# Design of a Zero Energy Office Building at Haakonsvern, Bergen

Inger Andresen[1], Frode T. Haanshuus[1], Jan Hoel[1], Ivar Jonassen[1], Nils Ivar Nilsen[2], Mads Mysen[3], Svein Nytræ[4], Berit Time[2]

[1]LINK Arkitektur AS, Dreggsallmenningen 10/12, NO-5003 Bergen
[2]Forsvarsbygg, Postboks 405 Sentrum, NO-0103 OSLO
[3]SINTEF Building and Infrastructure, The Research Centre for Zero Emission Buildings, NO-7465 Trondheim
[4]Multiconsult AS, Nesttunbrekka 95, NO-5221 Nesttun

## Abstract

An office building of about 2000 m$^2$ heated floor area is being designed for the Norwegian Defense Estates Agency (Forsvarsbygg). The building will be located at Haakonsvern, about 15 km from the centre of Bergen, Norway. The design aims at meeting the ZEB criterion of net zero energy balance for building operation during a year. The energy for operation of the plug loads (computers, printers, etc.) is not included in the balance.

The following design strategies have been explored:

- A compact building form and super insulated building envelope.
- Adequate exterior solar shading with daylight distribution.
- Efficient lighting with occupancy and daylight sensors.
- Utilizing thermal mass in the building construction and PCM panels in interior surfaces to reduce cooling and heating loads
- Automatically controlled windows for night time ventilation to reduce cooling loads
- Highly efficient ventilation system with high heat recovery. Active air supply diffusers for optimal control of ventilation and indoor temperatures. Using ventilation system to preheat interior space during night time, to avoid the need for radiators.
- Low temperature heating and cooling supplied from a seawater heat pump system.
- Building integrated photovoltaic system for electricity supply

The energy performance and thermal comfort have been simulated with the programs SIMIEN (www.programbyggerne.no) and EnergyPlus (http://apps1.eere.energy.gov/buildings/energyplus/). Daylight performance has been simulated using the program DIAL + Lighting (http://www.estia.ch). Life Cycle Costs calculations have been performed in order to select the most cost-effective solutions.

# Introduction

In January 2010, the project team consisting of LINK Arkitektur (architects) and Multiconsult (engineers), started the design of a new office building with 97 work places at the Haakonsvern naval base of the Norwegian armed forces. The assignment from the client, the Norwegian Defence Estates Agency (Forsvarsbygg), was to develop 2 alternative concepts; one that satisfied the criteria for Energy Label A (www.energimerking.no) and the Norwegian Passive House criteria [Dokka et al 2009], and an alternative concept that could be classified as a zero energy building. The design of the zero energy building should be carried out in cooperation with the Research Centre for Zero Emission Buildings (www.ZEB.no).

# Design Process

Before the design started, a kick-off workshop was arranged to define the specific goals for the project, and to test out different energy concepts that could potentially satisfy the goals. The 1-day workshop was attended by a multidisciplinary group consisting of architects, HVAC engineers, building physicists, and contractors. Representatives of the client and the project leader were also present. The definition of the zero energy building was proposed and explained by representatives from the ZEB centre: "The building should be calculated to be zero energy with respect to heating, hot water, ventilation, fans and pumps, lighting and cooling according to Norwegian Standard 3031 [NS 3031]. Appliances[1] may be excluded, but should also be documented and calculated". As a result of the workshop, 4 different energy concepts were proposed for the zero energy building, and the designs were documented by initial energy simulations. During the following course of the project, 2 more such interdisciplinary workshops were arranged, with special focus on heating, cooling and ventilation concepts.

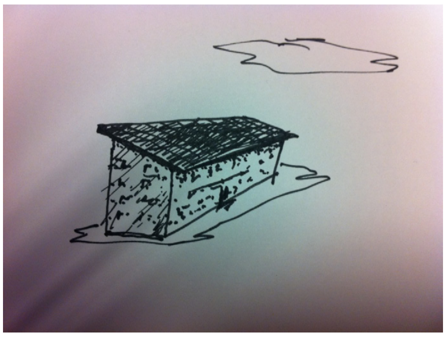


Figure 1. Sketch of one of the proposed building concepts from the first workshop.

In this paper, the design and energy performance of the Zero Energy Building are described and some of the more challenging topics are assessed.

