Passive houses in cold Norwegian climate

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1.0 Introduction

During the last 3-4 years the interest in low energy houses has increased considerably in Norway. More than 3000 low energy houses have been erected, are under construction or in the planning phase. More than 10 % of these dwellings have passive house ambitions (space heating demand equal to or below 15 kWh/m²a).

However, there still remain some unsolved matters regarding the passive house definition and technical solutions for Norwegian conditions:

- Several locations in Norway have cold or extremely cold weather conditions compared to Central Europe. A valid question is if the passive house definitions of 15 kWh/m²a and 10 W/m² should still apply for such cold climate. Is it possible to build such houses with current technology? And if so, are they economical feasible and marketable in the Norwegian housing market?
- The normal internal load used for calculating the space heating load in Norway is in the range 6-8 W/m², compared to the very low standard value of 2.1 W/m² used in the Passive House Planning Package [PHI 2004]. This high internal gain value used in Norway is partly due to historically low electricity price (compared to Central Europe). But what level of internal gain should be used for calculating the space heating demand in Norwegian passive houses?

Based on simulations and analyses of a few building projects, incorporating apartments, row houses and a detached house, these issues are discussed in this paper.

2.0 Methods

2.1 Simulation tool

The simulation program SCIAQ Pro [Dokka 2006] is used to simulate space heating load and peak demand. Simulations done with this program has been compared to results from the PHPP program from the Passive House Institute [PHI 2004], see section 3.3. SCIAQ Pro, which is based on a transient 3R-2C wall model, has also been validated according to the IEA BESTTEST [Judkoff 1995], see the user guide for details [PB 2006].

The main reason to use SCIAQ Pro instead of the PHPP, is due to the fact that the PHPP does not currently offer the necessary range of Norwegian climate data.

2.2 Building types

For the base case simulations, a building project including row houses and apartment buildings at Lillehammer and a single family house in Oslo is used. The apartment building is a 2 storey building with 10 apartments, each with a heated floor area of 57 m², see figure 1. The row house project consists of a section of 5 row houses, each with a heated floor area of 109 m², see figure 2. The 2-storey detached house in Oslo, has a heated floor area of 160 m², see figure 3. Areas and other important data for the building projects are given in table 1.

Table 1 Data for the three different building types.

	Apartment building[1]	Row houses[2]	Detached house[3]
Heated floor area	567 m² (10 x 56.7)	547 m² (5 x 109.4)	160 m²
Heated air volume	1327 m³	1231 m³	355 m³
External wall area	345 m²	327 m²	180 m²
Windows and door area (E/S/W/N)	109.7 m² (0/70.8/0/38.9)	87 m² (0/50/0/37)	35 m² (3.1/18.1/4.4/9.5)
Roof area	294 m²	285 m²	80.5 m²
Floor area (slab on ground)	294 m²	285 m²	80.5 m²
Air change rate[4] (mechanical vent)	0.45 ach	0.45 ach	0.45 ach
Indoor temperature	20 °C	20 °C	20 °C

[1] Areas are for the whole apartment building, i.e. for all ten apartments.
[2] Areas are for all five row houses.
[3] The window and door area for the detached house is reduced from 66.5 m² in the original design of the building to 35 m². This is done to be able to reach the passive house standard with reasonable technical solutions.
[4] Air change rate is given as the expected mean air change rate in the heating season, and not the design air change rate.

