Passive House for a cold climate

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SUMMARY:
Passive house refers to a specific construction standard for residential buildings with good comfort conditions during winter and summer, without traditional heating systems and without active cooling. Typically this includes very good insulation levels, very good airtightness of the building, whilst a good indoor air quality is guaranteed by a mechanical ventilation system with highly efficient heat recovery. The properties of the Finnish passive house were defined by VTT in the European research project Promotion of European Passive Houses (PEP) funded by Intelligent Energy Europe program in FP6:

- *The total primary energy use for appliances, domestic hot water and space heating and cooling is limited to 130 – 140 kWh/m*^{2}*,*
- *The total energy demand for space heating and cooling is limited to 20 - 30 kWh/m*^{2} *floor area;*
- *The airtightness of the building envelope* $n_{50} \leq 0{,}6$ *1/h*

Pilot projects fulfilling the cold climate requirements for a passive house are being built in Vantaa and Valkeakoski. Preliminary results show that the suggested definition is applicable in the climate of Southern and Central Finland.

1. Introduction

The energy demand is defined to be higher than the corresponding demand in Central Europe. Energy simulations [1] have shown that a Passive house in the climate of Central Finland would require insulation (thermal conductivity λ = 0,035 W/mK) thicknesses of 50 - 60 cm in exterior walls, 70 - 80 cm in the roof, and roughly 40 cm in the floor to fulfil the Central European requirement. At the same time window area should be minimized, and the total window U-value should be less than 0,5 W/m^{2}K. The economic viability of such a building is rather low, and thus the Central European definition is not justified.

The heating energy-saving potential of passive house is at least 75% of the current standard of construction in all climates in Europe. The experiences gained in Central Europe are not directly applicable in the Nordic or Baltic cold climate zones. There are several issues that restrict the use of existing passive house systems in cold climates, e.g.:

- The demonstrated concepts do not fulfil the energy demand requirement in a cold climate
- The hygrothermal performance of typical passive house building systems may not be appropriate
- The frost conditions in cold climate require foundation thermal insulation measures that have not been tested or provided with appropriate instructions
- The ventilation heat recovery efficiency is affected by defrosting that reduces the yearly efficiency of that of the best practice in milder climates
- The traditional Nordic heat supply systems are not applicable to passive houses due to high heat release power, and thus the user sensed thermal comfort differs of that typical, e.g., in Finland

If the passive house concept can be widely adapted to new construction the concept offers an important possibility to reduce the overall CO_2 emissions in Europe.

The definition of a passive houses bases on the energy demand. The aim of a passive house is also the use of renewable and low-emission energy sources. The total energy demand of a passive house refers to total primary energy demand. The problem with the primary energy approach is the use of conversion factors, as requested. Consumers can order, e.g., wind electricity via the grid. If the conversion factor refers to all electricity from the grid, the method does not promote the development of renewable energy supply. As such the conversion to primary energy is not applicable.

Thick insulation layers necessitate special attention to be paid to the performance of the structures. Frost protection of foundations, drying capacity of insulated structures, avoidance of thermal bridge effects, and long term performance of the airtight layers need to be considered. The concept development and construction of the first Finnish Passive houses tackled these challenges.

Experiences on ventilation heating systems show that simple heating systems are viable also in the cold climates. The increased heating power demand compared to climates in Central Europe does not reduce the indoor air quality. Room based control enables varying room temperatures according to specific needs of the users.

2. Passive house design

2.1 Building envelope

A passive house for a cold climate requires a high thermal insulation level. A passive house can be built of different building systems, and there is no special material dependence. The importance of thermal mass is also quite low in a cold climate. As the heating season is short, only 4 – 6 months, passive solar heating has also a low importance – there is only few sun shine hours in the midwinter months from November to January.

