of the building's envelope and installations. It also investigates in parallel the thermal indoor climate. The present pamphlet presents in a nutshell the results and observations revealed through calculations.

The pamphlet's aim is to provide a short and general overview of the project's results, which can be used in planning and design of office buildings, where energy consumption is considered. Furthermore, the methodology used in the analysis can serve as inspiration for conducting such analysis – also in other types of buildings. It is useful, especially in the initial phases of a design process, to rely on some "rules of thumb" based on estimates, so that the project team doesn't need to make time-consuming simulation at that time.



Two main types of buildings are analysed in the project: *Point-house* and *Long-house* (see illustrations to the right). In each case variations of the following parameters are performed:

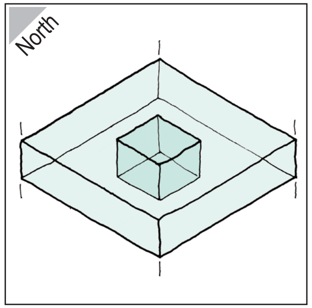
- building's orientation
- building's envelope
- heat accumulation
- location and size of windows
- type and size of solar-shading
- ventilation, cooling and heating systems
- lighting control
- energy consumption of lighting and appliances
- occupancy density



Calculation results are expressed both as the primary energy consumption in kWh/m^2/year and a portion of the working hours in a year with parameters within comfort requirements. In this case comfort requirements are defined as the operative temperature between 21.5 and 24.5 ^{o}C. The simulation program BSim is used for the calculation. All cases are based on a reference building. The reference building's properties are listed under the respective topics. See p. 13 for assumptions.

It should be emphasised that the calculation results obviously cannot be directly transferred to a project, which does not have the same building design and outfitting as the investigated one. However, it is the authors' assessment that the magnitudes and trends illustrated in the leaflet have a high degree of generality.

Building types



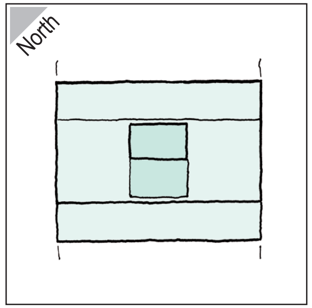
Point-house with an open plan facing north-south

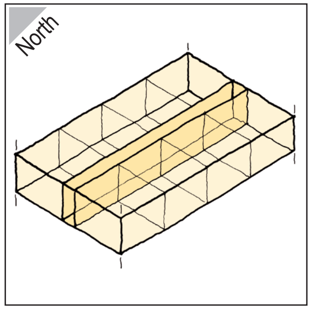
The point-house has one large open-plan office per floor and a service core in the middle. The buildings dimensions are adjusted to set-up two rows of desks along the facade. 10 m^2 net area per person is assumed plus the core and an aisle space around it. Each floor contains 24 working stations with those terms. This results in a point-formed (square) building with:

- a side length of 20 meters
- a core with a side length of 7 meters
- a room height of 2.7 m measured from floor level to the underside of the suspended ceiling
- facades facing N, S, E and W respectively.

Point-house with an open plan facing northeast-southwest

The same as the north-south oriented point-house, but simply rotated 45° from the cardinal directions. The building's corners are thus facing N, S, E and W respectively.





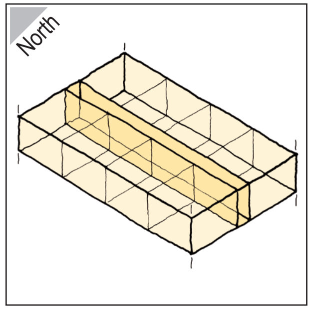
Long-house with cellular offices facing north-south

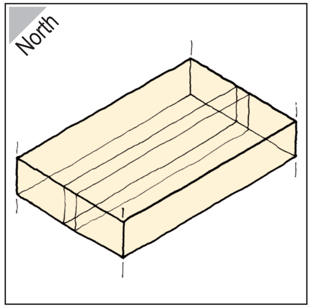
The long-house has cellular offices and a central aisle area along its length. The building's dimensions are determined from the depth of a typical cellular office (4.8 m). The width of the central aisle is set to half the depth of an office, so that the buildings width is 12 meters. This results in a long-house with:

- offices 2.4 meters wide, with a net area of 11.5 m^2
- the room height is in this case 2.7 meters measured from the underside of the suspended ceiling
- it is assumed one person per office
- the facades are facing N, S, E and gables E and W respectively.

Long-house with cellular offices facing east-west

The same as the north-south oriented long-house with cellular offices, but simply rotated 90° from the cardinal directions.



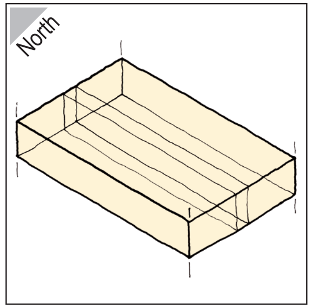


Long-house with an open plan facing north-south

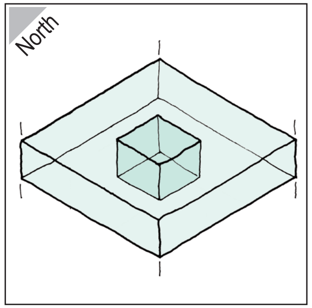
This type of long-house has an open-plan office and an open aisle area (without partition walls) in the centre of the building along its length. In this case the building has the same width and houses the same number of occupants as the case with cellular offices. The buildings facades are facing N and S and the gables E and W respectively.

Long-house with an open plan facing east-west

The same as the north-south oriented long-house with an open plan, but simply rotated 90° from the cardinal directions.

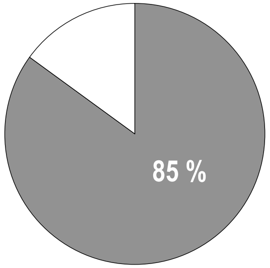


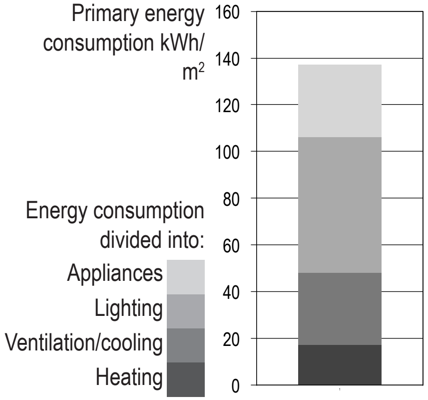
Overview



Point-house with an open plan facing north-south

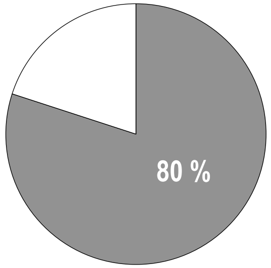
Percentage of working hours in a year within the comfort requirements between 21.5 and 24.5 °C.

