Performance of the Low-energy House in Sisimiut

Carsten Rode[1,*], Jesper Kragh[2], Egil Borchersen[1], Petra Vladykova[1], Simon Furbo[1] and Janne Dragsted[1]

[1] Technical University of Denmark
[2] Danish Building Research Institute

[*] *Corresponding email: car@byg.dtu.dk*

SUMMARY

A low-energy house was built in Sisimiut, Greenland in 2004-05 and since its inauguration in April 2005, its performance and operation have been object of study for researchers and students. The house is characterised by a highly insulated building envelope, advanced windows and a ventilation system with heat recovery, which should cut the energy consumption of the building to only half of what in 2006 became the permissible value in the Greenlandic building code. In addition to this, the house is equipped with a solar collector that supplies heat to the domestic hot water system and delivers auxiliary heat to a room in the building.

The paper will briefly introduce the design and technology of the house before reporting on the performance results until date. It has been a challenge in some aspects to introduce new technologies which have not been commonly used before in an Arctic environment, and the paper will illustrate some of the experiences in this regard.

KEYWORDS

Low-energy house, Arctic climate, design, measurements

INTRODUCTION

The objective of the low-energy house project in Sisimiut was to build a house with so little energy consumption that it could be justified to call it a low-energy house – given the conditions of the Arctic location. The definition of a low-energy house is that it is a house which consumes only half the energy permitted in the building code. The building code of Greenland from 2006 permits annual energy consumption for heating and ventilation of 230 kWh/m^2 for a single storey dwelling located north of the Arctic Circle. Given that this house has a ventilation system with heat recovery unit, it could be expected to consume around 70 kWh/m^2 less heating energy, and thus the, the permissible energy should be only 160 kWh/m^2, although there is official specification like this in the building code, since it does not assume dwellings to be equipped with a ventilation system with heat recovery unit. As a low energy house, it was set as a target that the energy consumption for heating and ventilation should be only half of that of the building code, and consequently the ambitious target value of 80 kWh/m^2 was chosen.

The means to reduce the energy consumption in comparison with common Greenlandic houses has been to use extra insulation in floors, exterior walls and the roof. A solar collector is installed on the roof to heat water for domestic use. The ventilation system is supplied with a heat exchanger that uses the warm exhaust air to heat the cold inlet air. Furthermore, improved windows are installed with low energy glazing using normally 3 layers of glass.

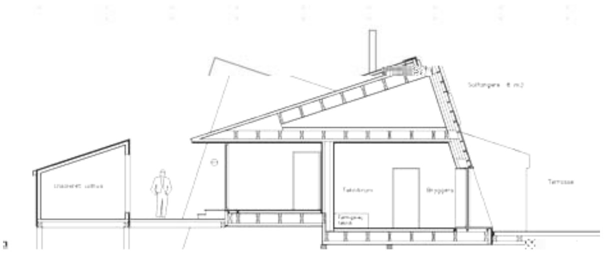


Figure 1. Cross section and floor plan of the low-energy house. The house is built as a double house with common scullery/boiler room and entrance hall.

THE LOW-ENERGY HOUSE

The low-energy house is made as a double-house with a floor area of 197 m², where the two living areas are built on each side of the boiler room and an entrance hall. Figure 1 shows a cross section and floor plan of the house. One of the two apartments serves as home for a family, while the other is used as an exhibition, and also occasionally functions as a guest

Table 2. Heat transmission coefficient (U_g, U_w), solar energy transmission (g_g, g_w) and net annual energy gain (Q_g, Q_w). Index *g* for glazing and *w* for window.