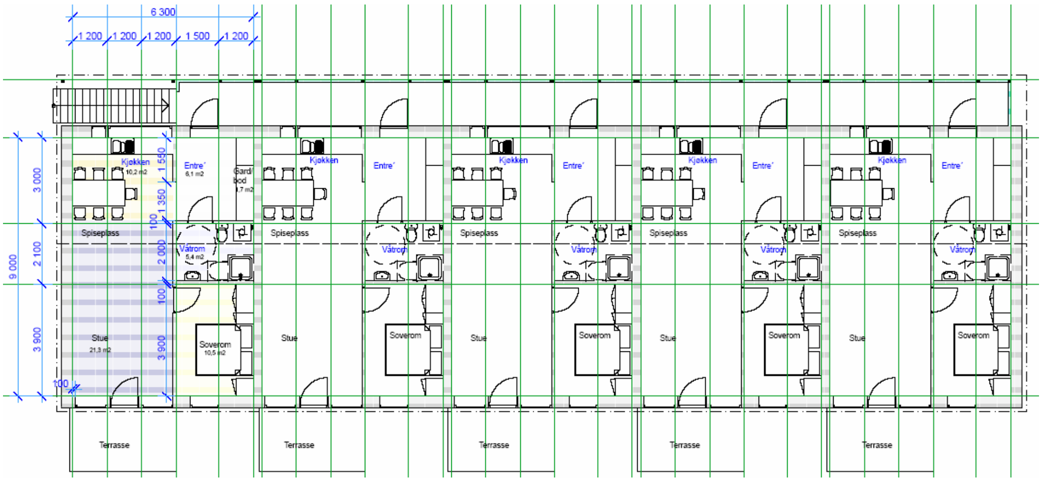

Figure 1 Ground floor of the apartment building at Smestadmoen Park in Lillehammer.

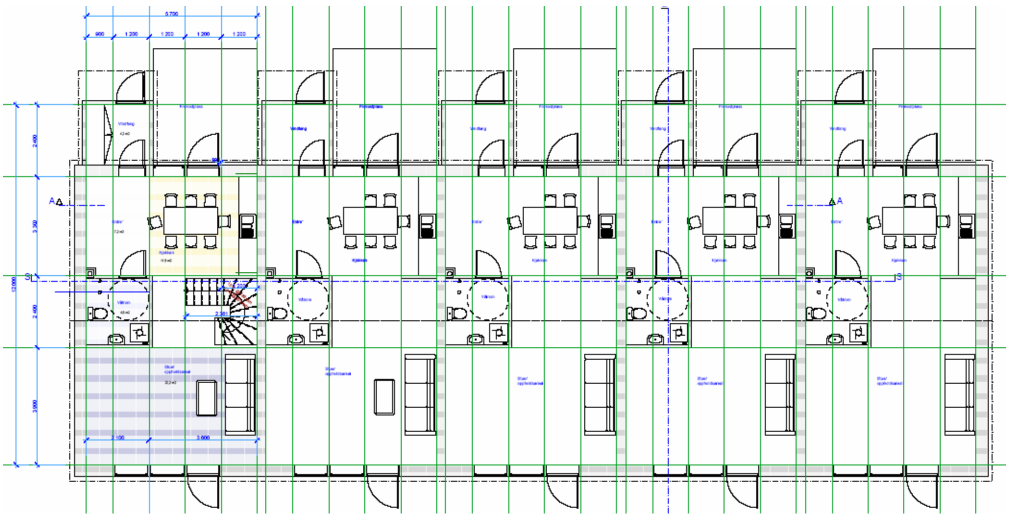

Figure 2 Ground floor of the five row houses at Smestadmoen Park, Lillehammer.

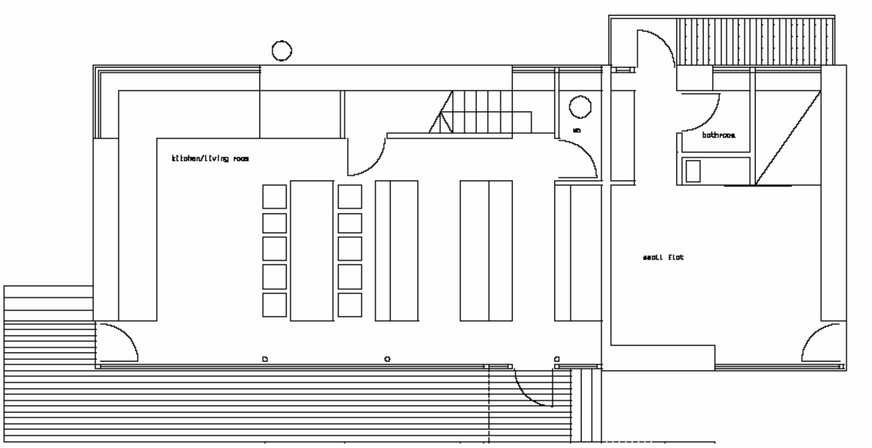

Figure 3 Detached house in Oslo. Ground floor plan.

