Technical University of Denmark

Low-energy house in Sisimiut

Annual report of Low-energy house performance July 2008 to June 2009

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BYG•DTU

LOW-ENERGY HOUSE IN SISIMIUT

Annual report of Low-energy house performance July 2008 to June 2009

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October 2009

Low-energy house in Sisimiut

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Preface

This Annual Report 4 of the low-energy house in Sisimiut, Greenland, contains data of the measurements collected from 1 July 2008 to 30 June 2009. The report has layout and structure which is identical with the "Annual Report of Low-energy house performance from July 2005 to June 2008”, which treated the first 3 years measurements. The report begins with a brief description of the low-energy house and the reference simulation used for evaluation / comparison of the estimated annual heat consumption. The report also presents measured results from the house.

It should be noted that only one half of the house is inhabited (2-3 adults, South-western apartment), so detailed analysis of low-energy house performance cannot be directly compared with the previous year's polls. The other part of house (North-eastern apartment) is used occasionally as a guest house.

This report is based on previous three annual reports made by Jesper Kragh. The report language is English.

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1. Introduction

In year 2001, BYG • DTU, represented by the Center for Arctic Technology, Technical University of Denmark, has applied for a donation of 5 million dollars for the construction of a low-energy house in Sisimiut in Greenland.

The low-energy house was designed by Erik Møller Arkitekter A/S, together with research team from the Technical University of Denmark. In Greenland, the house was designed by Ramboll A / S and built by Arctic Sanasut ApS.

The low-energy house is built as a house of 197 m² consisting of two similar units (apartments), separated by a common central section of the entrance and the technical room / scullery. One of the apartments is used as an ordinary dwelling inhabited by a typical Greenlandic family and the other as a guest apartment and exhibition for visitors.

The residents moved in February 2005, and in April 2005 the low-energy house was officially inaugurated / opened.

1.1 Key data for low-energy house

Net area of house: 197 m²
Number of occupants : 2-3 adults

Constructions

Table 1 U-values for construction

Construction	Insulation thickness	U-value
	[mm]	[W/m²K]
Floor	350	0.14
Wall	300	0.15
Roof/ceiling	350	0.13
Windows	-	1.0 – 1.1

Ventilation

Heat recovery with supplementary heating coil as after-heating of the supply air
Counter flow heat exchanger (two pieces connected in series with defrosting function)

Solar collectors

Area of collectors: 8.1 m²
Tilting of collectors: 70°
Orientation of collectors: Compass direction -56° (South = 0º, negative to East)
Solar tank: 257 liters

1.2 Layout and cross-section

Figure 1 shows the floor plan of the low-energy house and a vertical cross section through one of the apartments. The house is symmetrical around the symmetric line.

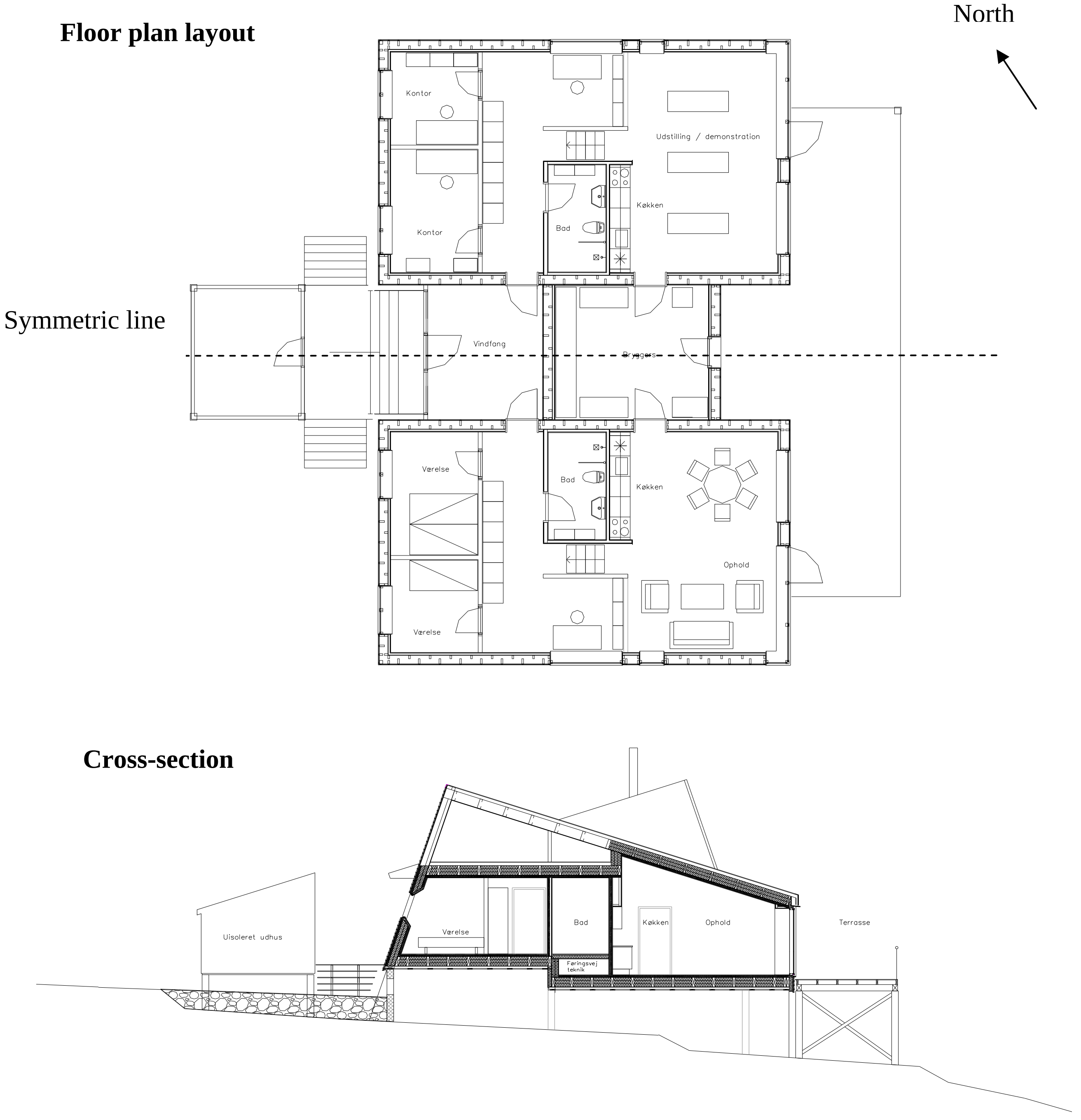

Figure 1 Low-energy house layout and cross section. The house is divided in two apartments, one serves as accommodation for a family and the other one as demonstration / guest house.

1.3 Simulated energy consumption for heating

A simulation model of half of the low-energy house was created in the building energy analysis program BSim / 2 /. For the simulation of ambient temperature the annual weather data of Sisimiut (TRY, test reference year) was used. Figure 2 shows the simulation model BSim. The simulation model is described in detail in / 1 /.