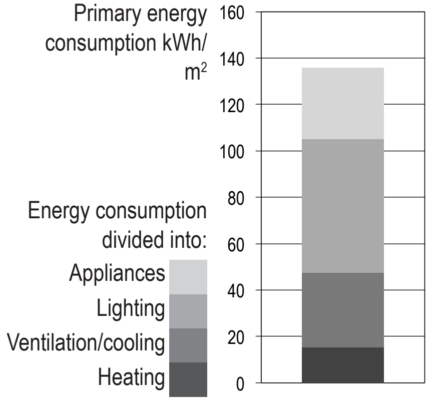


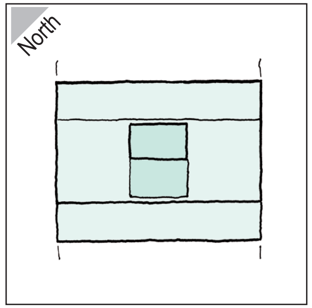


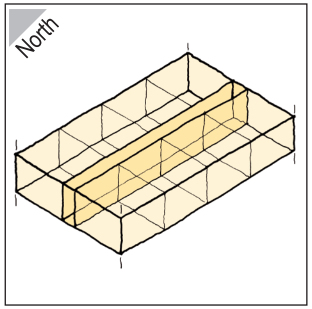
Point-house with an open plan facing northeast-southwest

Percentage of working hours in a year within the comfort requirements between 21.5 and 24.5 °C.



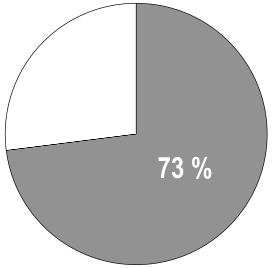


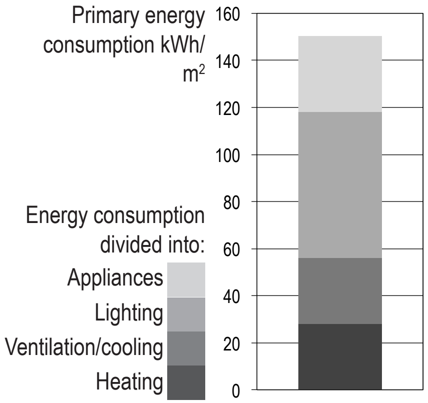




Long-house with cellular offices facing north-south

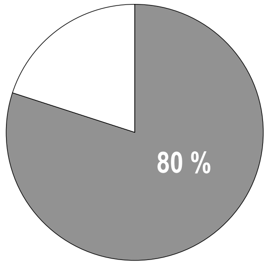
Percentage of working hours in a year within the comfort requirements between 21.5 and 24.5 °C.

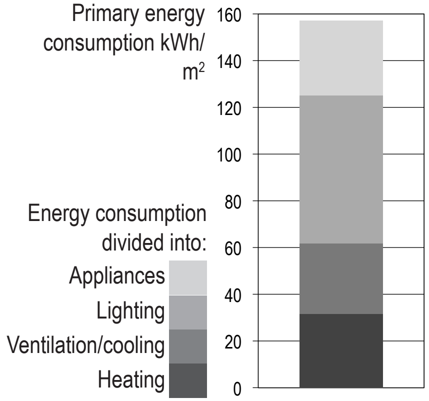


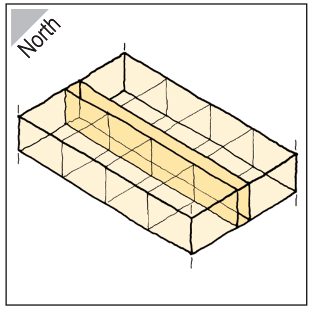


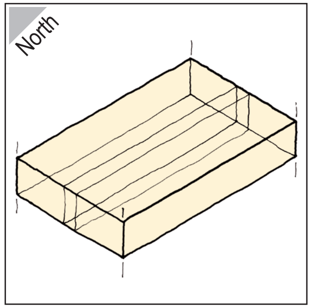
Long-house with cellular offices facing east-west

Percentage of working hours in a year within the comfort requirements between 21.5 and 24.5 °C.



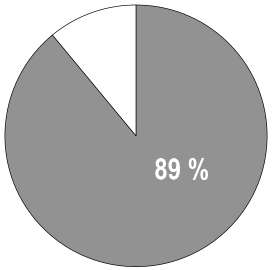


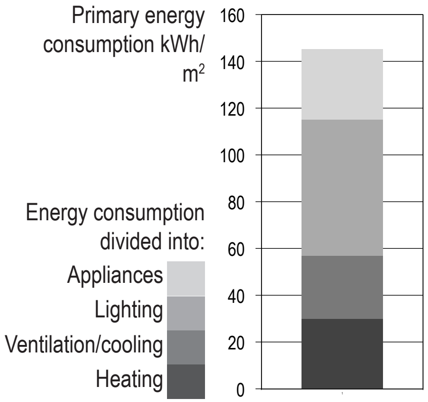




Long-house with an open plan facing north-south

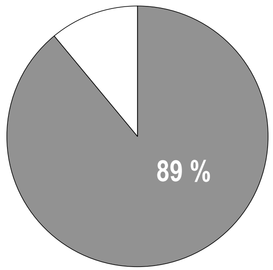
Percentage of working hours in a year within the comfort requirements between 21.5 and 24.5 °C.