2.3 Climates

To investigate how different Norwegian climates affect the space heating load, three different locations in Norway have been used:

- Oslo, the capital of Norway.
- Lillehammer, situated 150 km north of Oslo with a typical cold inland climate.
- Karasjok, one of the northernmost municipalities in Norway with very cold winters.

To compare to typical Central European climate, Zurich in Switzerland is used. A summary of the weather data for the four climates are given in table 2.

Table 2 Summary of weather data for the four climates.

Climate	**Annual mean temperature**	**Design winter temperature**	**Mean annual radiation on a horizontal surface**
Oslo	5.7 °C	- 17.6 °C	112 W/m²
Lillehammer	3.3 °C	- 25 °C	106 W/m²
Karasjok	- 2.5 °C	- 43.4 °C	79 W/m²
Zurich (Switzerland)	8.9 °C	- 9.4 °C	125 W/m²

2.4 Internal heat gains

In the proposal for the new building code in Norway [Thyholt 2003], the internal heat gain for residential buildings is set to 7.9 W/m². This is almost four times the standard value used in the PHPP [PHI 2004]. In [Dokka 2006] a Nordic proposal for internal gains in passive houses is set to 4.0 W/m². In this analysis, two levels of the internal heat gains are used: 2.1 W/m², which is the standard value used in the PHPP, and a “Nordic proposal” of 4.0 W/m².

3.0 Results

3.1 Building type dependency

All results in this section is based on an internal heat gain of 2.1 W/m², which is the standard value used in the PHPP [PHI 2004]. Results for other internal gains are given in section 3.3. Table 3 shows which U-values, air tightness and ventilation heat recovery values (called “the energetic building standard”), that are necessary for the row house project to achieve the passive house standard of 15 kWh/m²a. Simulations have also been carried out for the apartment building, but the results are very close to the row house results. In fact, the same energetic building standard can be used for the apartment building to meet the 15 kWh/m²a requirement. The results for the apartment building are therefore not included in this paper, but can with sufficient accuracy be taken as the same as the row house project. Table 4 gives the necessary energetic building standard for the detached house.

Table 3 Energetic building standard for the row house section, necessary to meet the passive house requirement of 15 kWh/m²a.

Climate	**Oslo**	**Lillehammer**	**Karasjok**	**Zurich**
Roof construction	U = 0.07 W/m²K (~550 mm iso)[3]	U = 0.07 W/m²K (~550 mm iso)	U = 0.06 W/m²K (650 mm)	U = 0.14 W/m²K (300 mm)
External wall, main façade	U = 0.11 W/m²K (~350 mm iso)	U = 0.11 W/m²K (~350 mm iso)	U = 0.07 W/m²K (550 mm)	U = 0.15 W/m²K (300 mm)
External wall, gable wall	U = 0.10 W/m²K (~400 mm iso)	U = 0.09 W/m²K (~450 mm iso)	U = 0.06 W/m²K (650 mm)	U = 0.15 W/m²K (300 mm)
Floor (slab on ground)[1]	U = 0.08 W/m²K (~350 mm iso)	U = 0.08 W/m²K (~350 mm iso)	U = 0.07 W/m²K (500 mm)	U = 0.15 W/m²K (200 mm)
Windows (total U-value and solar heat gain coefficient)	U = 0.80 W/m²K (g = 0.46)	U = 0.65 W/m²K (g = 0.46)	U = 0.54 W/m²K (g = 0.46)	U = 0.80 W/m²K (g = 0.46)
Ventilation per sqm (heat recovery)	1.02 m³/hm² (η = 83 %)	1.02 m³/hm² (η = 87 %)	1.02 ach (η = 97 %)	1.02 ach (η = 78 %)
Air tightness[2] (infiltration)	N50 = 0.6 ach (n = 0.04 ach)	N50 = 0.45 ach (n = 0.03 ach)	N50 = 0.3 ach (n = 0.02 ach)	N50 = 0.6 ach (n = 0.04 ach)
H" (specific heat loss)	0.36 W/m²K	0.31 W/m²K	0.22 W/m²K	0.47 W/m²K
Annual space heating demand	15.0 kWh/m²a	14.9 kWh/m²a	14.8 kWh/m²a	14.9 kWh/m²a
Peak heat load	10.0 W/m²	10.6 W/m²	8.8 W/m²	10.6 W/m²