Passive house design requires accurate knowledge over the properties of building component. The effects of thermal bridges need to be included into the thermal transmittance of the building envelope. Therefore the design bases on more accurate U-value calculations than, e.g., required by the building code. The following indicative proper-ties for thermal insulation of the building envelope help for structural and energy design of the house:

- Wall 0,07 – 0,1 W/m^2K
- Floor 0,08 – 0,1 W/m^2K
- Roof 0,06 – 0,09 W/m^2K
- Window 0,7 – 0,9 W/m^2K
- Fixed window 0,6 – 0,8 W/m^2K
- Door 0,4 – 0,7 W/m^2K

Ground conditions vary in different parts of the country. During a cold winter the ground may freeze down to 1,5 meters in Southern areas, and even down to 2,5 meters in Lapland. These conditions require special attention to foundation system design. Basically, depth of the foundation bed in the ground, heavy foundation insulation , or change of ground mass to non-frosting soil removes the risk. In a typical building the floor heat loss is used for reducing the frost heave risk. As the thermal transmittance of the floor is very low, the heat loss is not applicable any more. Therefore the risk need to be analysed carefully, as the guidelines for foundation design do not cover floor structures with U-values below 0,15 W/m^2K.

2.2 Heating demand

Internal heat loads cover a large part of a passive house's heating demand. Table 1 and Figure 1 show the dependence of the heating demand on the various properties in the climate of Helsinki. The risk of freezing of heat recovery unit is a problem connected to cold climate solutions. The energy performance requires an average heat recovery efficiency of more than 75% in the climate of Helsinki at the same time as defrosting is needed.

Defrosting by heat or cyclic use of heat recovery for reduces the efficiency of heat recovery. Thus other ways and means should be applied as far as possible.

Subsoil heat exchanger for preheating of supply air may reduce or eliminate the defrosting demand. Ståhl (2002) and Thevenard (2007) give the following guidelines on the performance and possible problems with solutions for a subsoil heat exchangers for a cold climate:

- Performance
    - 30 - 100% of the cooling demand in summer
    - Prevent freezing in the heat exchanger unit
    - Energy gain 1200 kWh with minor increase of intake fan power
    - Tube length 10 - 100 m
- Potential problems
    - Moisture control: mould and bacteria growth
        - pipes with a 2-3% slope, water collects at the lowest point, pumped out;
        - intake filters to prevent the entry of spores, insects, etc into the system;
        - access to the pipes for easy cleaning;
        - anti-microbial coating on the pipes.
    - Radon seepage from the soil: Airtight tube with connections

In the light of possible problems, subsoil heat exchanger can not be recommended to be used in a cold climate. However, ground heat is a possibility by using a heat well of ground loop system integrated with a heat exchanger to pre-heat the fresh air. This system will be used in the first passive house to be build and certified in Finland.

Table 1. Properties of a passive house for heating energy demand calculations for a passive house in Helsinki

Building envelope					
Component	m^2	a) W/m^2K	b) W/m^2K	c) W/m^2K	d) W/m^2K
Wall	343	0,12	0,1	0,09	0,09
Basement wall	110	0,12	0,1	0,08	0,08
Roof	235	0,1	0,07	0,07	0,07
Floor	235	0,15	0,15	0,1	0,1
Window		0,8	0,8	0,7	0,7
- South	6				
- East	8				
- West	30				
- North	6				
Doors	16	0,4	0,4	0,4	0,4
Air tightness					
n_{50} value	1/h	0,6	0,6	0,6	0,6
Ventilation					
Rate	l/s	2 x 76			
Heat recovery	%	70	75	75	80
Spaces					
Gross floor area	2 x 235 m^2 According to external dimensions				
Treated area	2 x 187 m^2 According to internal dimensions				
Gross volume	2 x 844 m^3 According to external dimensions				
Volume	2 x 540 m^3, room height: downstairs 2,6 m, upstairs 3,2 m				

