# Adaption of the passive house concept in northern Sweden - a case study of performance

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## Abstract

This study analyzes the performance of a case study of low energy house built in Östersund (lat. 63°N), Sweden. The building is a semi detached house for two families, with each apartment having a floor space of 160 $m^2$ divided on two floors. The building was constructed during 2010 according to the Swedish passive house principles with design that meet the requirements for Swedish passive houses as defined by the Forum for energy efficiency buildings (FEBY) and the Swedish center for zero energy houses (SCNH). The house is connected to the district heating network, which is the main heat source for domestic water heating, floor heating in the bathroom and water based pre-heater coil in the ventilation system. Additionally, a wood stove is installed in the living room for thermal comfort and convenience of the residents. The two identical residential units in the building were inhabited in the end of 2010 by families with different characteristics; a family with two young children in one unit and a middle aged couple in the other.

A one year energy measurement campaign started in May 2012 for both of the residential units. The measurements started after a period of adjustments of the building energy system and include space and domestic water heating (separate measurements), household electricity, the amount of fuel wood used in the stove, and indoor thermal conditions. The results show that it is possible to build passive houses in the Northern regions of Sweden. The specific final energy demand of the case study was 23% lower than the Swedish FEBY-requirements. Differences were found between the monitored and calculated specific final energy demand. These differences depend to a large extant on the occupants' behavior and household characteristics. The final energy demand for heating and domestic water heating found to vary significantly between the two households.

**Keywords:** Passive house, Specific final energy use, Northern Sweden, Final energy requirements, energy systems.

# 1. Introduction

The International Passive House Association [iPHA 2010] describes the passive house as: (1) exceptionally high level of thermal insulation; (2) well-insulated window frames with triple low-e glazing; (3) thermal-bridge-free construction; (4) airtight building envelope; and (5) comfort ventilation with highly efficient heat recovery.

The certification requirements for passive houses in the international standard (the Passive House Planning Package, PHPP), which is developed by the Passive House Institute includes: the space heating demand must not be more than 15 kWh per square meter of living space per year. Alternatively, the heating load must not exceed 10 W/m$^2$. If active cooling is required to ensure comfort in summer, the energy demand for this is also limited to 15 kWh/(m$^2$year). The primary energy requirement for the total amount of domestic hot water, heating, cooling, auxiliary and household electricity must not exceed 120 kWh/(m$^2$year) [iPHA 2010].

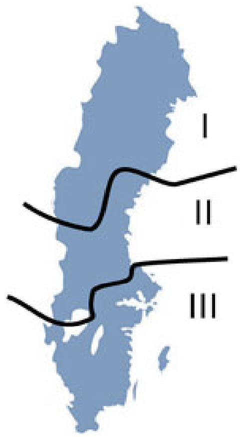

**Figure 1** The three climate zones in Sweden [Boverket 2012].

## 1.1. The Swedish criteria for passive house

The criteria for passive houses differ among different countries depending on existing local climates and building codes. For example, the *Swedish centre for zero energy houses* (*SCNH*), define passive houses as: "houses that has a high level of comfort, good quality, uses minimal energy and contributes to the reduction of carbon emissions" [iPHA 2010]. *SCNH* is a non-profit organization with the aim to promote the construction of low energy buildings, including passive houses. *SCNH* has released the [FEBY 12], which lists the criteria for zero energy-, passive- and mini energy- houses. The criteria take into account the international criteria but with adjustments to the three different Swedish northern climate zones (Figure 1) defined by the *Swedish National Board of Housing, Building and Planning* [Boverket 2012], as listed in Table 1. There are two main criteria: (i) the ratio of heat load demand to the heated floor area of the building; and (ii) the specific final energy demand. The two criteria are listed in Table 1 for the different climate zones.

**Table 1** The Swedish criteria for passive houses

| Climate zone: | | I | II | III |
|---|---|---|---|---|
| Heat load demand | W/m$^2$ | 19 | 18 | 17 |
| For non-electric heating systems | kWh/(m$^2$ year) | 63 | 59 | 55 |
| For electric heating systems | kWh/(m$^2$ year) | 31 | 29 | 27 |
| For combination of different type of energy systems | kWh/(m$^2$ year) | 78 | 73 | 68 |

## 1.2. Case study – the *Röda Lyktan* project

The case study is a semi detached house with two identical apartment units located in Östersund (latitude 63°N), Sweden and belong to climate zone I (Figure 1). The buildings were constructed during 2010 according to the Swedish passive house principles with design that meet the requirements for Swedish passive houses as defined by the Forum for energy efficiency buildings (FEBY) and the Center for zero energy buildings (SCNH). It is the first construction project that was built according to the passive house criteria in Northern Sweden. By this day the number of passive houses in the climate zone I region is much lower than in the rest of Sweden [Svensson 2012].