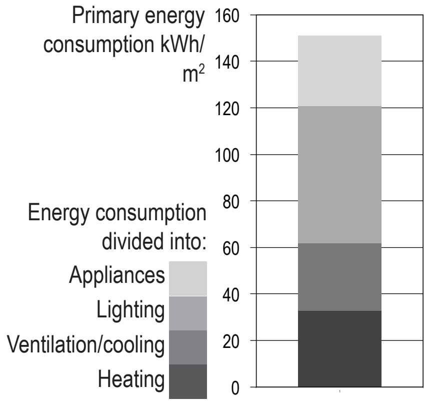


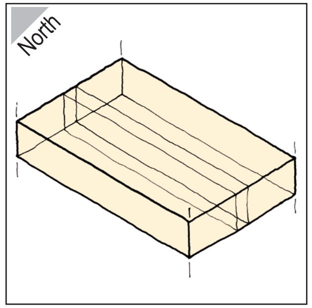


Long-house with an open plan facing east-west

Percentage of working hours in a year within the comfort requirements between 21.5 and 24.5 °C.







Heat accumulation

Exposing internal surfaces with high heat capacity is often considered to be an important measure in passive air-conditioning of buildings. It applies especially during the summer period, when it is interesting to allow the heavyweigth materials to absorb the additional heat during the day – and thus to create a cooling capacity at night by cooling the materials with outdoor air. This way the energy demand for mechanical cooling can be reduced or completely eliminated.

Calculations of typical distributions of heat-accumulating elements in offices have been performed, i.e. where the thermal mass is located in the office's ceiling and / or facade construction, and where the extent of the suspended ceiling varies.

Lightweight facades and lightweight ceiling

The building is equipped with a lightweigth facade consisting of a frame filled with insulation and lightweight cladding on both sides. Floor slabs are made of hollow-core concrete slabs and the suspended ceilings are made of mineral wool plates.

Heavyweight facades and lightweight ceiling (reference)

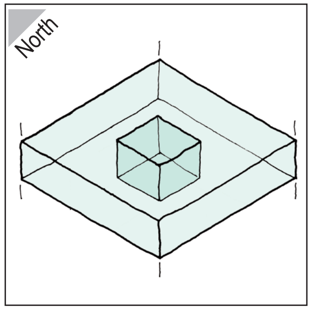
Here the lightweigth facade is replaced by a heavyweigth facade in the form of loadbearing concrete sandwich elements.

Heavyweigth facade and partly heavyweigth ceiling

Here the concrete sandwich elements are kept, but 20% of the suspended ceiling's area is removed so that the bottom side of the concrete slab is exposed in this area.

Heavyweigth facades and heavyweigth ceiling

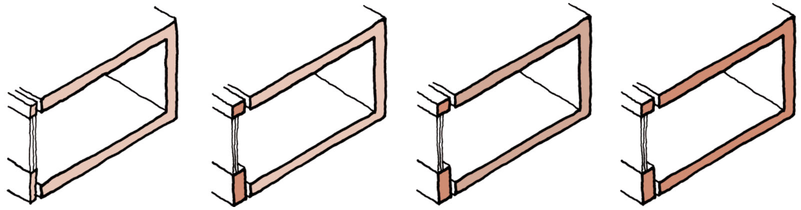
Here the suspended ceiling is completely removed and the entire bottom side of the concrete slab is exposed. This solution requires some consideration regarding the room's acoustics



Conclusion

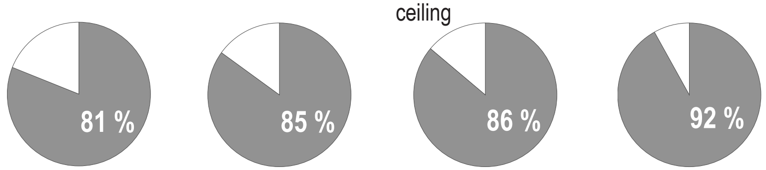
Heat accumulating mass has only a small influence on the annual energy consumption, whereas its significance for the indoor temperature is much larger – the more thermal mass, the more hours within the comfort parameters.

Office building with large thermal mass Pihl & Søn, Lyngby

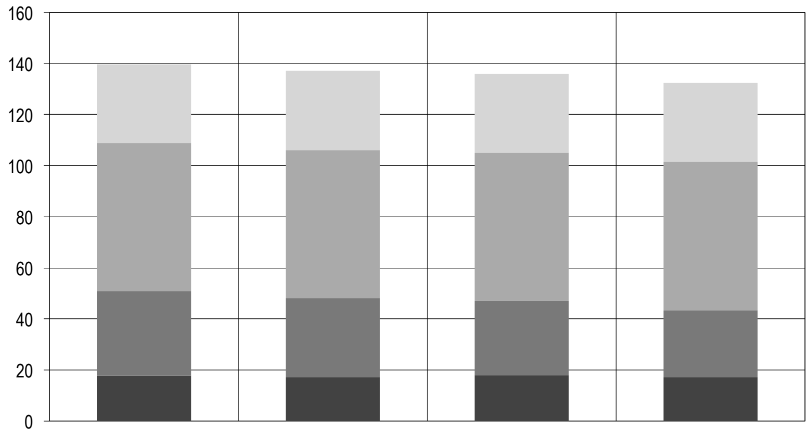


Lightweigth facade Lightweight ceiling | Heavyweight facade Lightweight ceiling | Heavyweigt facade Partly heavyweight ceiling | Heavyweight facade Heavyweight ceiling

Percentage of working hours in a year within the comfort requirements between 21.5 and 24.5 °C.



Primary energy consumption kWh/m²



Energy consumption divided into:
Appliances
Lighting
Ventilation/cooling
Heating

Window area

The share of the facade area covered by windows plays a big role in the building's energy consumption. However, the relation between the window area and the energy consumption is not always unambiguous:

- Large windows give a lot of additional heat from passive solar heat, but unfortunately in periods when there is no need for heating
- Large windows let a lot of sunlight in, but have also a large transmission heat loss during the winter

The window area gives thus some opposing effects and this requires a more detailed analysis in order to calculate the optimal window area from an energy point of view. The following cases are calculated for windows without solar-shading. In should be noted, that automatic lighting control is not considered in the calculations either.

Architectural game with limited window areas FIH-Bank, København

Small windows in the facade

The window area here is calculated as 15% of the floor area – which in many projects would be the smallest possible window area with regard to daylight and view.

Large windows in the facade (reference)

A subdivided window perimeter from 0.8 m above the floor up to 0.6 m below the suspended ceiling, corresponding to 22 % of the floor area.