Type	U_g W/(m²K)	g_g -	Q_g kWh/m²	U_w W/(m²K)	g_w -	Q_w kWh/m²
1: 1+2	0.7	0.45	172	1.0	0.30	-17.3
2: 2+Vac.glazing	0.7	0.40	136	1.1	0.27	-59.3
3: 2+1	0.8	0.56	228	1.1	0.47	67.1

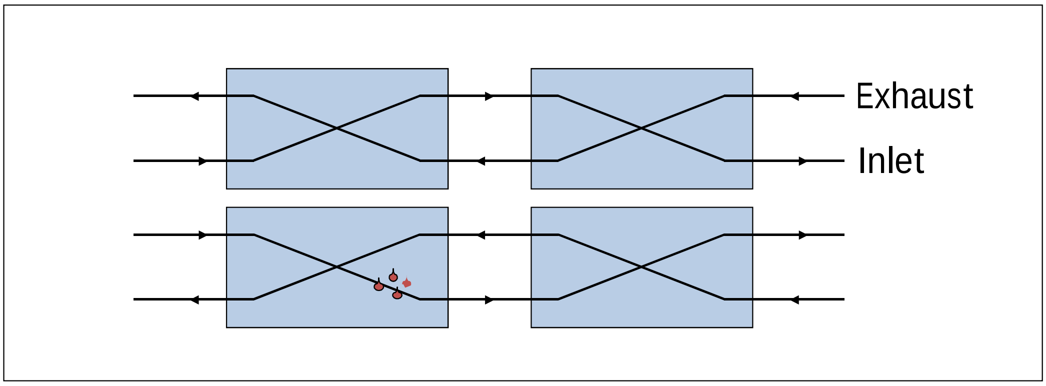
Heating system

The low-energy house is constructed with a hydronic floor heating system based on PEX-tubes installed in aluminium plates just below the wooden floor boards. The floor heating system in the toilets is based on PEX-tubes cast in the concrete. The ventilation system is equipped with a heating coil which is positioned on the supply air stream after the heat exchanger. The heating coil is meant to ensure that the supply air is not delivered to the rooms at a too cold temperature. The ventilation system’s heating coil is based on the same hydronic system as the floor heating.

Hot water for the floor heating and heating coil is supplied from an oil furnace, which is located in the boiler room of the house. Heat for the domestic hot water comes from a solar collector which has a size of 8 m^2 and faces south-east. The oil furnace supplies back up in periods when the solar heating is in insufficient. Finally, a radiator in the entrance hall is meant to be heated with excess heat from the solar collector system when available.

The ventilation system

A new heat recovery unit was developed for the low-energy house in Sisimiut in cooperation between EXHAUSTO A/S and the Technical University of Denmark. The dimensions of the unit are: Length 1,760 mm, width 930 mm and height 660 mm. The unit consists of two highly efficient aluminium counter flow heat exchangers coupled in a serial connection. A valve is able to switch the air flow direction through the units. When ice formation starts to reduce the airflow in the coldest exchanger the air flow direction is switched. The exchangers, valve and filters are mounted in a cabinet with 50 mm insulation, although the unit is recommended to be placed in a heated place to minimize risks of frost damages from the condensing water. The theoretical temperature efficiency of the heat recovery unit is approximately 90 %. A diagram of the system is shown in Figure 2.



Higher indoor temperature than designed

The average indoor air temperature has been some 2.5-3.0°C higher than anticipated in the simulations for the design of the building. Revised simulations (Rode et al., 2007) show that this means an increase in the expected annual energy consumption from 80 kWh/m^2 to 92 kWh/m^2 (for indoor room temperature = 23°C).

Insufficient function of the heat recovery system

The heat recovery system has in some periods been blocked by ice. Beginning ice formation in the system has had the effect to impair the cyclic change of the order of the two parts of the heat recovery system, so the defrosting function has not been fully functional, and the frosting situation has gotten worse. In October 2006, an insulated box was built around the heat exchanger unit, and an electric heater ensured heating of the air around the box to a temperature that approaches normal indoor air temperature. However this initiative has not eliminated the problem, and the temperature efficiency of the heat exchanger remains around 50% (in some periods only 30%), while the system was expected to have an efficiency of 80% (Rode et al., 2007 and 2008). Wasted energy by insufficient heat recovery (estimate): 30% of ventilation heat loss = approximately 25 kWh/m^2.