The two identical residential units in the building were inhabited by families with different characteristics: a family with two young children in one unit (Household 'A') and a middle aged couple in the other (Household 'B'). Each residential unit have 160 m$^2$ of floor area divided between two floors and includes: a cloakroom, hall, a kitchen, a living room, a toilet, a bathroom, a laundry room, a storage room and four bedrooms, as illustrated in Figure 2 and Figure 3. In addition, a wooden terrace, a balcony, an adjacent garage and a garbage room located at the outer side of the thermal envelope of the building and are not considered as part of the floor area.

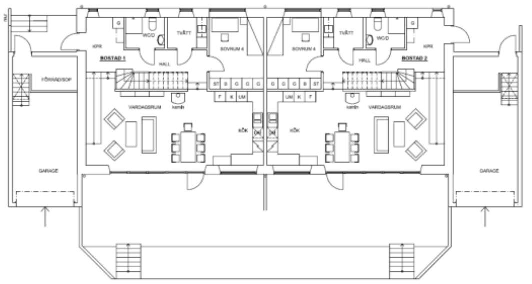

**Figure 2** Drawing of the first floor

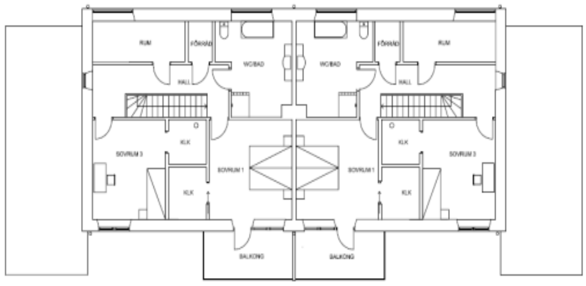

**Figure 3** Drawing of the second floor

### 1.3 Objective

The aim of this study is to analyze the adaption of the passive house concept in the climate of Northern Sweden by monitoring the final energy demand and the thermal comfort conditions of the *Röda lyktan* project.

## 2. Method

### 2.1. Thermal properties and energy systems

The case study building has a wooden frame on a concrete slab with steel mesh on foam sheets (cellular plastics). The exterior walls are made of several layers including: gypsum board, 175 mm stone wool, 240 mm cellulose fiber and wood panel at the exterior. The roof is made of metal sheets above composite wood board, cellulose fiber, stone wool and a gypsum board at the interior. The ratio between the building's thermal envelope and its floor area, i.e. the shape factor of the building, is about 2, which indicate on a relatively compact building. The thermal envelope of buildings with low shape is more energy efficient [Danielski et al. 2012]. The thermal properties of the different element are listed in Table 2.

**Table 2** Calculated thermal transmission.

| Building component | Ui-average W/($m^2$ K) | Area $m^2$ | Ui · A W/K |
|---|---|---|---|
| Roof | 0.078 | 168 | 13.1 |
| External wall | 0.093 | 242.5 | 22.6 |
| Windows | 0.75 | 57.6 | 43.2 |
| Doors | 0.8 | 4.2 | 3.4 |
| Slab on ground | 0.11 | 163.3 | 18 |
| Cold bridges - total | – | – | 8.9 |
| Thermal envelope | | 635.6 | 109.2 |

The main source for space and domestic water heating is the local district heating system network, operated by Jämtkraft. Space heating is delivered by water based pre-heater coils in the ventilation system and by floor heating installed both in the bathroom and the entrance hall areas. A wood stove is installed in the living room and used by the occupants according to their needs. Balance ventilation is installed with heat recovery by a rotary heat exchanger.

One year monitoring of final energy demand started in May 2012, after a period of adjustments of the ventilation system and comfort indoor temperatures, separately for each of the two residential units. Separate measurements were performed for space heating, domestic water heating, household electricity and for auxiliary electricity including electricity for the pumps and the ventilation system. The amount of wood fuel used in the stove was registered by the occupants. Indoor thermal conditions were monitored in three locations in each residential unit.

## 3. Results

A period of adjustment for ventilation air flow and indoor temperatures took place before the beginning of the measurements. The indoor temperature was adjusted separately for each household according to their wishes.