# Location, Layout and Form

The project site is located at the west coast of Norway, about 15 km from the centre of Bergen (latitude 60°N). The yearly mean ambient temperature is 7.5°C, and the yearly total solar horizontal radiation is 815 kWh/m$^2$. Winter design temperature is -11.7°C and summer design temperature is 18.9°C.

A compact and simple building form was chosen in order to minimize heat losses, avoiding air leakages, and minimizing costs. Good daylight conditions in the occupied spaces were obtained by placing the primary rooms (offices) along the facades, while the secondary rooms (meeting rooms/storage/technical rooms) where placed in the interior. Also, windows were designed to maximize daylight conditions, see section below.

The footprint of the building is rectangular, measuring 17 x 30 m. The building was designed having 4 main floors and a smaller 5$^{th}$ floor containing the technical room, and the main facades facing north/south. The south façade faces the sea, while on the north side of the building there is a small hill. The roof angle was designed for optimum solar collection. The heated floor area was 1873 m$^2$, and the total window/door area was approximately 18% of the heated floor area.

[1] Appliances include computers, printers, copy machines, and small kitchen utensils like coffee machines, etc.

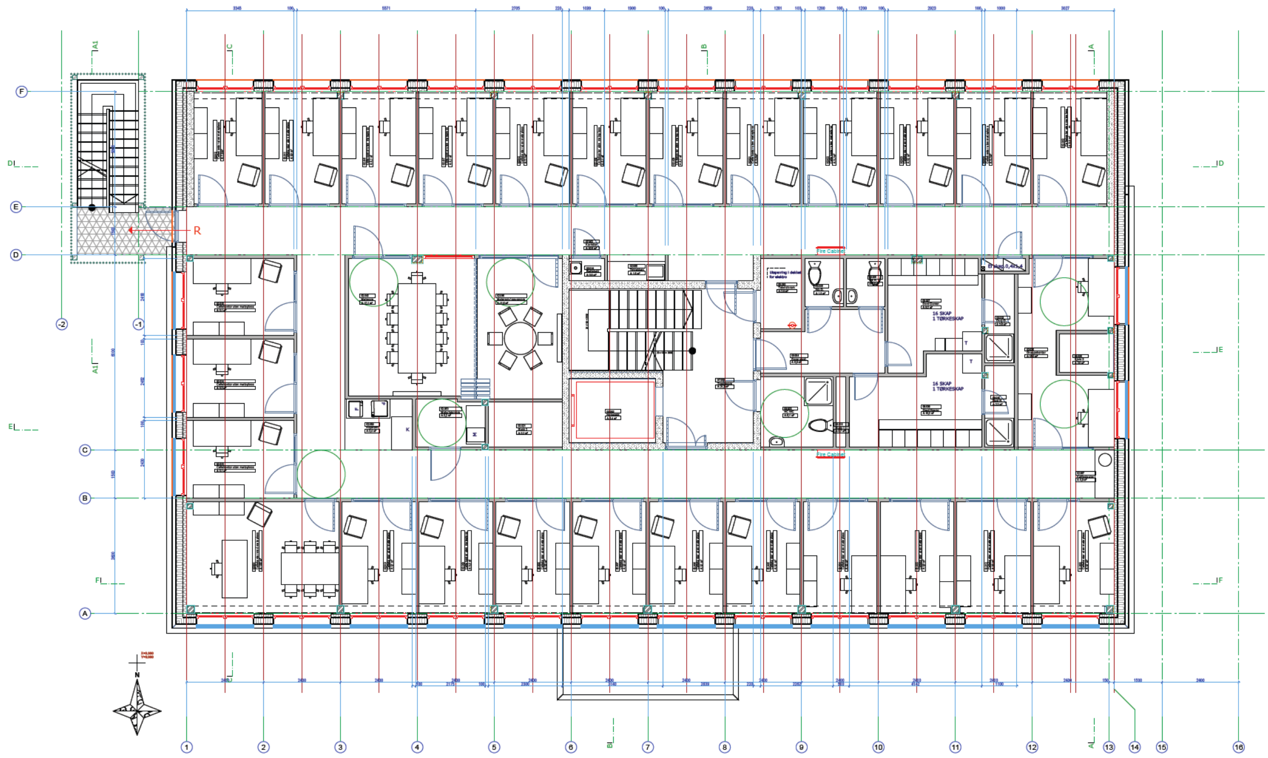


Figure 2. Typical floor plan (1st floor).