[1] This is the calculated U-value of the floor, including the thermal resistance in the ground, according to EN ISO 13 370.
[2] Infiltration rate is simplified, but conservative, calculated as one 15th of the air tightness: n = N50/15.
[3] The approximate insulation thickness is calculated based on an average conductivity of 0.04 (taking into account constructive elements in the wall and roof).

Table 4 Energetic building standard for the detached house necessary to meet the passive house standard of 15 kWh/m²a.

Climate	**Oslo**	**Lillehammer**	**Karasjok**	**Zurich**
Roof construction (nominal insul. thickn.)	U = 0.07 W/m²K (~550 mm iso)	U = 0.07 W/m²K (~550 mm iso)	U = 0.05 W/m²K (800 mm)	U = 0.10 W/m²K (400 mm)
External wall, façade	U = 0.09 W/m²K (~450 mm iso)	U = 0.08 W/m²K (~450 mm iso)	U = 0.05 W/m²K (800 mm)	U = 0.12 W/m²K (350 mm)
External wall, gable wall	U = 0.09 W/m²K (~450 mm iso)	U = 0.08 W/m²K (~450 mm iso)	U = 0.05 W/m²K (800 mm)	U = 0.12 W/m²K (350 mm)
Floor (slab on ground)	U = 0.07 W/m²K (~450 mm iso)	U = 0.07 W/m²K (~450 mm iso)	U = 0.05 W/m²K (650 mm)	U = 0.10 W/m²K (300 mm)
Windows(total U-value and solar heat gain coefficient)	U = 0.65 W/m²K (g = 0.46)	U = 0.54 W/m²K (g = 0.46)	U = 0.35 W/m²K (g = 0.35)	U = 0.80 W/m²K (g = 0.46)
Ventilation (heat recovery)	0.99 m³/hm² (η = 87 %)	0.99 m³/hm² (η = 92 %)	0.99 m³/hm² (η = 99 %)	0.99 m³/hm² (η = 80 %)
Air tightness (infiltration)	N50 = 0.45 ach (n = 0.04 ach)	N50 = 0.45 ach (n = 0.03 ach)	N50 = 0.3 ach (n = 0.02 ach)	N50 = 0.6 ach (n = 0.04 ach)
H" (specific heat loss)	0.38 W/m²K	0.33 W/m²K	0.20 W/m²K	0.51 W/m²K
Annual space heating demand	15.1 kWh/m²a	15.1 kWh/m²a	15.0 kWh/m²a	14.9 kWh/m²a
Peak heat load	10.9 W/m²	11.5 W/m²	10.2 W/m²	12.0 W/m²

3.2 Dependency to climate and internal gains

To illustrate the dependency to climate and internal heat gains, the necessary energetic building standard for the Oslo climate with an internal gain of 2.1 W/m² is used as the basis for the simulations (see the "Oslo" column in table 3 and 4). This building standard has then been simulated for a combination of the four climates and the two levels of internal gain (2.1 and 4.0 W/m²). The simulation results with respect to annual space heating load and peak heat demand are shown in table 5.

Table 5 Annual space heating load and peak heat demand for the different climates and the two levels of internal gain.

