

Innovative Danish Building Envelope Components for Passive Houses

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1 Introduction

The Passive House concept has not as yet become generally accepted in Denmark. But there is a growing awareness of the concept as a solution to achieve high thermal comfort conditions and a low energy demand on low construction costs. This growing awareness is partly due to the introduction of new tighter energy performance requirements in 2006 and a new classification system, where buildings can be classified as being a “Low energy building class 1 or 2”. These new requirements are based on the EU-directive on Energy Performance of Buildings, EPBD (2002/91/EC). The new classification system will make it possible for building contractors to better promote low energy houses and even passive houses to the consumers. The consumers will, in an easy way, be able to demand that their new house should have a better energy performance than the minimum requirements specified in the Building Regulations. The perhaps most important basic passive house concept requirement in a relatively cold Danish climate is envelope constructions with superior thermal insulation without thermal bridges. Some Danish producers of building components have during the last couple of years, developed new highly insulated and in some cases very innovative envelope constructions. In this paper, two of the most interesting components are described; a prefabricated light-weight exterior wall element with a load-bearing plywood and steel frame and a foundation / slab on ground solution based on concrete and EPS insulation materials. To illustrate the thermal efficiency of the new components in a realistic context, the paper will show results from detailed calculations of the space heating demand and peak heating load for a newly built single-family house.

2 Prefabricated light-weight exterior wall element

The exterior wall system (developed by Knauf Danogips A/S) is based on prefabricated framed walls with studs of plywood and thin plate steel (see figure 1). The width of the plywood and insulation thickness is optional. U-shaped galvanized steel profiles with a thickness of 1 mm and 12 mm of plywood boards are used. The steel profiles have a body width of 45 mm and 50/42 mm flanges.



Figure 1. Typical light-weight exterior wall element with a load-bearing plywood and steel frame. Notice that there is no steel going through the wall element, and the studs is only placed around openings. Thereby the thermal bridge effect is minimal.

The element in figure 1 has 350 mm of mineral wool. In addition a vapour barrier and 45 mm of mineral wool in a frame of Z-profiles are used on the inside of the load bearing frame. Thereby the barrier is protected from perforation related to the carrying out of electrical installations etc. On the inside the element is covered with two layers of 13 mm plasterboard and on the outside an airtight 12.5 mm Aquapanel cement-board and plastering of 12 mm are used.

The total insulation thickness is nearly 400 mm. Detailed heat loss calculations including the thermal bridge effects of the plywood and steel frame have showed that a mean overall U-value of about 0.11 is achievable in a typical Danish single-family house (see figure 3). The thermal bridge effect is only 12 %, i.e. the extra heat loss compared to an exterior wall without the steel and plywood skeleton. In a cavity wall with 400 mm of insulation the thermal bridge effect is typically about 25 %.

The development of the above described highly insulated exterior wall system has reduced the material expenses by about 20 % (exclusive of insulation) compared to traditional framed walls with studs of cold-formed steel profiles.

3 Foundation / slab on ground solution based on EPS

The foundation solution (developed by Sundolitt A/S) is based on principles used in the southern parts of Sweden for several years, which is very different from the building tradition in Denmark. New single-family houses in Denmark are typically constructed with a slab on ground solution (i.e. without basement) detached from the foundation by a small joint. The foundation depth is usually at least 90 cm below terrain. The typical and new design solutions are shown in figure 2. The idea of the new solution is to create a coherent concrete plate so that the house is standing on ground as a ship in the sea. This is done by a complete casting together of the inner foundation flange and the concrete slab on ground in order to prevent differential settlement.

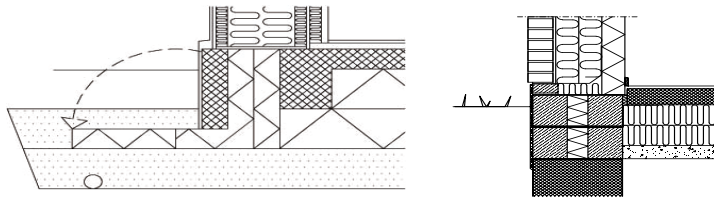


Figure 2. Left: New energy efficient foundation / slab on ground solution based on concrete and EPS insulation. Right: Conventional Danish foundation solution in energy efficient houses.