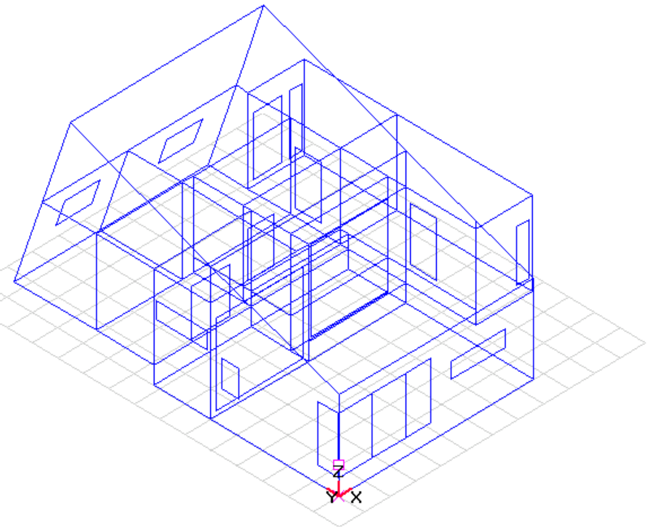

Figure 2 Simulated model from BSim

In Figure 3 shows simulated annual energy consumption for heating per square meter per year as a function of interior temperature.

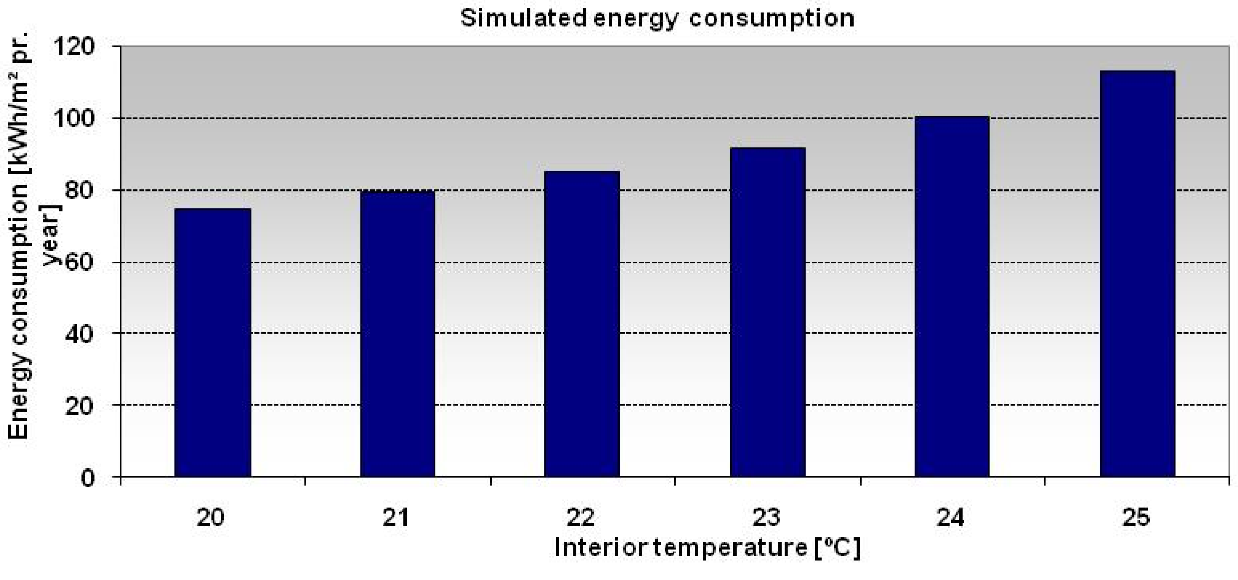

Figure 3 Simulated annual energy consumption (theoretical) for heating as a function of the interior temperature

It can be seen that the set point of interior temperature has a decisive influence on the energy consumption for heating. It is therefore necessary to know this when assessing whether the low-energy house lives up to the target in terms of energy consumption for heating.

1.4 Objectives for energy consumption for heating

According to the Greenlandic Building Code the energy frame for a single storey house which is built north of the Arctic Circle is 830 MJ / m²·year, equivalent to approx. 230 kWh / m²·year. The energy frame is based on the assumption that ventilation with heat recovery cannot yet be introduced in Greenlandic buildings, since experiences with the use of heat recovery system in buildings in the Arctic are still very limited. However, a standard Greenlandic single-family would probably be able to achieve a 50% reduction of its ventilation loss if a ventilation system with heat recovery were used. If demands for ventilation with heat recovery were introduced in the Greenlandic building code, the energy frame would likely be set to approximately 160 kWh / m²·year for the part of Greenland north of the Arctic Circle.

A low-energy house is historically defined as a house that needs at most 50 % of the energy for heating which is permissible according to the Building Code. Since furthermore the low-energy house in Sisimiut was planned to be equipped with a ventilation system with an optimized heat recovery unit, the goal was set at annual energy consumption for heating of 80 kWh / m².

Compared to the Danish energy frame, the requirement is equal to a low-energy class 2 house in the Danish Building Code. [1]

[1] The comparison is made by correcting for the total number of heating degree hours. The Danish and Greenland energy framework calculation differs also in terms of energy consumption for hot water. This is contained in the Danish energy framework and this is corrected with a typical consumption of 15-20 kWh / m² per year for a dwelling.

2 Overview of measuring

All major energy flows in the low-energy house are logged. Some of these measurements can be found online at: http://www.energyguard.dk (User name: DTU4, Password: sisimiut).

An overview of the measurements is shown below:

Oil

- Total oil consumption

Heating

- Floor heating
- After-heating of heat recovery unit
- Hot water consumption

Electrical energy

- Electrical consumption (Unit 1)
- Electrical consumption (Unit 2, guest apartment)
- Electrical consumption for technical room (common area)
- Electrical energy to el. panel in isolated VEX Box

Solar energy

- Transferred solar energy to solar tank
- Transferred solar energy to space-heating

Separate measurements

In addition to the above measurements, the following additional measurements are being logged.

Ventilation

- The volume flow rate of exhaust air (Keepfocus logging system with HOBO data logger)
- The volume flow of supply air (HOBO data logger)
- Temperature of exhaust air VEX (HOBO data logger)
- Temperature of exhaust air after VEX (HOBO data logger)
- Temperature of supply air before VEX (HOBO data logger)
- Temperature of supply air after VEX (HOBO data logger)

Indoor climate

- Indoor temperature (HOBO data logger)
- Indoor relative humidity (HOBO data logger)
- Temperature and moisture in constructions (Sensirion sensors and data logger)

External measurements

Outside climate (Sisimiut)

- Outside temperature (From DMI’s website)
- Solar radiation (ASIAQ)

3 Presentation of measurements

The following chapter presents the collected measurements of the low-energy house performance. The measurement period is chosen from July 1 to June 30 (cut off period).

3.1 Indoor temperature and humidity

As shown in Figure 3, the indoor temperature in the house has a large effect on the energy consumed for heating. Therefore it is interesting to see what temperature level has been inside the house through the previous year. Figure 4 shows the measured indoor temperatures in the kitchen through the year. Figure 5 shows the measured relative humidity in kitchen / living room through the year. The average temperature for kitchen and living room between August 2008 and August 2009 were 24.1°C for the inhabited apartment (South-western apartment) and 22.9 °C for the guest apartment (North-eastern apartment). The average values of relative humidity were 28.8 % and 30.1 %. The device was placed in the kitchen / living rooms of each apartment (Sensirion: T18, T20, RH18, RH20).