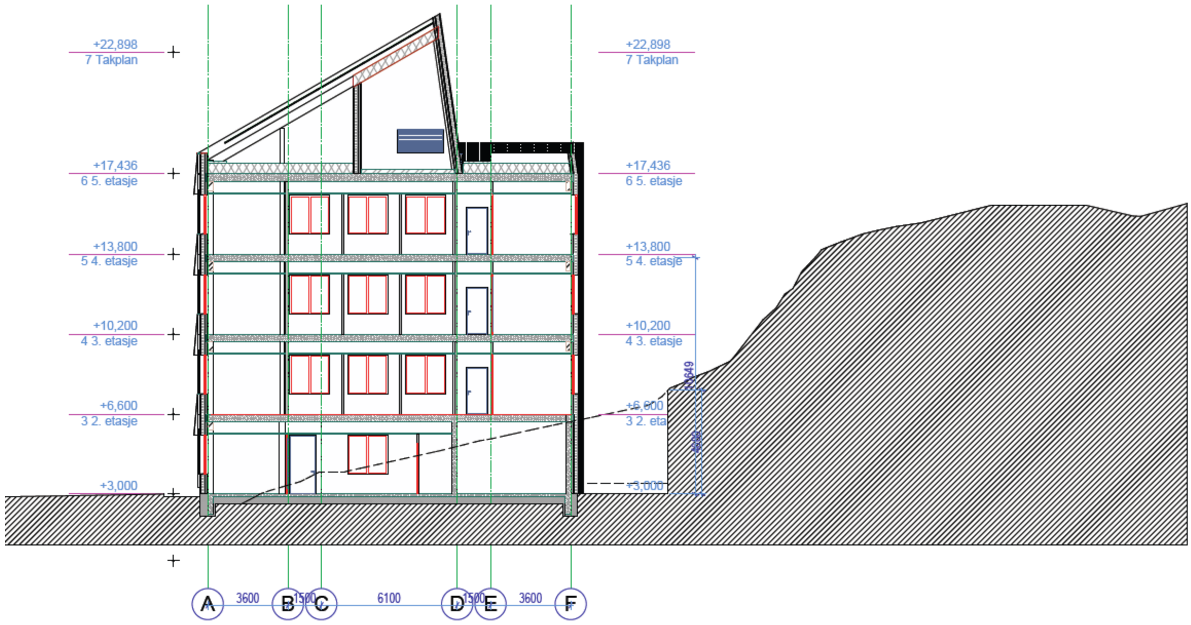



Figure 3. Section.

# Building Envelope and Structure

The structural system of the building was designed consisting of hollow core concrete slabs and steel columns. The columns were placed on the interior side of the continuous thermal insulation layer to minimize thermal bridges. The exterior walls have 200 mm of rigid mineral wool insulation (λ = 0,033) on the outside and 100 mm of insulation between wooden studs on the interior side (see Figure 4). The windows have exterior automatically controlled shading towards south, east and west. The technical specification of the building envelope and structure is shown in Table 1.

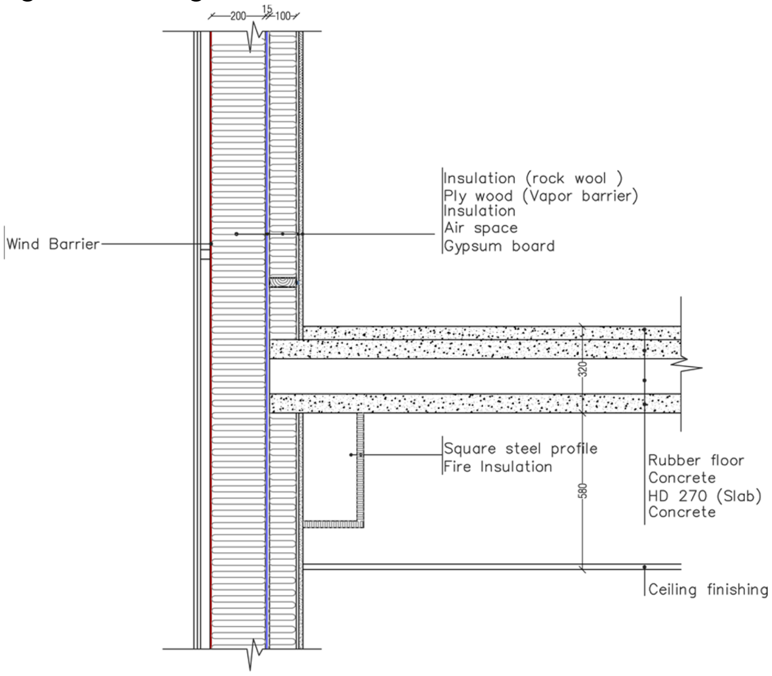



Figure 4. Cross section showing the structural system and the thermal insulation and wind barrier of the exterior walls.