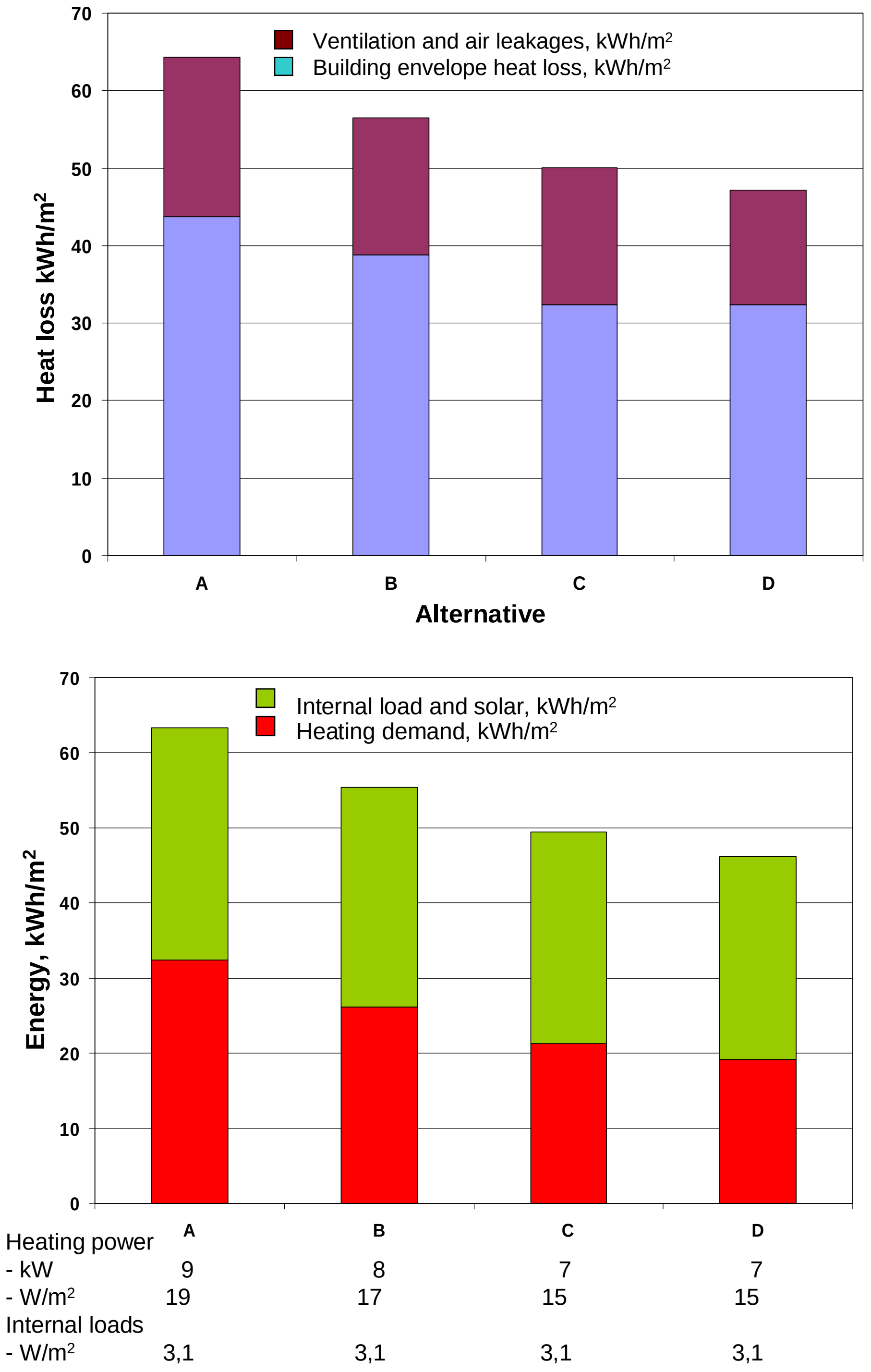

FIG. 1. Passive house’s heating demand according to different properties of the house (Nieminen, J. et al. 2008)

3. Pilot projects

Interest in passive houses has increased in Finland. Several projects started in 2007. Two passive house projects under construction serve as pilots where different technologies and parameters are being tested. The Vantaa passive house is a two storey two family house, Figure 2. Building is a massive building with exterior insulation composite system as thermal insulation.

The Valkeakoski passive house is a wooden single family house, Figure 3. The load-bearing structural system is a modified Nordic Platform with I-beam wall structure and internal floor. Basic structural details of the system are at http://www.puuinfo.fi/.

Both buildings have a trussed roof. The properties of these buildings are given in table 2.

FIG. 2. Passive house Vantaa.