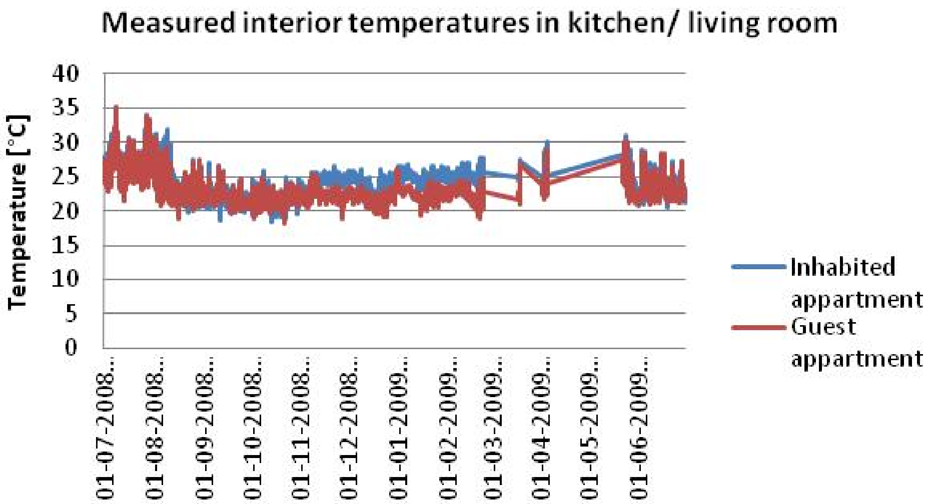

Figure 4 Measured air temperature in kitchen / living room from July 2008 to June 2009

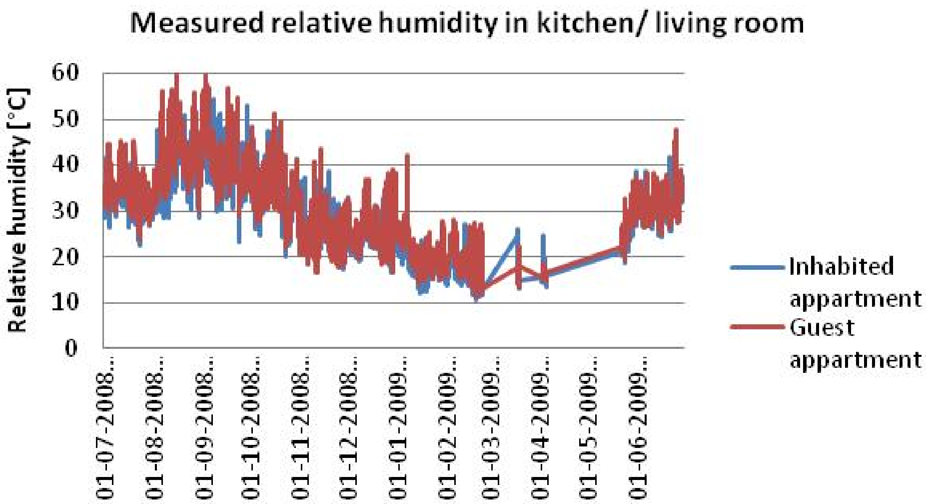

Figure 5 Measured relative humidity in kitchen / living room from July 2008 to June 2009

Comments on the indoor temperature

The measured kitchen temperature in the right apartment from August 2008 and August 2009 shows rather high indoor temperature of 24 °C, the unoccupied apartment has measured indoor temperature of 22 °C. One explanation could be that the inhabitants often increase the set point of the temperature control. Other possible explanation could be the extra heat from the inhabitants, their electric equipment, cooking, etc.

As expected, the relative humidity is seen to be lower than normal for Danish conditions.

3.2 Ambient temperature and heating degree hours

In order to have a better correlation and comparison for the low-energy house every year, it is necessary to know the outside temperature throughout the year. From DMI's weather archives, these data can be drawn for Sisimiut.

Data of ambient outside temperature are also compared to a reference year (TRY), which has been prepared designed for detailed simulation of the annual energy need for heating the house. The reference year is composed of 12 " typical" months, found by statistical analysis of at least 10 years of measured weather data.

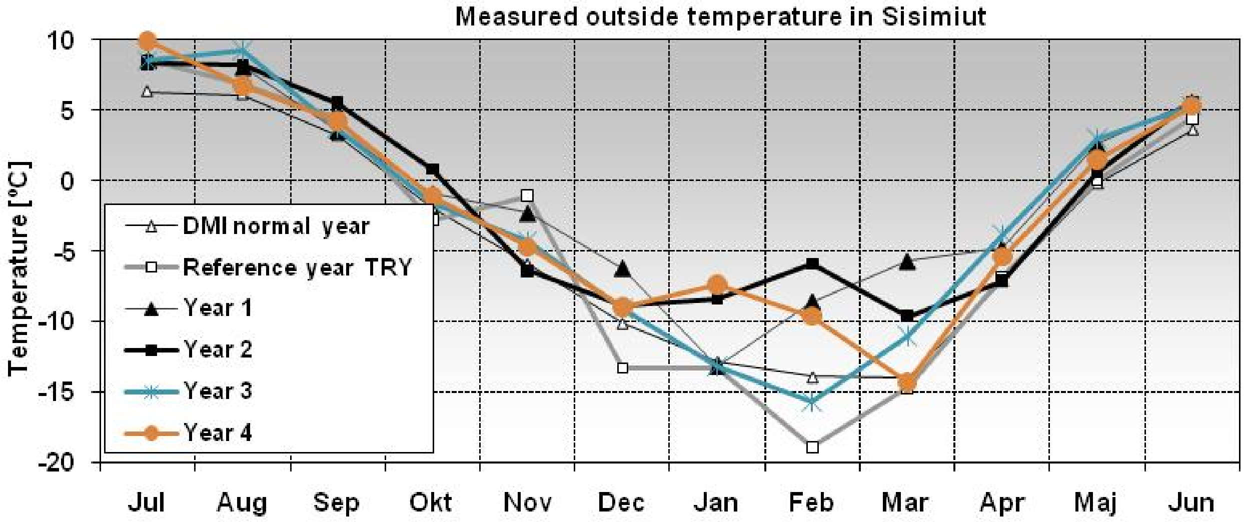

Figure 6 Measured outside temperature in Sisimiut (year 4). DMI normal year from www.dmi.dk. Data for reference year (TRY) from ASIAQ.

DEGREE HOURS

Based on an indoor temperature of 20 ºC the monthly degree hours are calculated as:

$$Gd_m = \sum \left(20 - T_{out,m}\right) \cdot t_m \,, \qquad (1)$$

where

Gd_m	number of degree hours per month	[Kh]
$T_{out,m}$	monthly mean ambient temperature	[ºC]
t_m	number of hours throughout month	[-]

Figure 7 shows the estimated total annual of degree hours. These values are compared with DMI's normal year and reference year (TRY).

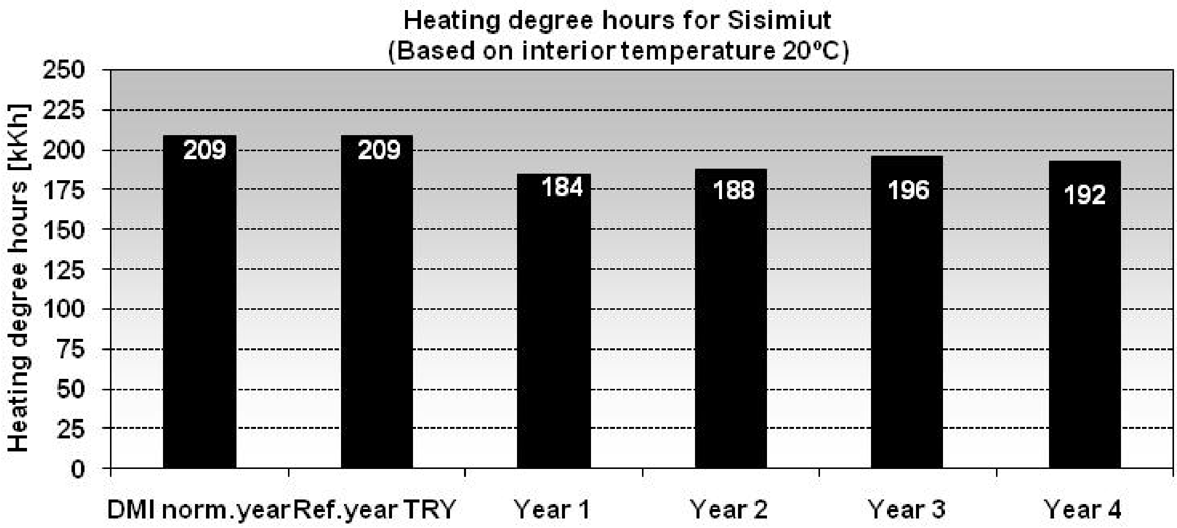

Figure 7 Calculated heating degree hours with interior temperature 20ºC.