A window perimeter with a parapet

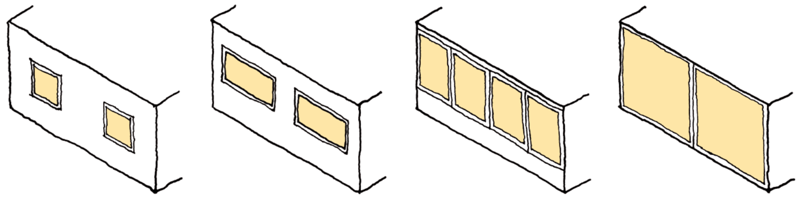
A continuous window perimeter with a 0.8 m parapet and windows continuing up to the edge of the suspended ceiling, corresponding to 36% of the floor area. This case allows a lot of daylight to enter the building.

Glass facade from floor to ceiling

Here the windows cover the facade from floor to the bottom edge of the suspended ceiling, corresponding to 51% of the floor area.

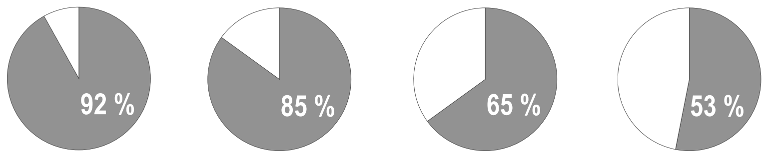
Conclusion

The charts show that there is a clear relation between the windows' area and the energy consumption as well as temperature: The larger the window area, the bigger the energy consumption and the higher the indoor temperature. This applies regardless of the opposing effects, mentioned at the top of the page.

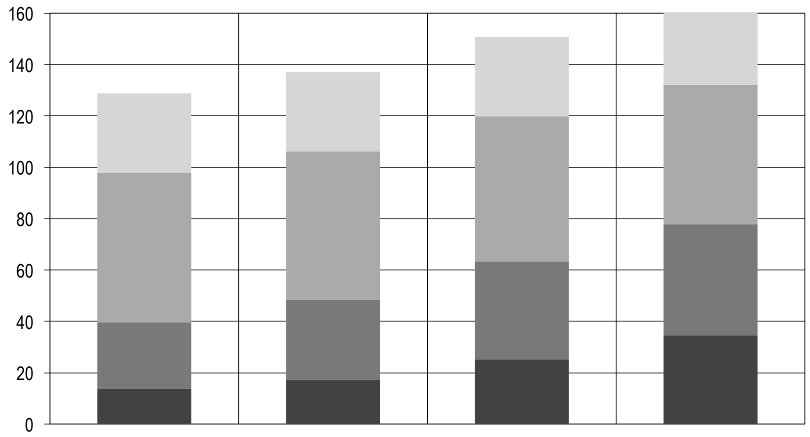


Small windows in the facade — Large vindows in the facade — A window perimeter with a parapet — Glass facade from floor to ceiling

Percentage of working hours in a year within the comfort requirements between 21.5 and 24.5 °C.



Primary energy consumption kWh/m²



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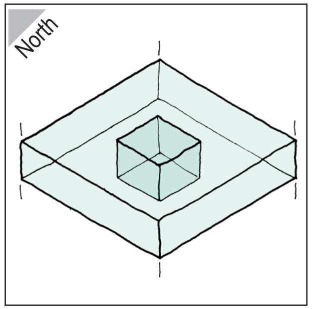


Solar-shading

Solar-shading influences the amount of sunshine entering through the windows – and thus both the inflow of solar heat and daylight. Dynamic solar-shading is distinguished from fixed solar-shading by the ability to adjust in accordance to prioritizing the inflow of solar heat or daylight.

It should be noted that automatic lighting control is not considered in the following cases. This means that lights are on during the working hours, throughout the year, and are not impacted by the amount of daylight.

Without shading (reference)

A building without solar-shading is used as reference.

Horizontal fixed solar-shading

Horizontal, fixed overhang with the depth of 0.5 of the windows' height. When the sun is low on the horizon, it will shine on a part of the pane.

Horizontal dynamic solar-shading

External, automatically controlled blinds with a shading factor of 0.1. The blinds are activated, when there is direct sunshine on the facade in question.

Solar-shading glass

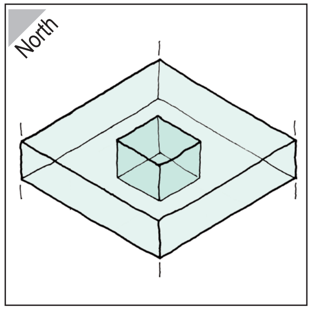
The windows are assembled with solar-shading glass with a solar heat gain factor (g-value) of 0.34.

Conclusion

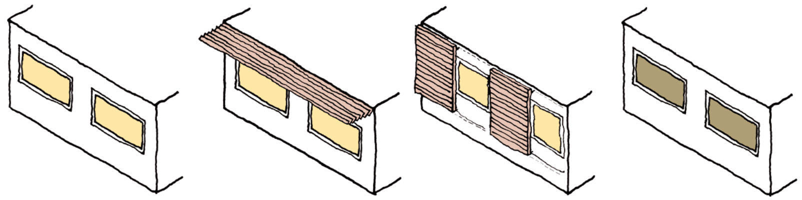
The energy consumption in the first three cases is almost the same. However, the number of hours within the comfort temperature parameters slightly increases with the increased effectiveness of the solar-shading.

The highest number of working hours within the comfort parameters is achieved by solar-shading glass, but with a small increase in the energy consumption. This is due to the permanent reduction of the solar heat inflow in comparison to panes with regular glass – and thus in the cold part of the year as well, when the solar heat could be exploited.

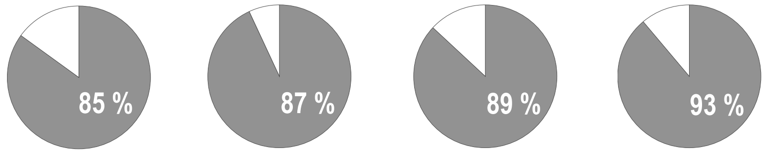
In should be noted that the importance of solar-shading for energy consumption and thermal indoor climate will rise, if the window area increases.