FIG. 3. Passive house Valkeakoski

Table 2. Properties of a passive house for heating energy demand calculations for a passive house in Helsinki

Building envelope			
House		Vantaa	Valkeakoski
Wall	W/m^2K	0,1	0,08
Basement wall	W/m^2K	0,1	-
Roof	W/m^2K	0,07	0,07
Floor	W/m^2K	0,10	0,10
Window	W/m^2K	0,8	0,75
- South	m^2	6	30
- East	m^2	8	2
- West	m^2	30	1
- North	m^2	6	42
Doors	W/m^2K	0,7	0,7
Air tightness			
n_{50} value	1/h	0,6	0,6
Ventilation			
Rate	l/s	2 x 76	
Heat recovery	%	80	80
Spaces			
Gross floor area	m^2	2 x 235	290
Gross volume	m^3	2 x 844	1200

3.1 Energy demand

The pilot buildings' energy demands were simulated using VTT House simulation program. VTT House is a non-commercial building simulation application with integrated calculation of heat transfer and fluid flow processes. Calculation basics are

- Free nodal approach with discrete definition of mass balance, momentum, and heat balance equations
- True modelling on thermal conduction, convection, and radiation
- SIMPLE Algorithm
- Sparse matrix solver (Preconditioned Conjugate Gradient Method)
- A graphical interface for building material, HVAC system, and other necessary input data definitions.

Both the Vantaa and Valkeakoski passive houses have a ground preheating system for the ventilation fresh air. In the Vantaa house, two 100 m loops locate at 2 m depth in the ground. In the Valkeakoski passive house, a heat well will be utilized.

Figure 4 and 5 shows the hourly heating power demand and heating energy demand of the Vantaa passive house. The total heating power demand is 6,6 kW or 14 W/m^2 without ground source preheating of ventilation fresh air, or 5,6 kW or 12 W/m^2 with ground heat. The total heating energy demand is 18 kWh/m^2, however, the expected heat recovery efficiency requires reduction in the defrosting energy loss.

The heating system in the Vantaa passive house is ventilation heating. The room based heating power demand varies from 2 kWh/m^2 up to 36 W/m^2 in the in the different spaces of the house.

The estimated energy gain from the ground loop system net energy gain from the ground is roughly 1000 kWh.

The Valkeakoski passive house is now under design phase. The calculated heating energy consumption is 30 kWh/m^2 according to specifications in the table 2. The required demand level is 25 kWh/m^2. To meet the demand, e.g., widow area needs to be limited by 20 m^2.