In addition, the outside temperature for year 4 has been measured locally at the low-energy house, as it is shown in Figure 8.

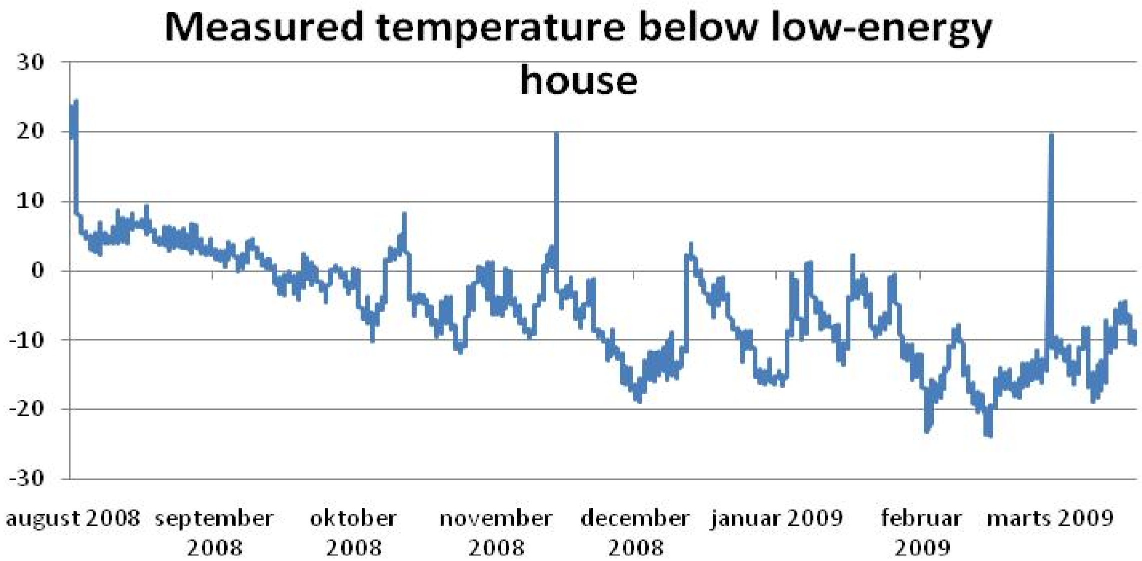

Figure 8 Outside temperature measured locally below the low-energy house

For outside temperature measured under low-energy house the data are missing from April to August 2009 due malfunction of HOBO device.

Comments on the outside temperature
Compared to year 3 and TRY data, the year 4 is milder, e.g. the number of heating degree hours is smaller. The heating degree hours cannot be calculated from measured values below low-energy house due to missing data.

3.3 Oil consumption

Figure 9 shows the measured oil consumption spread over the months of the year.

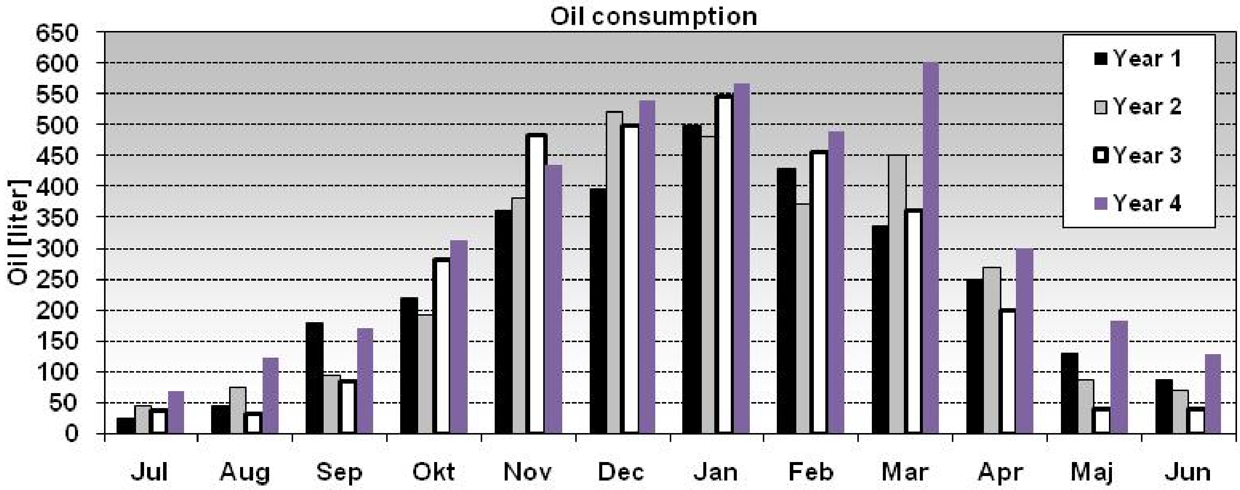

Figure 9 Oil consumption throughout the years

Figure 10 shows the total annual oil consumption.

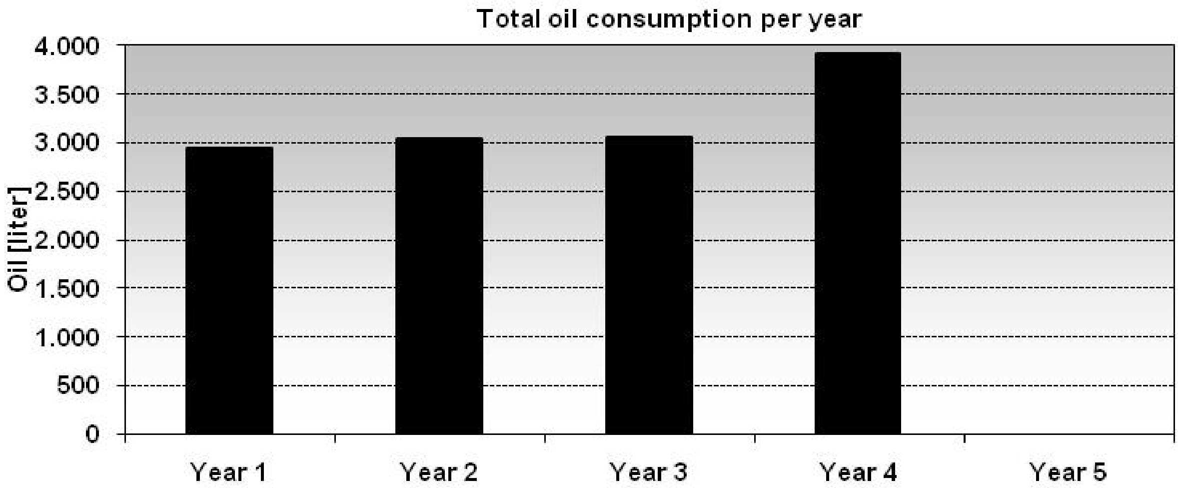

Figure 10 Comparison of oil consumption for every year

Commenting on oil consumption
It can be seen that the oil consumption for the 4th year is around 4.000 liters. Oil covers consumption for heating and domestic hot water.