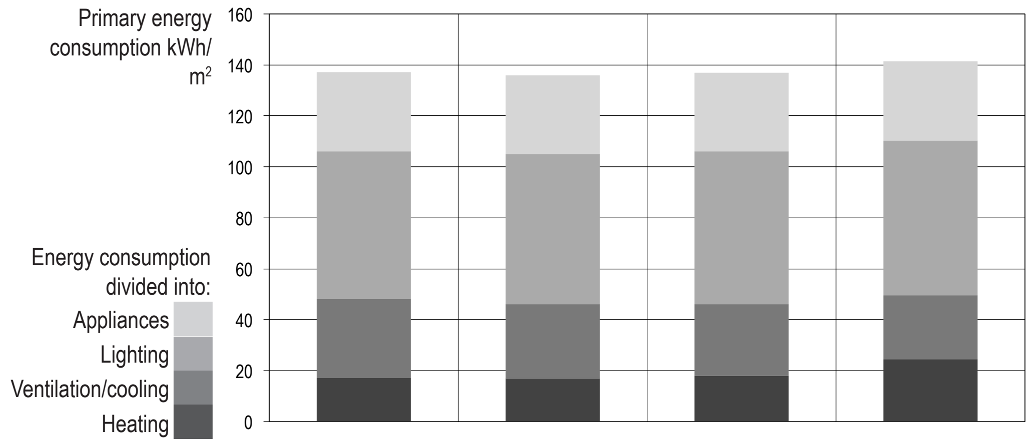


Automatic solar-shading for daylight and indoor climate control CBS, Frederiksberg



Percentage of working hours in a year within the comfort requirements between 21.5 and 24.5 °C.





Heating

The way the heat is supplied to the rooms can have an impact on both the energy consumption and the thermal comfort.

Floor heating will have a slower responsiveness and will therefore have more difficulties to adapt the performance to the actual requirement. This problem is however reduced, when the heat demand is low. In the following cases the central heating system is active only in the heating season.

Only radiators (reference)

Heat is supplied entirely by radiators located at parapets under the windows.

Radiators and floor heating

Half of the heat is supplied by floor heating.

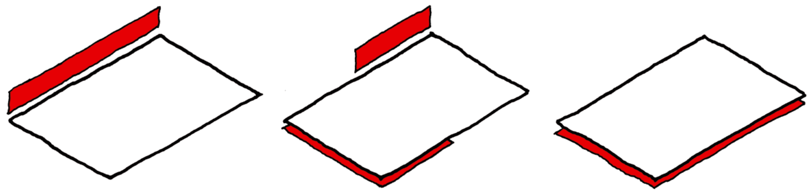
Only floor heating

Here the heat is entirely supplied by floor heating.

Conclusion

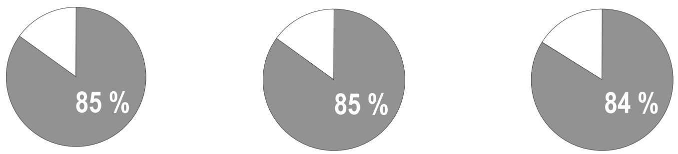
The charts show that the thermal indoor climate is practically the same in all the cases. The energy consumption shows a decreasing trend together with higher use of floor heating. This is due to the fact that with a higher share of floor heating the same operative temperature can be maintained with a lower air temperature.

An effective insulation can minimize the heating demand
Rockwool, Hedehusene



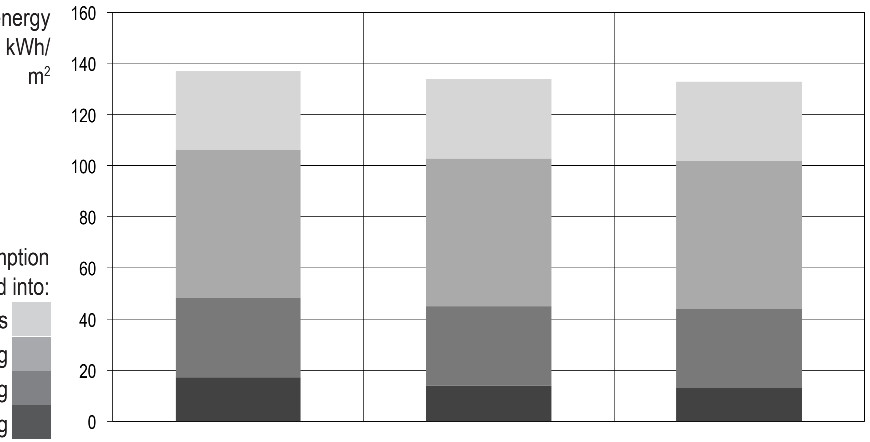
Only radiators | Radiators and floor heating | Only floor heating

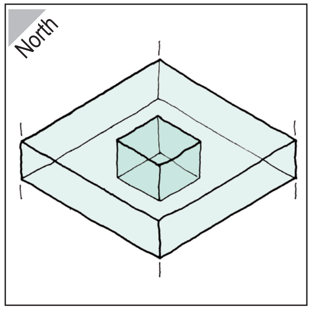
Percentage of working hours in a year within the comfort requirements between 21.5 and 24.5 °C.



Primary energy consumption kWh/m²

Energy consumption divided into:
Appliances
Lighting
Ventilation/cooling
Heating





Ventilation

The sizing, design and control of the ventilation system have a big impact on the indoor temperature as well as the energy consumption.

In calculations electricity consumption of mechanical ventilation is an important factor, as it is multiplied by 2.5 (in DK) when calculating the primary energy consumption. Therefore, it is desirable to try to minimize the electricity consumption by e.g. shorter operation time of mechanical ventilation and a better electrical efficiency of the system. Ultimately the electricity consumption can be completely eliminated by using only natural ventilation. In turn the heat consumption will be significantly higher due to the lack of heat recovery.

Mechanical ventilation with heat recovery (reference)

The ventilation system in this case is a VAV system without mechanical cooling – with an air volume exchange rate of app. 5 times/hour. The system operates within the working hours and also in relation to night-cooling in hot periods.

Mechanical during the day – natural ventilation at night

To decrease the electricity consumption, natural ventilation is used as night-cooling.

Optimised mechanical ventilation system

The ventilation system functions as in the reference case, but it is optimised in regard to heat recovery and electrical efficiency. Furthermore, the air exchange rate during the winter is controlled by CO_2 levels and thus relatively low.

Natural ventilation

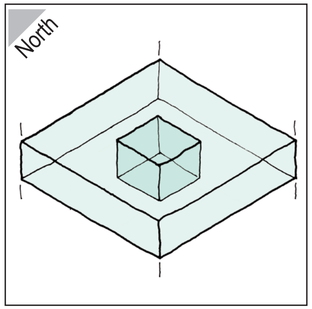
The air exchange rate is controlled by CO_2 levels during the winter. During the summer the air exchange rate is controlled by the indoor temperature and there is night-cooling as well. Draughts might occur during the cold season.