| | | |
|---|---|---|
| Exterior walls<br>Roof<br>Slab on ground<br>Windows and doors | U = 0,13 W/(m$^2$K)<br>U = 0,09 W/(m$^2$K)<br>U = 0,08 W/(m$^2$K)<br>U = 0,73 W/(m$^2$K) | ~ 200 + 100 mm mineral wool<br>~ 450 mm mineral wool<br>~ 300 mm mineral wool, included heat resistance of ground<br>Average value. Triple glazing with 2 LE-layers and argon gas filling, insulated frame and sash. G-value 0.5, Lt-value 0,7 |
| Normalized U-value for thermal bridges | 0,03 W/(m$^2$K) | Simple building envelope, carefully planned details, quality control of construction |
| Air leakage number at 50 Pa | 0,4 ACH | Simple building envelope, carefully planned details, quality control of construction |
| Thermal heat capacity | 66 Wh/(m$^2$K) | Hollow core concrete floor with thin rubber flooring. Gypsum interior walls. Suspended ceilings. |

Table 1. Specification of the thermal characteristics of the building envelope and structure.

# Daylight

Daylight calculations were carried out for different window configurations in order to maximize the daylight penetration and related energy savings from reduced need for electric lighting. Due to the shallow depth of the occupied zones, the daylight conditions within the space are potentially very good. Figure 1 shows the result of daylight calculations for the final window design.  A section of the 1st floor of the building was modeled. The section has dimensions 7.2 x 17 m, and consists of 3 offices along the north and south facades.  Each of the offices has a window opening of 1.79 x 1.74 m, of which the frame/sash comprises 20%. The windows have triple glazing with 2 low-E coatings and argon gas filling, with a light transmission of 70%. Between the offices and the corridors, there are single glazed interior walls almost from floor to ceiling, i.e. with a parapet of 20 cm.

The north facing windows receives some shading from the terrain. The south facing windows are not shaded by the terrain, but have been modeled with fixed horizontal lamellas in the upper part of the window to allow for daylight penetration into the room when the exterior movable blinds are activated in the lower part of the window. Interior walls and ceilings have been modeled with a light reflection of 70%, while the floor has a light reflection of 30%. The daylight calculations were carried out by the program DIAL+ Lighting (http://www.estia.ch). The program does not have the possibility of modeling interior transparent walls, thus the interior glass walls were omitted in the model. However, an approximate estimate of the effect of the interior glass walls may be obtained by multiplying the resulting daylight factors behind the walls by 0.9.