	Internal heat gain: 2.1 W/m²		Internal heat gain: 4.0 W/m²	
	Rowhouse	Detached house	Rowhouse	Detached house
Oslo	15.0 kWh/m²a (10.0 W/m²)	15.1 kWh/m²a (10.9 W/m²)	8.1 kWh/m²a (8.0 W/m²)	9.0 kWh/m²a (8.9 W/m²)
Lillehammer	20.1 kWh/m²a (12.8 W/m²)	20.0 kWh/m²a (14.2 W/m²)	12.1 kWh/m²a (10.9 W/m²)	13.1 kWh/m²a (12.3 W/m²)
Karasjok	37.1 kWh/m²a (19.7 W/m²)	37.9 kWh/m²a (21.5 W/m²)	26.9 kWh/m²a (17.8 W/m²)	29.0 kWh/m²a (19.6 W/m²)
Zurich	8.4 kWh/m²a (7.6 W/m²)	7.1 kWh/m²a (7.5 W/m²)	2.9 kWh/m²a (5.4 W/m²)	2.4 kWh/m²a (3.5 W/m²)

3.3 Comparison with PHPP calculations

For comparison, the row house with Oslo weather data was calculated with the PHPP. The constructions, internal gains, air change rate and efficiency of heat recovery were kept the same as for the SCIAQ calculations. The resulting space heating load was 16 kWh/m^{2}a and the peak demand was 10.9 W/m^2. The slightly higher annual space heating demand is probably due to the fact that the ambient temperature data used for the PHPP calculations are somewhat lower over the year than the ones used in the SCIAQ simulation. The peak demand calculated with the PHPP is fairly close to the one calculated by SCIAQ.

4.0 Discussion and conclusions

4.1 Building type

The above calculations have shown that in order to build a row house with passive house standard in Oslo climate, the following technical standard is required: Insulation thickness between 550 and 350 mm, a heat recovery rate of 83 %, air tightness of 0.6 ach and windows with a U-value of 0.80 W/m²K. This is quite ambitious, but it is technical possible to build with available technology. However, it is well above the passive house standard for row houses in central Europe. The extra costs associated with such a standard will also be quite high, and will probably hinder the market penetration of passive houses in Norway. However, if the internal gains are increased to 4.0 W/m² (Nordic value), the passive house standard for row house will still be ambitious, but more economical reasonable. I fact, for the row house, it seems like the increase from 2.1 to 4.0 W/m², approximately corresponds to moving the house from Oslo to Zurich (se table 5).

For the detached house the requirement for technical solutions are even higher, incorporating insulation thicknesses between 450 and 550 mm, a heat recovery rate of 87 %, air tightness of 0.45 ach and window U-value of 0.65 W/m²K. This is also technical possible, but due to high costs it is probably not marketable in the current Norwegian housing market. If the internal gains are increased to 4 W/m², the technical solutions required to achieve the passive house standard are quite reasonable, and fairly close to the technical solutions necessary for the detached house in Zurich climate (see table 5).

4.2 Climate and internal gains

The simulations show that the dependency of the climate is quite strong. The annual space heating load for Lillehammer is 4-5 kWh/m²a higher than for Oslo (around 30 %). For the extremely cold climate of Karasjok, the annual space heating load is around 2.5 times higher than that of Oslo. Oslo on the other side, has around 2 to 3 times higher space heating load than Zurich, i.e. typical Central European climate.

The influence of the level on the internal gain is also very important, as shown in table 5. It seems like the effect of the internal gain (in percent) is greater when the space heating load is very low (at or below 15 kWh/m²a). Roughly, the increase of the internal gain from 2.1 W/m² to 4.0 W/m² corresponds to moving the house from typical Norwegian climate (Oslo) to typical central European climate (Zurich).

4.3 Conclusions

- With a standard internal gain of 2.1 W/m² it is technical possible but probably quite costly to build row houses that meet the 15 kWh/m²a requirement in Oslo climate. Detached houses are even more costly to build.
- In cold climates like Lillehammer and extremely cold climates like Karasjok it is unrealistic to meet the 15 kWh/m²a requirement, based on an internal gain of 2.1 W/m².
- If the internal gain is increased to 4.0 W/m², it is technical possible and economical reasonable to meet the 15 kWh/m²a requirement in both Oslo and Lillehammer climates.
- In the Karasjok climate it seems very difficult with current technology to meet the 15 kWh/m²a requirement, regardless of internal gains (up to 4.0 W/m²) and building type. However, only a small percentage of the Norwegian dwelling stock is located in such climate.
- The increase of the internal gain from 2.1 W/m² to 4.0 W/m² roughly equals the effect of moving the house from typical Norwegian climate (Oslo) to typical central European climate (Zurich).

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