Conclusion

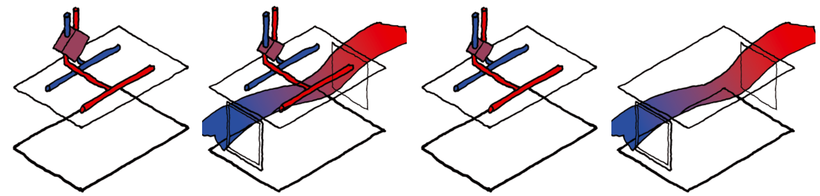
Natural ventilation at night-time slightly reduces the energy consumption and a further reduction is achieved by optimising the mechanical ventilation system without significantly affecting the indoor temperature in either case.

The solely natural ventilation system achieved a noticeably lower energy consumption than the reference case. The heat consumption is quite increased due to the lack of heat recovery, but the electricity consumption decreases much more, because electricity is not used for the operation of fans. Furthermore, the natural ventilation results in more hours within the comfort parameters, which could be attributed to the heating of the supply air by the fans.

The difference in the primary energy consumption between the natural and mechanical ventilation systems will therefore depend on, how much heat is released from the appliances, machines, etc. in the building.

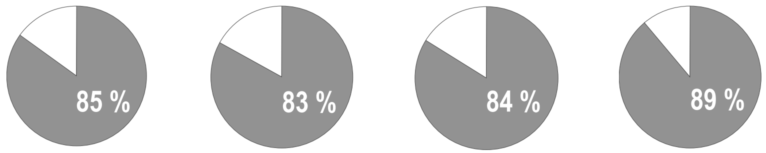


Controlled natural ventilation in a low-energy office building VKR-Holding, Hørsholm



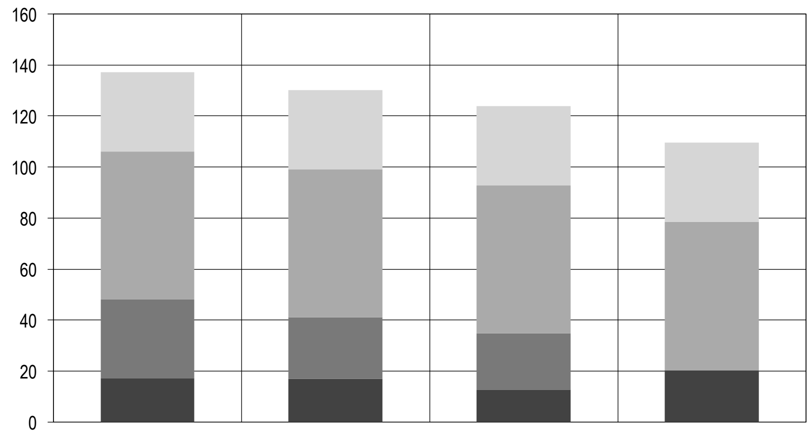
Mechanical wirh HR | Mechanical (day) Natural (night) | Optmised mechanical | Natural ventilation

Percentage of working hours in a year within the comfort requirements between 21.5 and 24.5 °C.



Primary energy consumption kWh/m²

Energy consumption divided into:
Appliances
Lighting
Ventilation/cooling
Heating



Cooling

None of the cases described previously have included mechanical cooling. In some case this has resulted in indoor temperatures not meeting the recommendations of DS 474 (Danish Code of Practice for Indoor Thermal Climate), i.e. max 100 working hours/year above 26 °C and max 25 working hours/year above 27 °C.

Mechanical cooling is used in many newer office buildings because of problems with overheating, partly due to a big increase in the use of IT-equipment, and partly because of an architectural focus on the use of large glazed facades. Mechanical cooling, with a sufficient capacity to meet the DS 474 recommendations, is thus introduced in the cases below.

VAV without cooling (reference)

The ventilation system in this case is a VAV system without mechanical cooling – with an air exchange rate of approx. 5 times/hour. The system operates within the working hours and also in relation to night-cooling in hot periods.

VAV with mechanical cooling

Same as the reference case, but supplemented with mechanical cooling as part of the ventilation system.

CAV with chilled beams

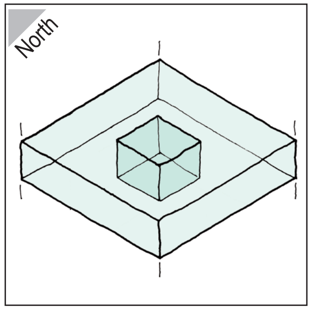
The VAV system in this case is replaced by a CAV system with chilled beams and an airflow corresponding to the VAV system's minimum airflow. The system is operational only in the working hours and also in relation to night-cooling in hot periods.

Conclusion

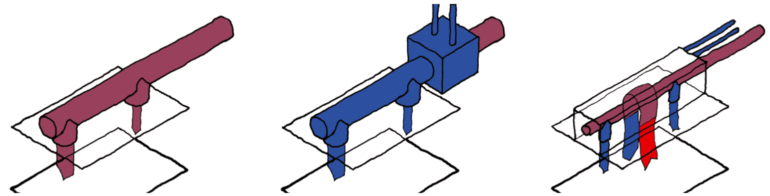
The introduction of cooling in a VAV system results in a noticeable improvement of the indoor temperature in comparison with the reference case – and a slight increase in the energy consumption.

There is further a slight increase in the energy consumption with CAV, which may be attributed to the annual average electricity consumption for air transport (SEL-value) being lower with VAV than CAV.

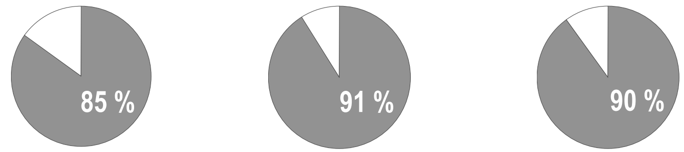
The conclusion is therefore that mechanical cooling results in an increase of the primary energy consumption. At the same time both VAV with mechanical cooling and CAV with chilled beams result in almost the same indoor temperatures and primary energy consumption.