One possible explanation for the high consumption can be that the effectiveness of the oil furnace was not as high as in year 1. Also the average temperatures for year 4 are 24.1 °C for occupied apartment and 22.9 °C for guest apartment, while the average temperature for year 1 was 22.6 °C, year 2 was 22.7 °C, year 3 was 24.5 °C. The influence of interior temperature on oil consumption was calculated in Figure 3 based on simulation in BSim. The increase of interior temperature can explain the high consumption of oil in year 4. It seems also that the malfunction of the after-heater in the ventilation system may cause some of the extra oil consumption (see Figure 13).

3.4 Heating consumption

Figure 11 shows the measured heating consumption spread over the months throughout measured years. Heating is excl. domestic hot water.

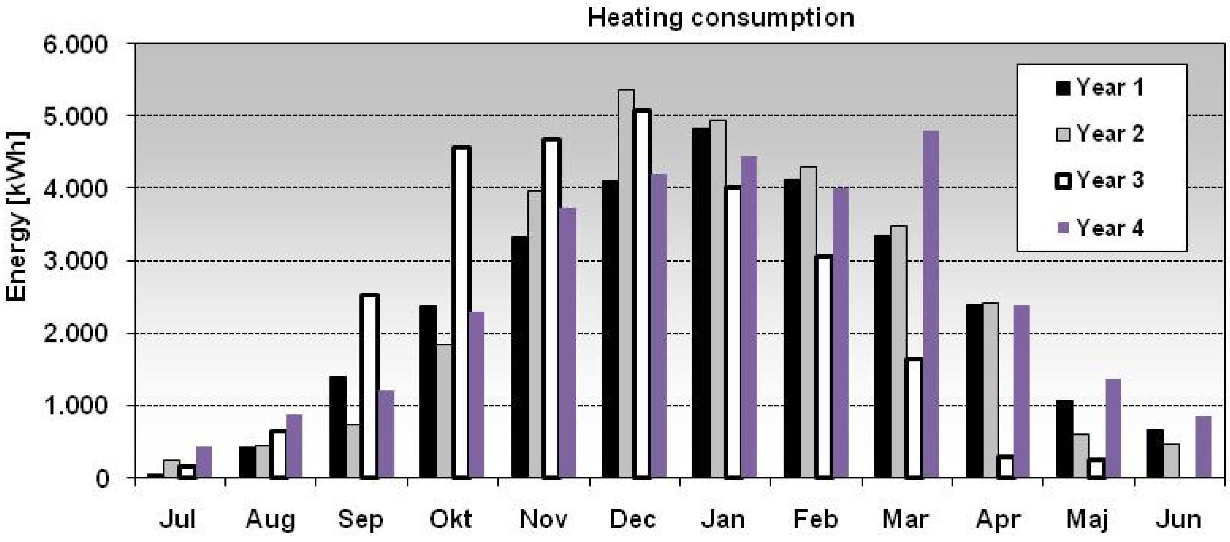

Figure 11 Heat distribution through the years

Figure 12 shows comparison of the annual heating consumption for each year and the targeted heating consumption.

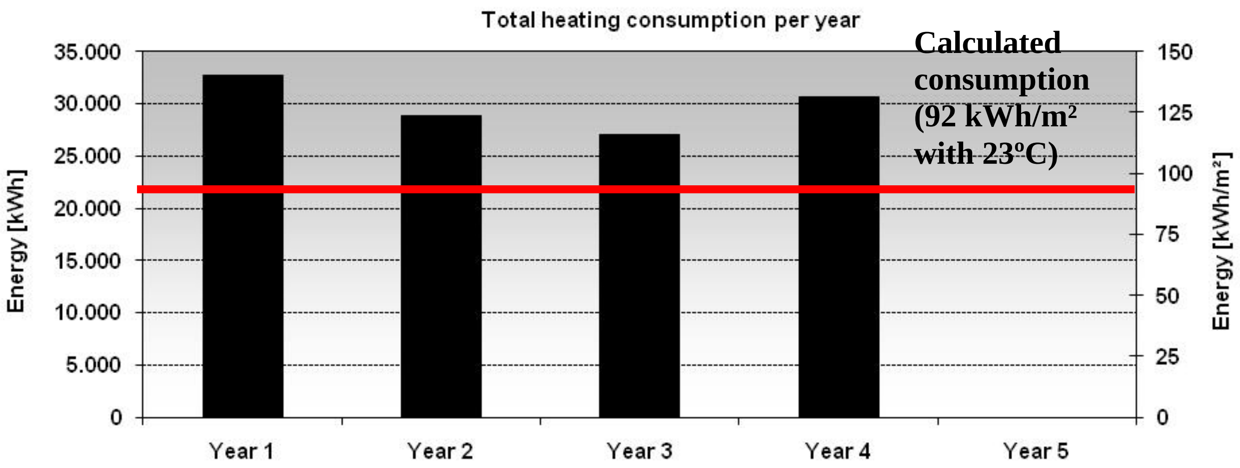

Figure 12 Comparison of heating consumption for each year

Figure 13 shows how heat is distributed between the air heating with of the ventilation and floor heating.

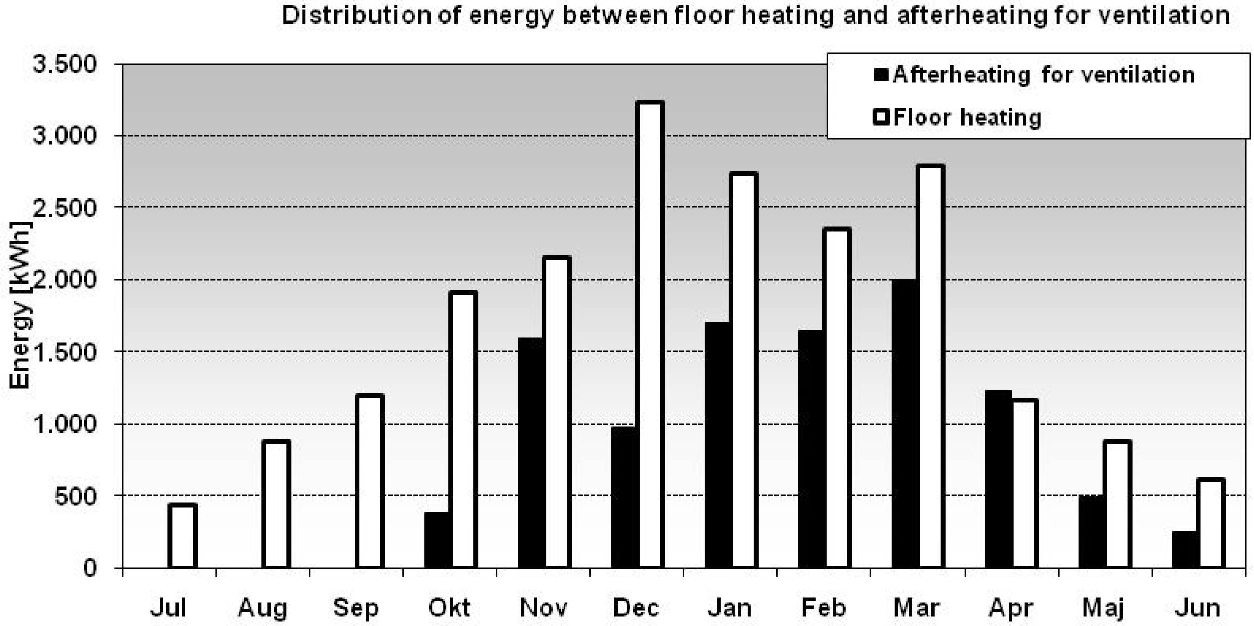

Figure 13 The distribution of heat between the after-heating for ventilation and floor heating

Commenting on the heat

The total oil consumption in year 4 is much higher, approximately 900 liters more than in year 3. The measurement of energy consumption for the after-heating unit for the ventilation system shows large consumption due to problems with the after-heating device and location of ventilation ducts above the ceiling insulation. The control of the after-heating system has been problematic, since it does not regulate the supply air temperature as it should. The misuse of energy is due to the fact that the air blown into the house has been at a temperature of approximately 40 °C, although it should have been only 15-20 °C.