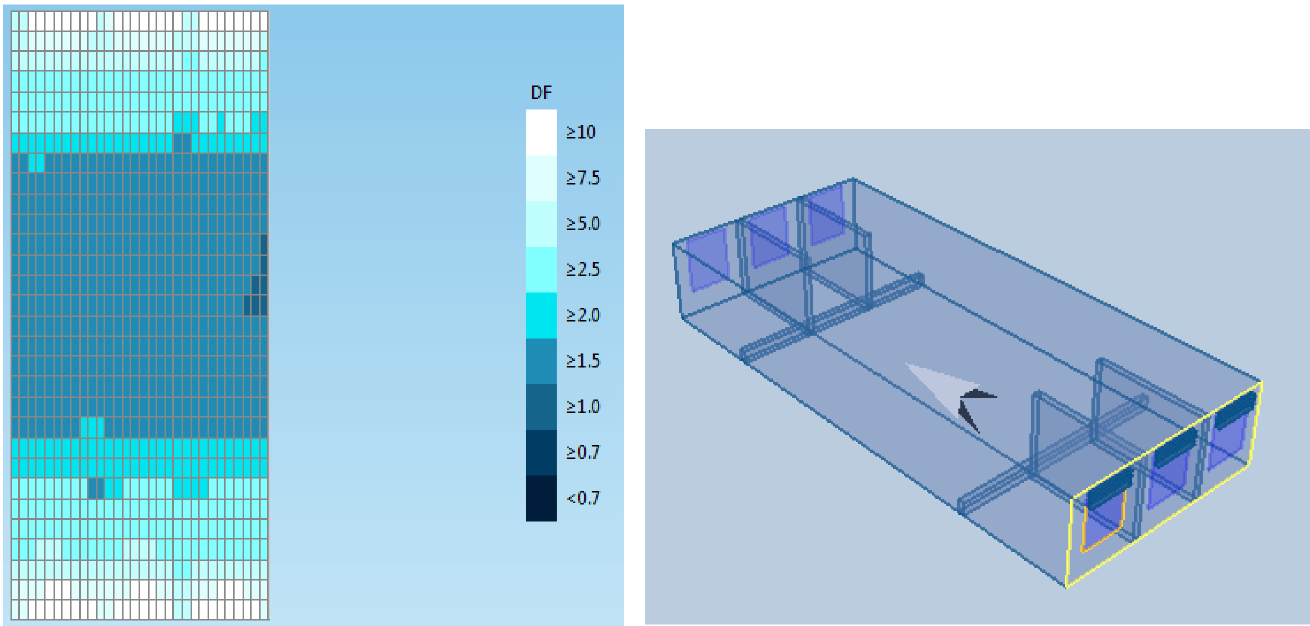



Figure 5. Left: The calculated daylight distribution (DF) on the work plane (North direction is up). Right: The modeled building section, the arrow showing direction north.

To get an estimate the potential for energy savings by the dimming of the electric lighting depending on the daylight levels, the daylight autonomy has to be calculated. Daylight autonomy is defined as the fraction of the occupied times per year, when the required minimum illuminance level at the point can be maintained by daylight alone. In contrast to the daylight factor, the daylight autonomy considers all sky conditions throughout the year. For example, a daylight autonomy of 70% means that the occupant can potentially work 70% of the year by daylight alone. The daylight autonomy calculation done by DIAL + only includes overcast days (diffuse illumination), since it is assumed that the movable solar shading is activated in direct sun.

Figure 6 shows the results of daylight autonomy calculations for the offices and corridors, respectively. The required illuminance level for the offices is set to 500 lux, and 150 lux for the corridors. The figures show that electric lighting can potentially be switched off for at least 60% of the time. This indicates that by installing a daylight control system for the electric lighting may reduce lighting energy use by more than 60%, and even more if a continuous dimming system is installed.