The foundation depth is only about 40 cm. Having only 40 cm of soil to the lower edge of the outer foundation flange and about 60 cm to the perimeter drain, there is an immediate risk of frost heave of the foundation and frost in perimeter drain. To solve these problems a solution with double purpose was created. U-shaped EPS insulation elements are used to cast out the outer concrete flange. While the concrete is still adaptable the front of the elements is cut lose. The cut off toe with a length of roughly 50 cm is then laid down on ground as shown in figure 2 (left) protecting the perimeter drain and soil from penetrating frost. Detailed calculations have indeed showed that the foundation including drain is protected against frost heave. A positive effect from the complete casting together of the concrete slab and inner foundation beam is a better protection against air penetrating upwards from subsoil (pollution and radon) compared to conventional solutions. Radon is an overlooked health problem in Denmark and many other European countries. On a European level an investigation of the risk of lung cancer associated with exposure at home to the radioactive disintegration products of naturally occurring radon has been carried out. These studies show appreciable hazards from residential radon and indicate that it is responsible for about 2% of all deaths from cancer in Europe [Darby 2004]. The National Board of Health in Denmark estimates that about 300 Danes yearly dies from lung cancer due to residential radon. This is almost as many as all traffic casualties in Denmark.

The thermal efficiency of the solution is good. The insulation thickness of 400 mm in the slab on ground construction corresponds to a U-value of 0.09 W/m²K. The typical line loss coefficient is 0.09 W/mK (the value is 0.18 W/mK at doors and other large openings).

4 Heating demand in Danish Single-family House with New Innovative Components

This paragraph illustrates the thermal efficiency of the new components in a realistic context by detailed calculations of the space heating demand and peak heating load in a newly built single-family house (see figure 3 below). The new components are used together with mechanical ventilation with heat recovery and traditional Danish

windows as well as highly insulated windows with slim frame profiles. Results will be compared to the passive house standard.



Figure 3. Danish low energy single-family house situated in Lemvig. The gross floor area is 145 m² (net area is 115 m²). The area of windows and doors is 26 m²

4.1 Description of constructions and systems

Exterior wall and foundation / slab on ground constructions have been described above. The ceiling construction is a typical rafter construction where insulation is placed below, between and above the foot of the rafter. A total of 450 mm is used. The windows are traditional wooden windows with double-pane low-e-glazing. Table 1 shows the heat loss coefficients and insulation thicknesses.

Table 1. Heat loss coefficients and insulation thicknesses for the house in figure 3.

Building envelope component	U-value [W/m ² K]	t _i [mm]
Exterior wall	0.11	400
Slab on ground	0.09	400
Ceiling	0.09	450
Windows and doors	1.62	-
Thermal bridge / assembly	ψ-value [W/mK]	t _i [mm]
Foundation	0.10	-
Window reveal	0.02	-

It is obvious that the heat losses from the thermal envelope (except from windows) are at the desired level of passive houses (0.1 W/m²K). But it is evident that in order to further reduce energy consumption and to reach “passive house level” there is a need for windows with much better thermal properties (greater energy contribution); products which are not available on the Danish market as yet. However, stimulated by the mentioned EPB-directive manufactures are slowly beginning to realize the potential. The ventilation system with heat recovery (Nilan Comfort 300 EC) has an annual average temperature efficiency of about 85 %. The power consumption (SEL-value) of the used fans with EC-motors is 0.8 kJ/m³ corresponding to 33 W at a typical average air flow rate of 150 m³/h and a pressure drop of 100 Pa outside the heat recovery unit. The passive house recommendation is an electricity efficiency

less than $0.4 \text{ Wh/m}^3 = 60 \text{ W}$. The power consumption of the actual system is almost half of that.