The ducts have originally only been insulated with 50 mm. The plan was to put up another extra 100 mm of insulation on pipes (October 2009) and to mend the control of the after-heating (the execution of work in December 2009).

3.5 Domestic hot water consumption

Figure 14 shows the measured energy needed for domestic hot water.

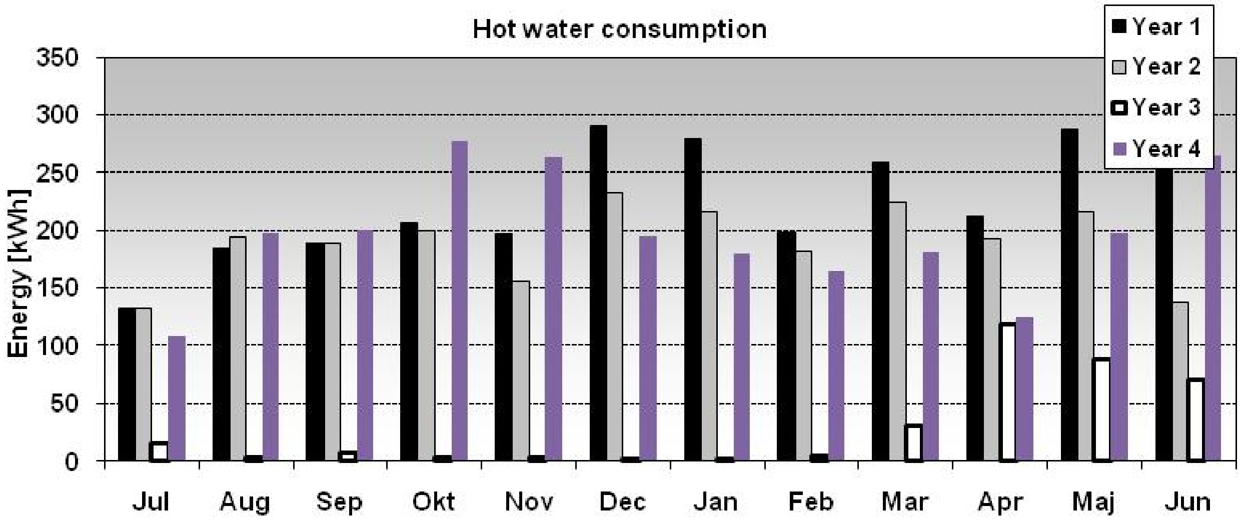

Figure 14 Measured energy consumption for hot water

Figure 15 shows the annual energy consumption for hot water is obtained from the hot water tank.

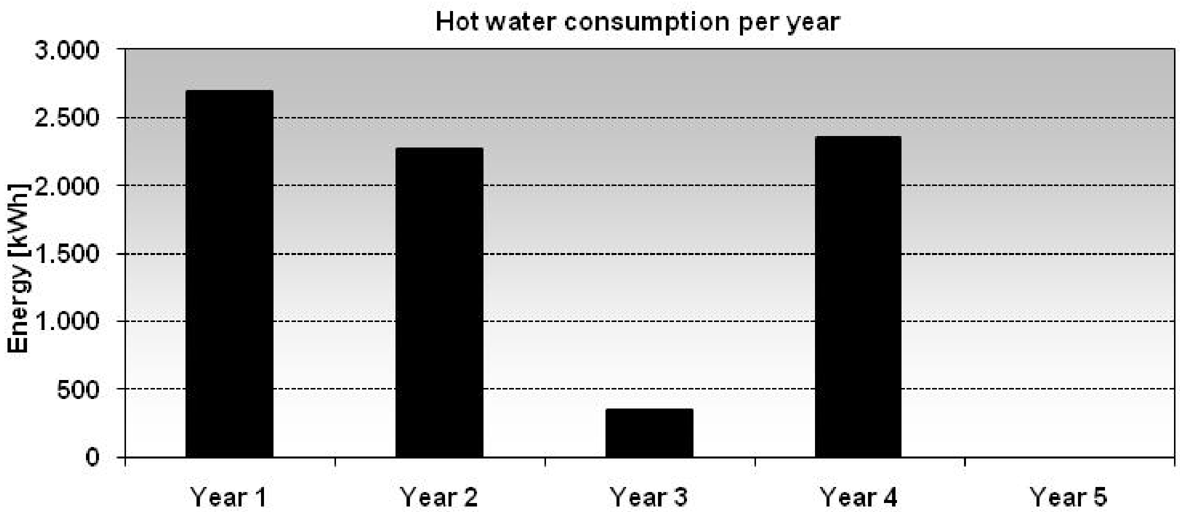

Figure 15 Annual collected energy for hot water

Comments on the energy consumption for hot water
Hot water consumption for years 1 and 2 shows almost the same consumption, as the house has been inhabited throughout the year. Consumption in year 3 is low due the fact that the house has not been occupied during the winter, and inhabitants moved in during spring in the end of the 3rd year. The energy consumption in year 4 is comparable to the years when the house was normally inhabited.

3.6 Solar gains

Solar radiation is important both for the solar gain collected with solar panels and for solar gain received by windows. In Figure 16 show a comparison of monthly global radiation for reference year and for measurement (measured horizontally) made by ASIAQ / 2 /.

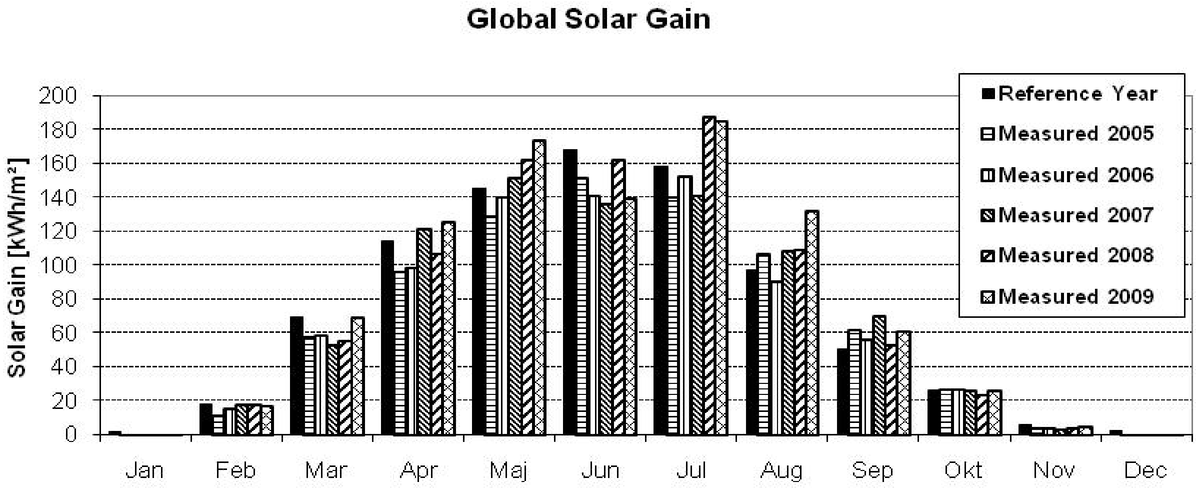

Figure 16 Comparison of reference year and measured global solar radiation for 2005-2009

Solar radiation perpendicular to the South, East, West and North measured also by ASIAQ every 5 minutes was done in 2005/5006 only. These data are used to make an analysis of the sun through the windows for each month. Each window is included with orientation, size and g-value to calculate the transmitted sun, as shown below:

$$Simulated = Q_{sol,refernceyearr} \cdot A_{window} \cdot g_v$$

$$Measured = Q_{sol,measured} \cdot A_{window} \cdot g_v$$

Figure 17 shows the monthly values of radiation on vertical surface for measured values in 2005/2006 and for simulated values (DRY).