Insufficient insulation of air ducts in attic

The exhaust air from the rooms has to travel some 20 m in the cold attic before it reaches the heat exchanger unit. The ventilation duct is insulated with 50 mm insulation, and a temperature drop of 5 °C has been measured before the air reaches the heat exchanger (Rode et al., 2008). The heat loss in the return air duct may further be a part of the explanation why ice has formed so easily in the heat exchanger. Also the air in the supply air duct has a similar temperature drop before reaching the diffuser at the room inlet. A plan to add more insulation to the exhaust and supply air ducts in the attic has still not been implemented at the time of writing this paper. The total annual heat loss from ducts and other air-handling units in the attic amount to some 5000 kWh, corresponding to 25 kWh/m^2. Some of this could be saved by insulating the ducts and units better.

Poor control of the heating coil for heating of the of the ventilation supply air

In order to prevent supplying too cold air to the rooms, the ventilation system has been equipped with an auxiliary heating coil on the line of the supply duct between the heat exchanger and the inlet to the rooms. However, the control of the heating coil has been malfunctioning, so hot air was often led to the rooms even in periods when no heating was needed. This has caused some extra heat expenses. Contradictory to the expectations, almost as much heat is consumed by the auxiliary heating coil as by the floor heating system of the house. Of the total heating energy consumed in the house (approximately 140 kWh/m^2), around 30-50 % have gone to the heating coil in the supply air duct (and the rest to the floor heating). Since the heat delivered to the auxiliary heating coil has been poorly controlled, and therefore not always needed, it gives an indication of how much heat has been wasted due to the malfunctioning control. It might be 10-20% of the 140 kWh, i.e. around 20 kWh/m^2.

User behaviour

In periods it does get quite warm in the house. A typical user reaction has been to open the terrace door in the living room to the outside in order to cool the air. However, even if the room air is warm, the outdoor air is always colder than the indoor comfort temperature, and this cold air will then be sweeping over the floor and the floor heating system.

Furthermore, it has been noted that the inhabitants, who in periods were occupying some parts of both apartments, quite often let the doors open between the living zones and the entrance hall, thereby causing an extra heat loss from the living zones.

Poor air-tightness of the building envelope

A so-called blower door test has been carried out on February 7, 2009. The test showed an average leakage of 3.2 h^{-1} measured at 50 Pa over- and under-pressure. While this air leakage is not too high compared to the Greenlandic Building Code, since there are no requirements, it is significantly above the requirement imposed since 2006 in the Danish Building Code, that the air change must not exceed 1.5 h^{-1} when measured at 50 Pa pressure difference. Problem areas were identified around windows, at floor joints, at electrical outlets, and possibly under the floor (see Figure 5).

Figure 5. Infrared and normal picture of north-west facing window taken during blower door test.

For a building which is not in a sheltered environment, it can be expected that the free air change due to infiltration/exfiltration, n_{inf} is around 10% of n_{50} (DIN, 2003) and thus infiltration/exfiltration in the house can be expected to be around 0.32 h^{-1}. The volume of air in the building is 530 m^3, and thus the annual ventilation heat loss associated with this air change can be estimated to be 68 kWh/m^2 (based on the average outdoor temperature: -3.9°C). The assumption when designing the house was that the infiltration/exfiltration air flow would be only 0.1 h^{-1}, and thus the annual extra energy consumption due to poor air tightness of the building envelope, amounts to approximately 45 kWh/m^2.

Measurement of air change rate under neutral air pressure conditions were carried out using tracer gas equipment at three occasions in July 2005 (Mouritsen, 2006). The ventilation system was switched off, but its openings were not sealed from the rest of the house while the air change measurements were carried out. Mouritsen found air change rates of 0.39 h^{-1}, 0.27 h^{-1}, and 0.30 h^{-1}, i.e. values that support those found by the recent pressure test.

Electricity consumption

The annual electricity consumption for running the building services of the whole building amounts to approximately 5000 kWh. The anticipated consumption for running known systems such as fans, heating of the insulated box around the heat recovery system, data acquisition equipment and UPS, and the solar heating system, amounts to 1700 kWh (Rode et al., 2007). Thus a consumption of 3300 kWh remains unaccounted for. A current suspicion at