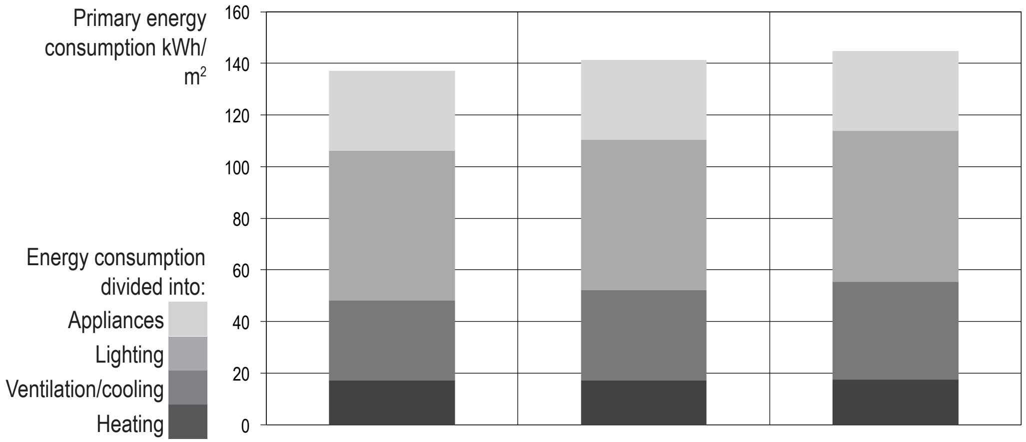
Cooling is necessary in many newer offices Vattenfall, Sydhavn



Percentage of working hours in a year within the comfort requirements between 21.5 and 24.5 °C.



Primary energy consumption kWh/m²



Lighting and appliances

In all previous cases the internal heat gains from occupants, lighting and appliances have been the same. A series of new analyses has shown that bigger reductions in the building's total primary energy consumption can be achieved by focusing on a wide range of electricity savings, which is more comprehensive than those in the energy regulations. Therefore, the effects of introducing energy efficient lighting and PC's is analysed in the below cases.

Typical lighting and appliances (reference)

In the reference case the general lighting is assumed to be constantly on in the working hours, though adjusted to the season, so that the power output is highest during the winter and lowest during the summer. PCs have an effect of 80 W per PC, corresponding to a stationary PC with a flat screen. Desk lamps are assumed to be old, with traditional 60 W light bulbs

Daylight control and typical appliances

Same as the reference case, but with daylight control of the general lighting.

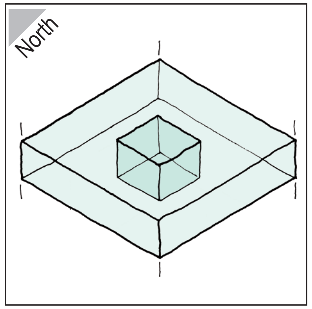
Daylight control and energy efficient appliances

In this case, apart from daylight control of lighting, a heat output of 50 W per PC is assumed, corresponding to a laptop computer and a flat screen. Furthermore, desk lights are equipped with fluorescent light bulbs with an effect of only 15 W and the general lighting is more efficient.

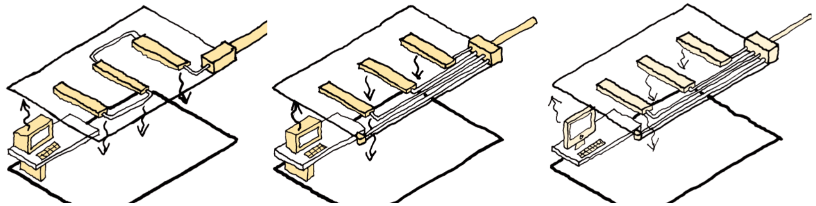
Conclusion

The charts illustrate that daylight control alone does not alter the indoor temperature, but there is a slight reduction in the energy consumption due to the saving in electricity consumption. If PCs and desk lamps with a low heat output are also used, a dramatic improvement of the energy consumption, but also an improvement in the indoor temperature, is obtained.

Traditional consideration of heat output from appliances as free surplus heat, which minimises the heating demand, can thus be seen as problematic. A campaign aimed at electricity savings will result in lower heat outputs, better comfort conditions and a reduced cooling demand and thus a lower primary energy consumption in office buildings as a whole.

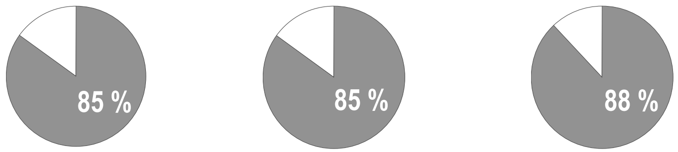


Office focused on electricity efficient equipment and appliances
KfW Banken, Frankfurt

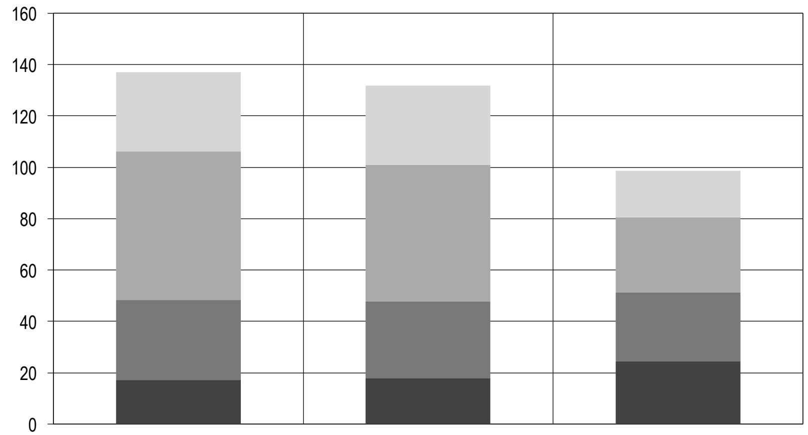


Typical lighting and appliances | Daylight control and typical appliances | Daylight control and energy efficient appliances

Percentage of working hours in a year within the comfort requirements between 21.5 and 24.5 °C.



Primary energy consumption kWh/m²



Energy consumption divided into:
Appliances
Lighting
Ventilation/cooling
Heating

Super optimization

The significance of the building's overall design and orientation is modest, as shown in the Overview section. A trend can however be observed that open plans obtain a lower energy consumption and a higher thermal comfort than with cellular offices. At the same time such open plans increase the flexibility inside the building.