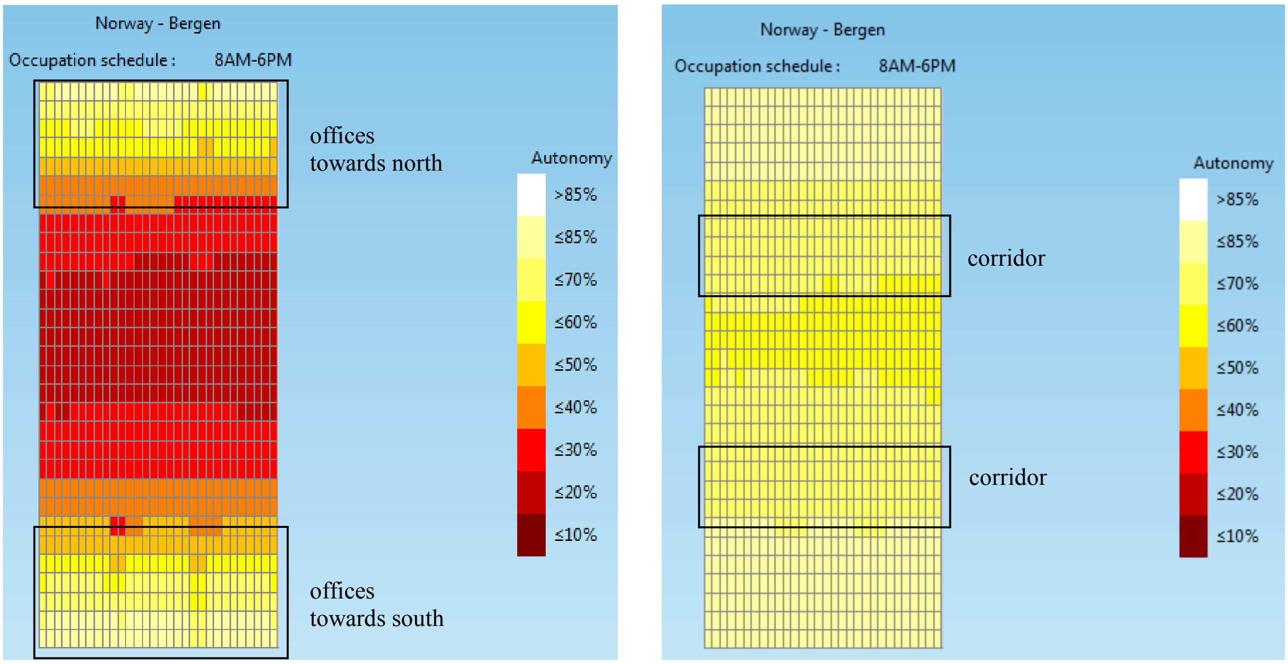



Figure 6. Left: Daylight autonomy at the work plane in offices, required illumination 500 lux. Right: Daylight autonomy in corridors, required illumination 150 lux.

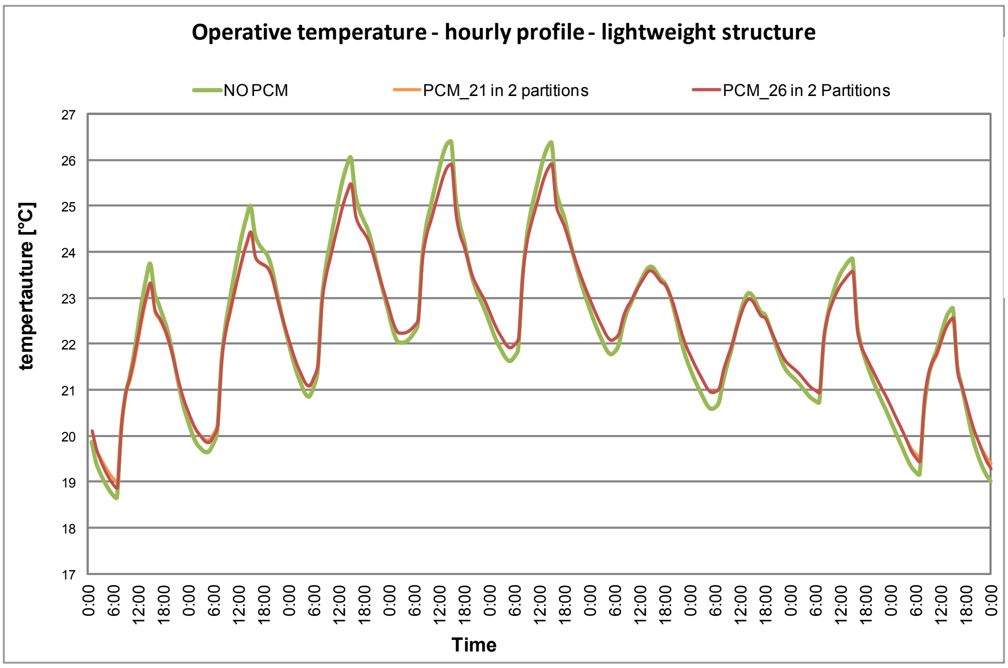
# Thermal Mass and Phase Change Materials (PCM)

One of the measures that was investigated, was thermal mass activation of the concrete ceilings with night flushing with outside air to reduce cooling loads. Simulations showed that this could eliminate the need for mechanical cooling. However, due to the large amount of small offices and the preference towards a uniform leveled ceiling all over, the architects opted for a suspended ceiling in all spaces. Thus, the possibility of using PCM boards in the interior partitions was investigated. A laboratory test carried out by SINTEF [Cao et al 2010] showed that PCM boards from DuPont of type Energain [DuPont 2007] installed behind gypsym boards could potentially reduce the peak indoor air temperature of 2°C.