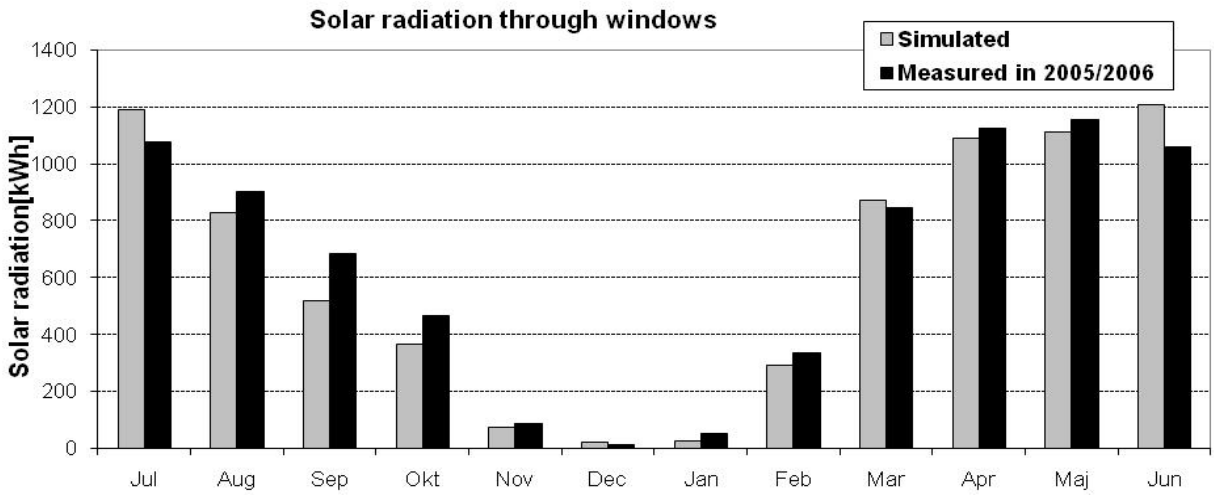

Figure 17 Solar radiation through the windows of the low-energy house

Comments on solar radiation

Global radiation appears to be similar for the reference year and the measured data. It can be seen that the solar gain through the windows (simulated and measured) is not quite the same, but nevertheless in an appropriate level. The reason for the difference between measured and simulated solar gain on vertical surface is partly due to the fact that solar radiation in the reference year has collection of different year variations.

The mean values of monthly values for global solar gain in 2005-2009 seems to be very close to the year value for the reference year, hence the Figure 16 does not indicated much. The Solhat measurement on vertical surface is not working since year 2007, therefore the solar radiation on vertical face cannot be calculated for current year (Figure 17).

3.7 Solar heating

The annual projected thermal performance of the solar heating system is influenced by the hot water consumption. In / 3 / the net utilized solar energy for the solar heating system is calculated to be approx. 1700 kWh assuming a hot water consumption of 3000 kWh.

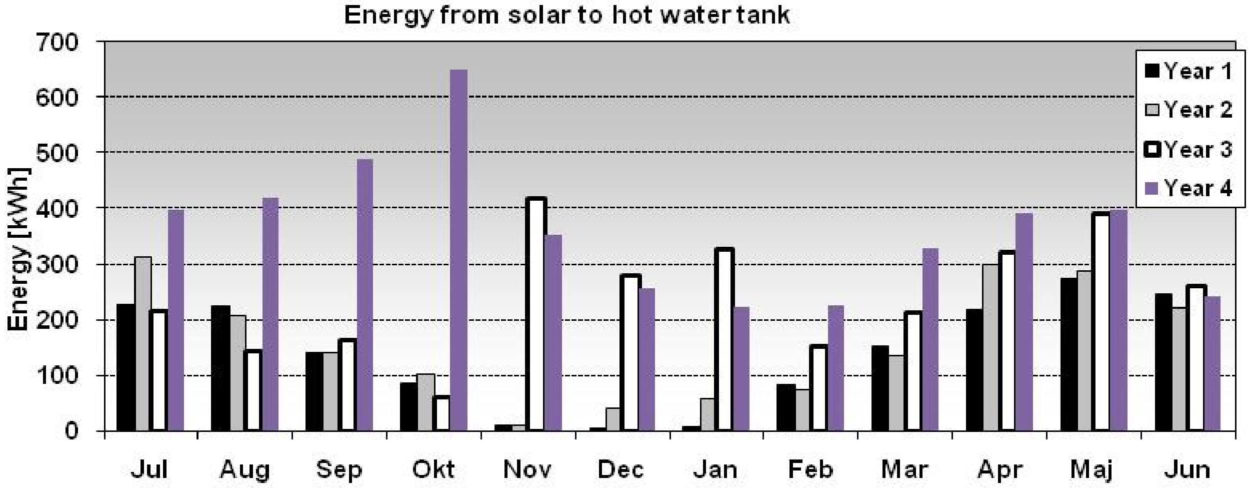

Figure 18 Energy supplied by solar panels for hot water tank

Besides the solar heat transferred from the solar collectors to the hot water tank, solar heat was from the spring 2009 also transferred to a separate radiator in the house. In sunny periods where the temperature in the hot water tank is high enough heat is transferred from the solar collectors to the radiator. The energy transferred from the solar collectors to the radiator is shown in Figure 19.

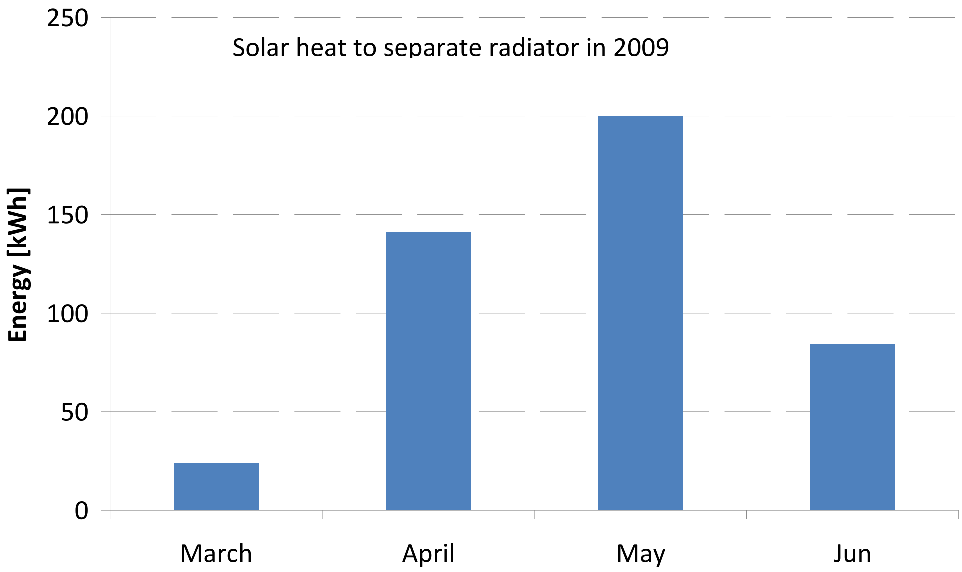

Figure 19 Energy transferred from solar collectors to separate radiator

Figure 20 shows the annual energy transferred from collectors to hot water tank.