4.2 Calculation of space heating demand

Calculations are made based on standard Danish input data, i.e. indoor temperature of $20 \text{ }^\circ\text{C}$, typical external climate data (DRY=Danish Reference Year) an internal heat load of 5 W/m^2 and a ventilation air flow rate of 0.3 l/s/m^2 or about 0.5 ACH. The internal heat load and ventilation air flow rate are per m^2 gross area. An infiltration rate of 0.1 ACH is used, which is based on n_{50} -air leakage measurements on other energy efficient single-family houses, which showed air changes of around 1.5 ACH. The calculations were carried out using the building simulation program BSIM [BSIM 2006]. Thermal properties of both investigated window solutions are shown in table 2.

Table 2. Thermal properties for two investigated windows solutions.

Scenario	Traditional Danish windows	“Passive house windows”
U_g [$\text{W/m}^2\text{K}$]	1.20	0.70
g_g [-]	0.63	0.50
λ_g [W/mK]	0.087	0.035
U_f [$\text{W/m}^2\text{K}$]	1.40	0.75
Frame width [mm]	Not less than 100 mm	A_f reduced by 40 %
U_w [$\text{W/m}^2\text{K}$]	1.62	0.85
g_w [-]	0.38	0.38

The frame width of the traditional Danish windows is about the same as for typical passive house solutions. The assumptions regarding the model with “passive house windows” are the use of triple-pane low-e-glazing with a high solar transmittance (Pilkington Optitherm S3), an insulated frame construction and a non-metallic spacer. Also, a slimmer frame construction is simulated by reducing the frame area by 40 %. A slimmer frame construction is a straightforward route for reduction of the frame heat loss and increase of the transparent area leading to increased solar energy and daylight transmission without changing the glazing composition. The consequence of using better insulating glazing is a reduction in the solar heat gain. But by using a slimmer frame, the effect can be neutralized as the above example show (the overall g-value is 0.38 in both cases).

The calculated yearly space heating demand with traditional Danish windows is $21 \text{ kWh/m}^2/\text{a}$ and the demand with “passive house windows” is $11 \text{ kWh/m}^2/\text{a}$. As the Danish method uses gross floor area and the passive house method operates with the internal net floor area there is a difference in the heating demand of about 20-30%. Even more significant is the difference in the internal heat load where the passive house method describes a load of 2.1 W/m^2 compared to 5 W/m^2 used in the Danish method.

4.2.1 Comparison with the passive house definition

The definition of a Passive House is a house with a peak heating load less than 10 W per m² living area (= max. heat load that the ventilation system can distribute), which is independent of climate. Figure 4 shows the heating load during the year for the house in Lemvig with “passive house windows” and an internal heat load of 5 W/m².

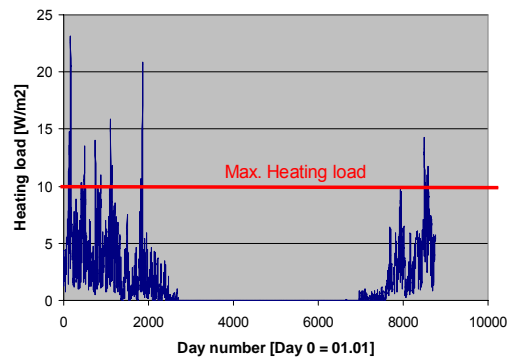


Figure 4. Heating load in W per m² living area (internal area).

It is obvious from figure 4 that most of the time during the heating season the heating load is below 10 W/m² and therefore it can be argued that the energy efficiency of the house is good enough. To further reduce the heat load, relevant measures are better air tightness and less thermal bridge effects.

5 Conclusion

By using the described innovative components with insulation thicknesses of about 400 mm in a typical and fairly airtight Danish single-family house together with, of course, energy efficient ventilation with heat recovery with temperature efficiency of 85% and slim framed windows with U-values close to 0.8 W/m²K, the passive house standard can be reached.

6 References

- [Darby 2004] Darby, S, et al. Radon in homes and risk of lung cancer: Collaborative analysis of individual data from 13 European case-control-studies. BMJ Publishing Group Ltd. 2004.
- [BSIM 2006] BSIM. Building Simulation. Integrated software for thermal analysis of buildings and installations. Danish Building Research Institute (2006).