Dynamic energy simulations of a south facing office were carried out with the simulation program EnergyPlus (http://apps1.eere.energy.gov/buildings/energyplus/). Simulations were done for a warm week in August with the following parameters:

- Room width: 2.4 m, room depth 3.6 m, room height 3.3 m with a suspended ceiling at 2.7 m.
- Façade: lightweight sandwich construction with U-value of 0.12 W/(m$^2$K). Window geometry (including frame): width = 1.80 m, depth= 1.75 m. Windows have triple glazing and total U-value of 0.7 W/m$^2$K, SHGC (with no shading device) = 0.43, visible transmittance (with no shading device) = 0.63.
- Shading: Exterior venetian blinds, activated when the solar irradiance exceeds 170 W/m$^2$
- Roof: Concrete slab plus insulation, U-value = 0.09 W/(m$^2$K)
- Floor: 15 cm concrete + 7 cm light weight concrete
- Occupation schedule: Working time: Mon to Fri, 08:00 – 16:00
- Ventilation air flow: Working time: 6 m$^3$/(hm$^2$), Non-working time: 10 m$^3$/(hm$^2$). Ventilation supply air temperature equals outdoor temperature.
- PCM boards of 5 mm thickness behind 5 mm gypsum boards in 2 interior walls

The results of the simulations, see Figure 7, show that the adoption of a PCM layer presents little impact on the operative temperature. In the most favorable condition, the adoption of 2 walls (partitions) with a PCM layer can decrease the peak of the operative temperature of about 0.5°C. A parametric analysis was also conducted on the temperature range of the PCM layer. The reason for this analysis lies in the assumption that a transition temperature 16-26 °C seems to be quite low, if the aim of the PCM technology is to reduce the cooling load. A transition range 21-31 °C seemed to be more adequate. However, as can be seen in Figure 7, the simulations do not show a significant difference between the two different transition ranges. This fact, which is quite unexpected, may rise some doubt about the reliability of the simulations.




*PCM_21* layer:
5 mm (thickness), transition range
16-26 °C, enthalpy of fusion 80 kJ/kg

*PCM_26* layer:
5 mm (thickness), transition range
21-31 °C, enthalpy of fusion 80 kJ/kg

Figure 7. Simulated operative temperature for a south facing office for a week in August.

In conclusion, the simulations did not indicate that the PCM layer is able to considerably improve the thermal conditions of the indoor environment, in contradiction to the results of the previous mentioned laboratory measurements. Is must be mentioned also that the calculation tool presents some limitations (e.g. the solar irradiance that enters the indoor environment is divided homogeneously on all the indoor surface, without taking into account the geometry of the incoming solar beams). Furthermore, the enthalpy of fusion adopted during the calculations (80 kJ/kg), and derived from experimental measurements on the DuPont panel [Cao et al 2010], is substantially lower than conventional value of pure paraffin wax (150-200 kJ/kg). This may also explain the little impact that the PCM layer seems to have on the thermal environment. However it is proposed to perform a field test in some of the offices in the building investigating the performance of PCMs in real buildings in cold climate. These studies will be performed in the ZEB centre.

# Ventilation, Heating and Cooling Systems

Different ventilation concepts were discussed during the early phases of design. A main goal was to be able to minimize the energy use for fans, heating and cooling by passive strategies and effective demand control. Natural ventilation by automatically controlled window opening was considered, but was not chosen due to cost, maintenance and security reasons. However, the possibility for the users to open the windows was considered important for user satisfaction, it is a requirement according to the Norwegian building code and it was recommended for the rooms without special security restrictions.

The ventilation system had to be designed for the given room layout with many small offices with suspended ceilings. Maximum flexibility and controllability were important design goals. Hence, the chosen ventilation strategy was based on VAV with *active supply air diffusers* [Maripuu 2009]. The active air diffusers have built-in controls that automatically measure and control the air volumes and temperatures at the room level. The diffusers contain temperature sensors and motion detectors, and may be coupled to $CO_2$-sensors. The air volume is controlled by a small motor in the diffuser; this controls the lamella openings so that the air volumes may be quickly increased while the air velocity is kept constant. In this way the diffuser provides an optimum draft-free distribution of fresh air within the whole range of minimum to maximum ventilation air volumes. Quick fluctuations in loads, for example a change in the occupancy density or fluctuations in solar gains, may then be tackled by an instant change in supply air volume based on the difference between duct temperature and room air temperature. This provides for very precise demand control and consequently a minimization of energy use for heating, cooling and ventilation fans. Three separate ventilation units were selected to serve north, south and interior zone respectively. With this ventilation system, it was projected that a mean ventilation rate of 6 $m^3/(m^2h)$ during occupied hours would provide a comfortable indoor climate. With a temperature efficiency of the heat exchanger of 85% and a Specific Fan Power of 1.0 $kW/m^3/s$, the system is also very energy efficient. The predicted net energy demand is shown in Table 2.