The indoor temperature varies considerably between the two households, as illustrated in Figure 4 and Figure 5. Household 'A' prefers warmer indoor conditions, which varies between 21°C and 25°C. The lowest temperatures were registered in the main bedroom, while temperatures higher than 25°C were monitored in the bathroom. The reason is not overheating by solar radiation but the installed floor heating in the bathroom. According to the house owner, the wood stove was mainly used to attain "a pleasant atmosphere" and less for achieving thermal comfort. About four months during the summer the house was vacant and lower temperatures were monitored.

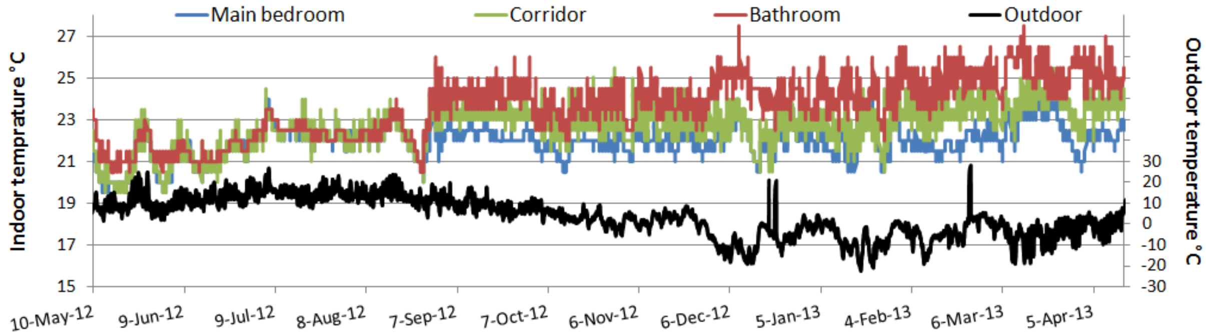


**Figure 4** The annual variations in outdoor temperature and in indoor temperature in selected rooms for household A – two parents and two small children.

The indoor temperature in household 'B' varied between 17°C and 23°C with the highest and lowest temperatures monitored in the bathroom and main bedroom, respectively, similar to household 'A'. Very low indoor temperatures were registered during the Christmas holiday, while the house was vacant for a short period. During the period of the measurements the two households stated that they were pleased with their thermal conditions. Therefore it can be concluded that the 2.5°C difference in indoor temperature during the heating period is the results of differences in perception of what is a good indoor thermal comfort conditions between the two households.

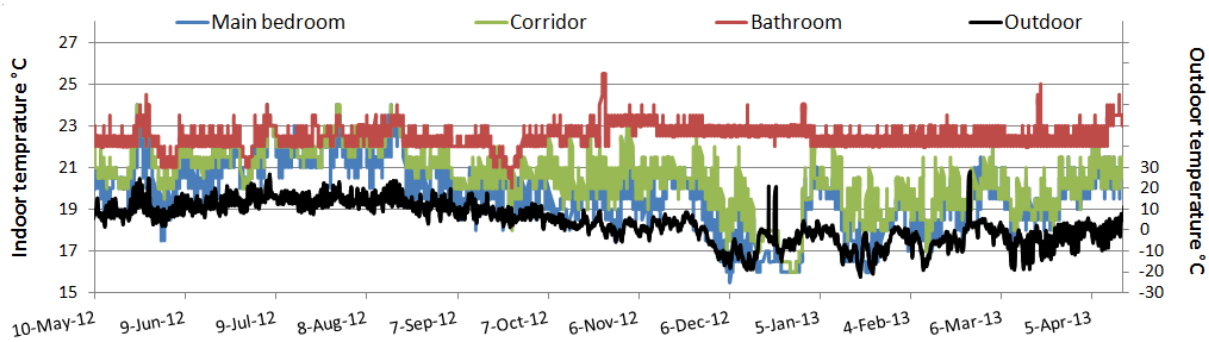


**Figure 5** The annual variations in outdoor temperature and in indoor temperature in selected rooms for household B – a middle age couple.