In general the calculated examples show a relatively small difference in the primary energy consumption. This is due to, among other things, the lighting being controlled only in a few of the examples. And, since the electricity consumption for lighting is in general the biggest single contributor to the primary energy consumption, variations in the other parameters give only a relatively small change in the total energy consumption.

To summarize the results a super-optimized low-energy office is presented here, which is calculated cumulatively:

Reference

The building is designed as in the reference case.

Daylight control and energy efficient appliances

Daylight lighting control and energy efficient appliances are added to the reference case.

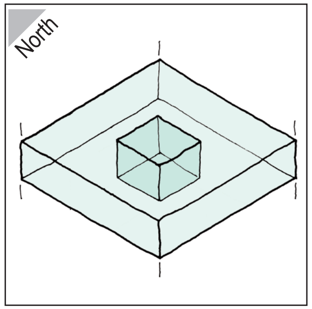
Natural ventilation during the summer – Mechanical heat recovery in the winter during daytime

The VAV system in the reference case is replaced by natural ventilation during both day and night outside of the heating season and outside the working hours during the heating season. The natural ventilation is CO_2-controlled during the day and temperature controlled during the night. The VAV system is kept operational during working hours within the heating season.

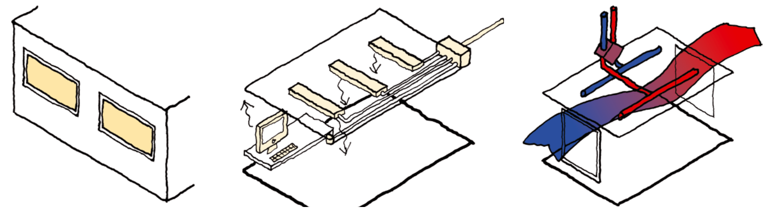
Conclusion

The results show that the electricity consumption for lighting and appliances significantly lowers the total primary energy consumption – as shown in section "Lighting and appliances".

Another measure with a big energy saving potential is the use of natural ventilation. Despite heavily optimising a mechanical ventilation system, the primary energy consumption is higher than for natural ventilation with the same air performance. Here there is also the energy saving potential in reducing the electricity consumption, which, when transferred to the primary energy consumption by multiplying with a factor of 2.5, carries a big significance in the calculation.



Low-energy solutions in a holistic perspective.
EnergiAkademi, Samsø

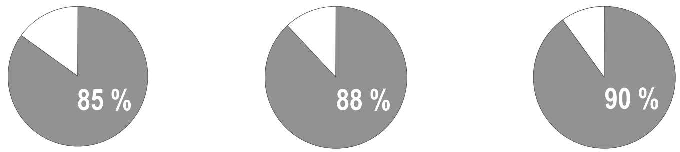


Reference building

Dailight control and energy efficient appliances

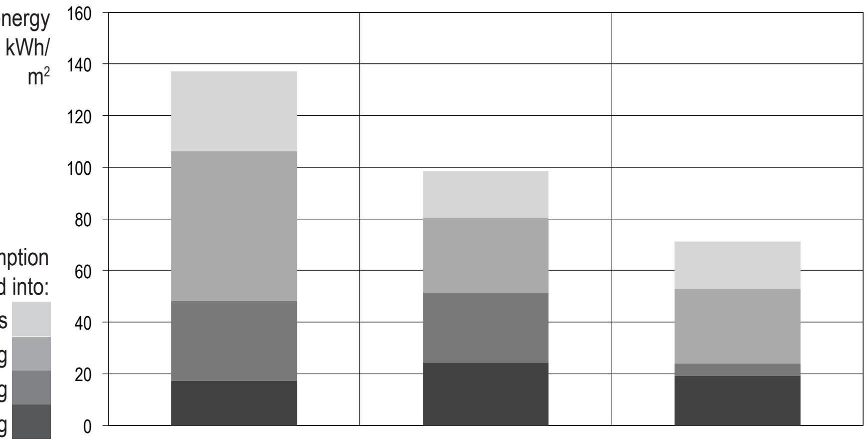
Natural (summer) Mechanical (winter/dag)

Percentage of working hours in a year within the comfort requirements between 21.5 and 24.5 °C.



Primary energy consumption kWh/m²

Energy consumption divided into:



Appendix

Flexibility

Buildings should be able to function for many years after being built. The application can change over time – e.g. more / fewer employees, more / fewer occupants, other functions. The building must be flexible and thus future-proof. This can be expressed among other things by:

- Access to the building – a common entrance allows changes in the number of occupants
- Access to offices, etc. – the building can function with changes to the number of occupants.
- Shared facilities, e.g. canteen – allow variations in the number of occupants and the simultaneity factor can be used for optimising the areas.
- Flexible layout of the floors – cellular offices can easily be changed to open-plan ones / meeting rooms / other and the other way around, by using open floor areas with few fixed elements (toilets, stairs, etc.)
- Modular installations – that make it possible to build partition walls. The heating system can be divided into zones with radiators at the parapets in each facade-module, e.g. 3 meters apart.
- Oversized ventilation system – it should be possible to easily increase the airflow, should it be needed. This obviously especially applies to the duct systems – and especially to the end sections.
- Open-plan offices – are less sensitive to concentrated heat loads.
- Meeting rooms – located often at the inner section of the building. There will occur shorter, intense heat loads. It should be considered how to solve this problem, without impacting the rest of the system.
- Secondary meters (for heating, water and electricity) for the higher consumption – ventilation, data-server and canteen as well as the consumption in the office areas. In the office areas can the electricity consumption be divided into sections, where the consumption from computers, lighting and regular sockets is measured respectively.
- Stand-by energy loss – it is important to consider the stand-by energy losses in the design phase. When the number of people in the building is changed, the energy consumption should change as well.
- Low energy consumption – for a better protection against the higher energy prices, which can be expected in the future.

Total electricity consumption

The simulations, which are the background of the pamphlet, cover only about a half of the total electricity consumption in a typical office building. Only the consumption in the office areas is included.

Additionally there is electricity consumption in the shared installations – many with a constant consumption (data-server and the associated installations, wiring closets, elevators, etc.) and common areas (especially kitchen). It is important to pay attention to the consumption here, to achieve low "built in" energy consumption.

Project report

An explanation of the project and the results, including a more detailed description of the calculation model and the calculated building zones, can be found in the project report:

Energy optimisation of office buildings. SBi 2011:16.
Danish Building Research Institute (2011).

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