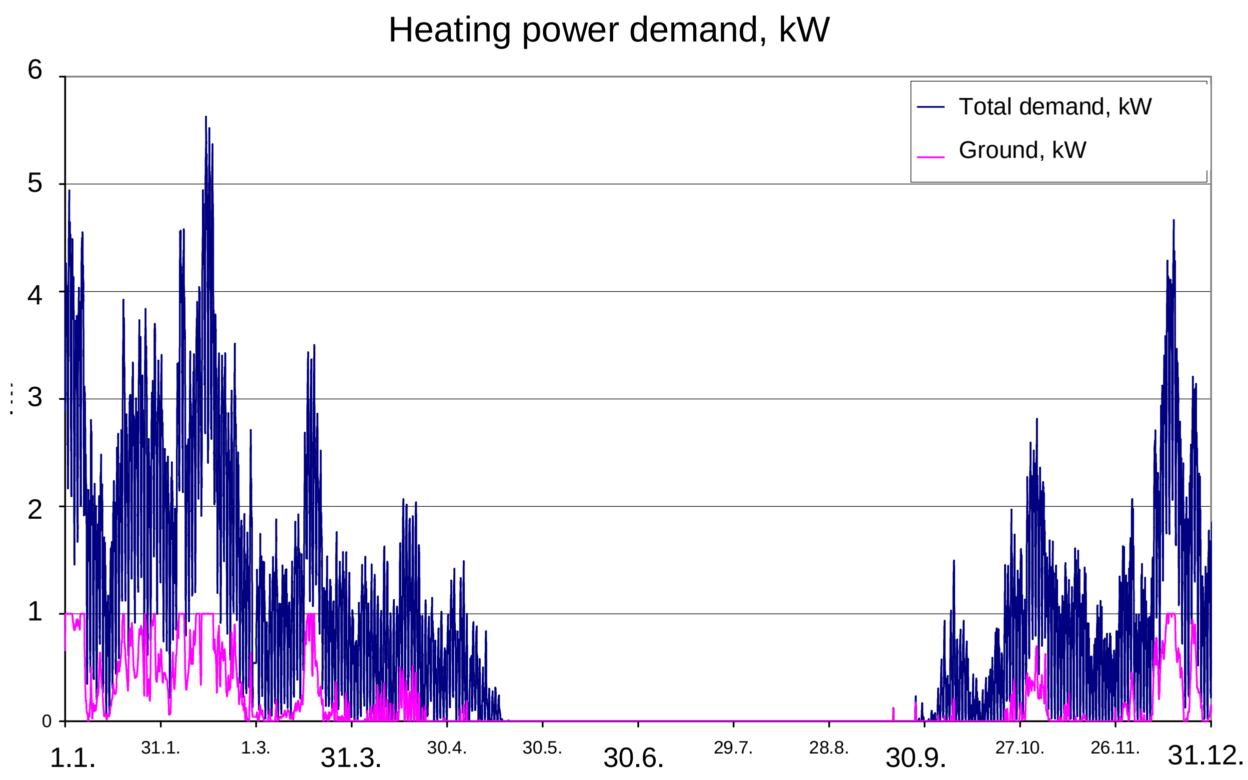

FIG. 4. Hourly heating power demand of the Vantaa passive house (Nieminen et al. 2008)

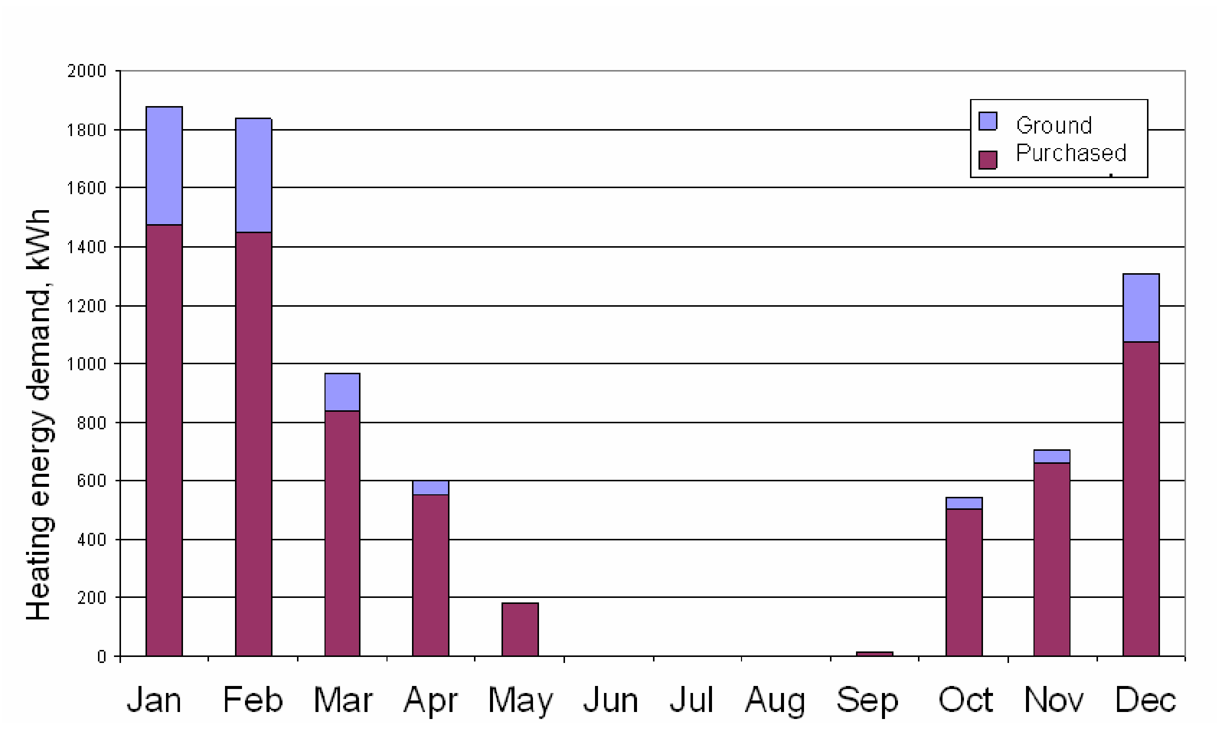

FIG. 5. Space heating demand of the Vantaa passive house (Nieminen et al. 2008). The total space heating demand is 18 kWh/m^2.The estimated utilizable ground heat supply is 1200 kWh.

4. Conclusions

The pilot projects show that the suggested specifications for the Finnish climate can met. However, The research results show that there are specific problems initiating from the thick insulation layers especially in the floor structures and floor external wall connections. In the phase of this study, also the building physical performance of the building systems of the pilot houses will be studied.

Acknowledgements

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