The calculated final energy demand by type of energy is illustrated in Figure 6 and compared to the final energy demand of the two households. The calculated final energy demand (excluding household electricity) has similar value as for household 'B' but is lower by 5 kWh/($m^2$ year) in

comparison to household 'A'. However, large differences were found between the calculated and monitored final energy demand for each energy type; the calculated energy for space heating and household electricity was under estimated, while the calculated energy for domestic water heating and auxiliary electricity was over estimated.
The measured household electricity include beside indoor electricity consumption also activities that do not contribute to the heat balance in the building, such as outdoor lighting, car motor heating and garage heating for household 'B'. Household 'B' uses a simple resistance heater in the garage to have above water freezing temperature during the winter, which is probably the main explanation for the higher value of household electricity in household 'B'.
The final energy demand for space heating in household 'A' was found to be higher by 45% or 13 kWh/($m^2$ year) in comparison to household 'B'. This is mainly because of the higher indoor temperatures. On the other hand, the final energy demand for domestic water heating in household A was found to be lower by 48% because of the long period in which the house was unoccupied during the summer. Larger differences in final energy demand would be expected if the 'Household A' apartment would have been occupied the whole year around, as illustrated by the "Third scenario" in Figure 6 with 20% higher heating demand (space heating + Wood stove + Domestic water heating) with comparison to 'Household B'.

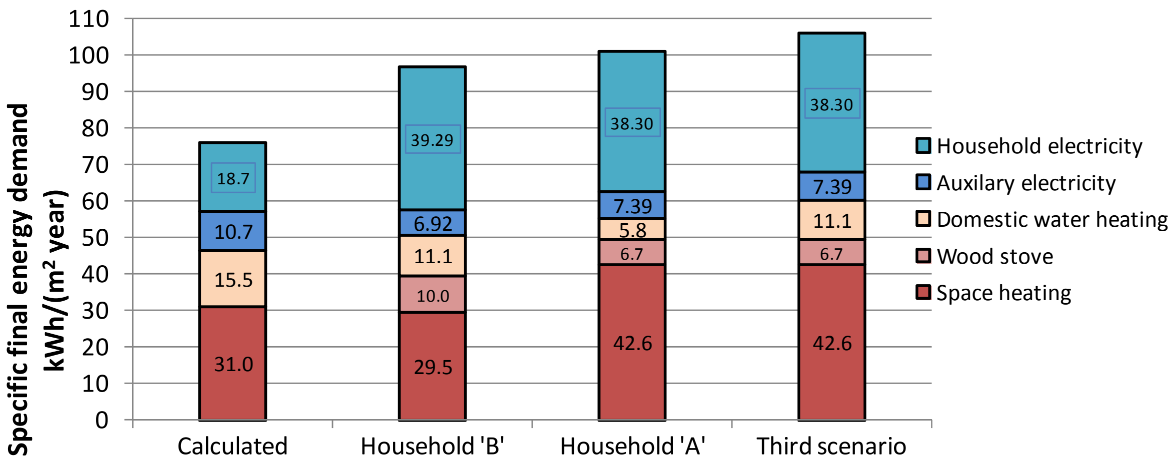


**Figure 6** The calculated final energy demand by energy type compared to the monitored final energy demand of the two households and a hypothetical scenario with final energy demand for space heating and domestic water heating from household A and household B, respectively.

For buildings that include different heating systems, as the case study, FEBY suggests different weighting factors for each heating systems: 0.8 for district heating, 1.0 for wood fuel and 2.5 for electricity. The passive house case study has two heat sources: the district heating and a wood stove and therefore 78 kWh/($m^2$ year) as a requirement for its specific final energy demand, as listed in Table 1. Under these conditions the specific final energy demand of the case study is 23% below the maximum limit, as illustrated in Figure 7 by the 'District heating + Wood stove' scenario. Calculation showed that the case study would have met the FEBY requirements, according to Table 1, even with other type of energy systems, as illustrated in Figure 7. However the difference between the requirements and the specific final energy demand would have been smaller (Figure 7).