| | | |
|---|---|---|
| Space heating | 7.6 | kWh/m² |
| Ventilation heating | 2.8 | kWh/m² |
| Hot water | 5.0 | kWh/m² |
| Fans | 6.0 | kWh/m² |
| Pumps | 1.0 | kWh/m² |
| Lighting | 12.5 | kWh/m² |
| Appliances | 15.7 | kWh/m² |
| Space cooling | 0.0 | kWh/m² |
| Ventilation cooling | 2.8 | kWh/m² |
| **Total net energy demand** | **53.4** | **kWh/m²** |

Table 2. Predicted yearly net energy demand for the building, per net heated floor area. Calculations are based on statistical weather data for Bergen, and according to [NS 3031:2010] using the computer program SIMIEN (www.programbyggerne.no).

Since the heating and cooling loads of the building are so small, a ventilation system with active air diffusers may also facilitate the function of heating and cooling of the space in a comfortable way. During cold nights, the ventilation system will be used to heat the interior space with recirculated and central heated supply air.
Thus radiators, fan coils and other conventional heating systems may be omitted.

# Energy Supply Systems

There is a local energy central with a sea water based heat pump located close to the building. This is owned and operated by Forsvarsbygg. The pipelines pass just in front of the building. Given the very low energy demand for heating and cooling, it was not considered cost-efficient to install any thermal energy systems in the building. The local energy central has a high efficiency, the yearly system efficiency factor (COP including distribution losses) was estimated to 3.0 for heating and 10.0 for cooling (mostly free cooling by sea water). This gives a calculated delivered energy to the building of 41.8 kWh/yr.

To be able to satisfy the defined criterion for a zero energy building, the installation of a photovoltaic system on the south facing roof was proposed. To fulfill the ZEB criterion, the photovoltaic system should consequently deliver a yearly energy production of (41.8-15.7) kWh/m$^2$ = 26 kWh/m$^2$, which is about 50,000 kWh/yr. According to statistical weather data for Bergen [NS 3031:1987], the yearly total solar radiation on a south facing surface with a tilt of 30° is 964 kWh/m$^2$. This is the optimal orientation of a photovoltaic panel in Bergen, and it corresponds to the orientation and tilt of the roof of the building, which has an area of 310 m$^2$. Photovoltaic panels typically have an efficiency of 10-20%, depending on the type. To satisfy the ZEB criterion, the system efficiency of the photovoltaic system has to be about 17% to produce 50,000 kWh in a statistical normal year. More detailed calculation of the PV system need to be done in the detailed design stage to determine the optimal layout of the system.

# Conclusions

The approach taken in the design of this zero energy building was an integrated process with the involvement of a multi-disciplinary group from the early phases. There was a high focus on minimizing investment and operation costs, while providing a user friendly and robust solution. In this way, the group was able to optimize the building layout in conjunction with the technical systems, which led to a very simple and resource efficient design. The total life cycle costs of the zero energy building were calculated to be approximately the same as the energy class A building.

# References


[Cao et al 2010] Cao, S., A. Gustavsen, S. Uvsløkk, B.P. Jelle, J. Gilbert and J. Manuksela: *The Effect of Wall-Integrated Phase Change Material Panels on the Indoor Air and Wall Temperature – Hot box Experiments*. Proceedings of the Renewable Energy Research Conference 2010, Norwegian Universisty of Science and Technology, Trondheim June 7-8, 2010.

[Dupont 2007] DupontTM Energain® Energy-Saving Thermal Mass Systems, Data Sheet-Measured Properties, DupontTM EnergainR, 2007. [Online]. Available: http://energain.co.uk/Energain/en_GB/assets/downloads/tech_info/dupont_energain_datasheet.pdf

[Maripuu 2009] Maripuu, M. *Demand Controlled Ventilation (DCV) Systems in Commercial Buildings Functional Requirements on Systems and Components*, Thesis For The Degree Of Doctor Of Philosophy, Building Services Engineering Department of Energy and Environment Chalmers University of Technology Göteborg, Sweden.

[NS 3031:2010] Norsk Standard NS 3031:2010. *Bergning av bygningers energiytelse. Metode og data. Calculation of energy performance of buildings. Method and data.* Standard Norway, Oslo.

[NS 3031:1987] Norsk Standard NS 3031:1987. *Varmeisolering - Beregning av bygningers energi- og effektbehov til oppvarming og ventilasjon. Thermal insulation - Calculation of the energy and power demand for heating and ventilation in building*. Standard Norway, Oslo.