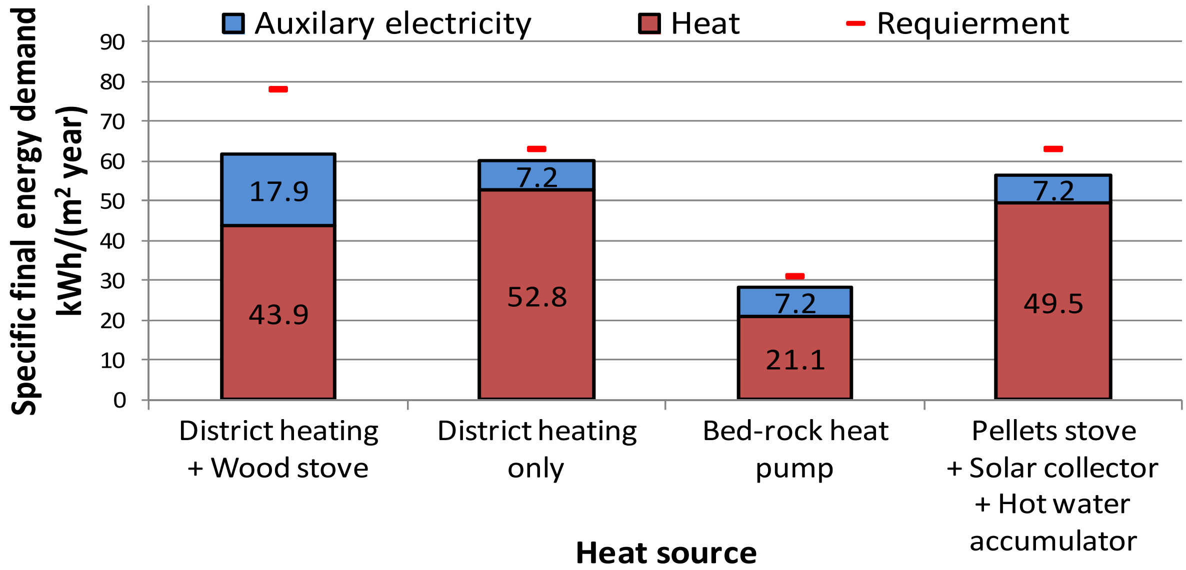


**Figure 7** Comparison between the FEBY suggested requirements according to Table 1 and the specific final energy demand of the case study under different heating systems scenarios. The 'District heating + Wood stove' scenario represent the actual case study, with its two households, calculated according to FEBY's weighting factors. For the 'Bed-rock heat pump' scenario, a 2.5 is assumed as the coefficient of performance of the Bed-rock heat pump [The Swedish energy agency 2005]. For the 'Pellets stove…' scenario, the solar collector assumes to deliver 40% of the energy for the domestic water heating [Wall 2006].

## 4. Discussion

One year of measurements of the case study building confirm that it is possible to build houses compliant with the passive house requirements in northern parts of Sweden. The final energy demand for space and domestic water heating in the case study detached passive houses was found to depend in large extent on the behavior and indoor thermal conditions of the occupants. In this study large differences in indoor temperatures and time spend indoors were found. Other parameters related to occupants, may have an impact as well, for example, the size of the family. These parameters are not a property of the building but still may have a large impact on the final heating demand in passive houses.

Labeling of electric apparatus differ from the labeling of buildings. For example a refrigerator obtains its energy class labeling by monitoring its electricity consumption under specific conditions. Once it is in operation, its electricity consumption may differ considerably depending on external factors like the daily amount of food that is cooled, how many times it is opened and for how long, etc.

However, labeling of a passive house includes the use of external factors, for example outdoor temperature and the occupant's energy demand for different indoor activities such as household electricity and domestic water heating. Such external factors may vary among different households, different locations and even with time as occupants habits and indoor activities may change as well as climate conditions. Differences in thermal comfort conditions among different households found to have large impact on the final energy demand of detached passive houses as well. As a result, large variations may exist between the calculated and monitored values of the final energy demand [Danielski 2012.].

FEBY suggests labeling passive house by the heat load criteria (Table 1). The heat load is the ratio of heat losses to floor area and express by $W/m^2$. Calculating the heat losses instead of the heating demand will eliminate the need to assume values for household electricity and domestic water heating. However the difference between the indoor and the outdoor temperatures is still included in the calculations by using a “normal” climate conditions and 21°C as indoor temperature. That may not represent the actual conditions as the climate may differ among different years and the indoor temperature may differ among household, e.g. 2.5°C in these two case studies. As a result, large variations between the calculated and monitored final energy demand may still exist.

Instead of concentrating on the final energy demand or energy losses while labeling energy efficiency in buildings, it may be better to introduce requirements for the thermal envelope efficiency of the building and its design. This should be studied further.

# 5. Conclusions

This study conclude that it is possible to build detached houses that meet the passive house requirements in as high latitude as 63°N. However the choice of energy system and the behavior of the occupants may have large impact on the final energy demand and energy requirements. These factors has very little to do with the energy efficiency of the building to resist to heat losses.

# 6. Acknowledgement

The financial support from the European Union Regional Development Fund is gratefully acknowledged.

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