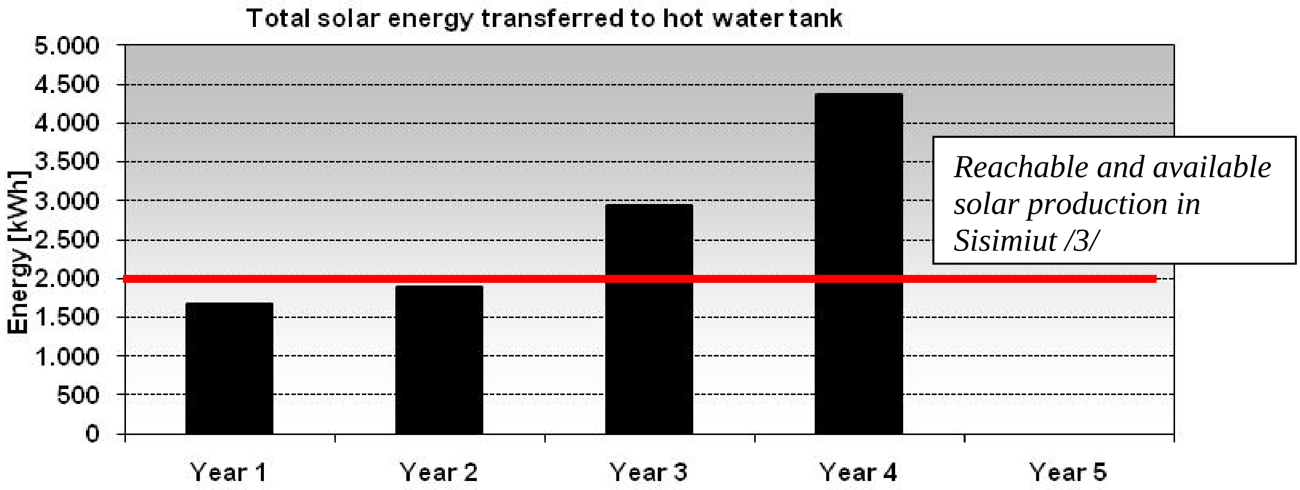

Figure 20 Total annual energy production transferred from the collector to hot water tank

Comments on the solar heating system

The thermal performance of the solar heating system is fine in the summer period. The measurements also show that there are problems: In the cold winter it seems that the solar collectors produce heat. This is however not the case. The solar collector fluid circulates backwards through the solar collector loop by means of thermosyphoning in periods with a high driving force due to a strong cooling of the solar collector fluid in the solar collector. In this way energy is lost from the house to the surroundings. The monitoring system considers this energy to be positive. Hopefully an installation of a magnetic valve in the solar collector loop can solve this problem. The magnetic valve will be installed soon.

3.8 Electricity consumption

Figure 21 shows the monthly electricity consumption through the year. The low-energy house has two meters that log consumption in each unit of the house and one electric meter that log consumption in technical room and the other common electrical energy.

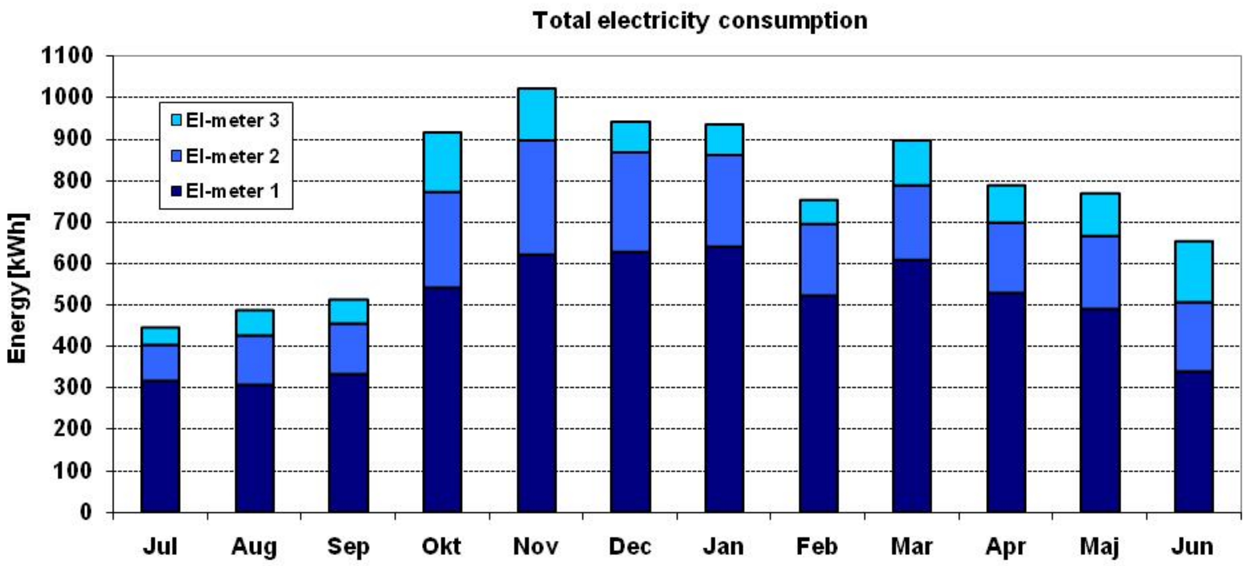

Figure 21 The distribution of electricity consumption throughout the year

Commenting on electricity consumption
Comparing year 3 (total el. consumption 5.943 kWh) to year 4 (total el. consumption 9.129 kWh) it can be seen that the house has a very high consumption. It will be checked if the use of leakage of electrical energy from the system goes to frost protection of the sewer pipes or to fans for the ventilation system. It has been observed that the sewer pipe is set to be on after October 2009, before this date the frost protection was switched off.

El-meter 1 is for the common areas, el-meter 2 is for inhabited apartment (South-western apartment) and el-meter 3 is for guest part of the house (North-eastern apartment). The electricity consumption for common areas (el-meter 1) includes also consumption of wash machine, dryer for clothes, freezer, microwave, e.g. every appliance located in entrance and technical room. These appliances are used by occupants and it should be added to their consumption.

3.9 Ventilation

Ventilation of a dwelling in a cold climate is both energy-consuming and problematic because draught may cause discomfort for the residents. To reduce energy consumption a heat recovery system with heat exchanger (VEX) can be used in which the energy in the warm exhaust air is used for heating the cold supply air. In cold climate there is a risk of ice formation inside the heat exchanger. When the warm humid room air is brought in contact with the cold surfaces of the exchanger (cooled by the outside air), the moisture in the exhaust condensates in the heat exchanger. If the outside air temperature is below zero the water vapor then can freeze to ice and the system may stop. In the low-energy house thus is made a prototype of a VEX with a defrosting function.

Figure 22 and Figure 23 show the logged data of one month (March 2009) of respectively air temperatures and volume flows in the ventilation system. Measurements of temperature are made in the ventilation channels directly in the inlets and outlets of the VEX. Figure 24 shows the calculated / measured temperature performance for the period.

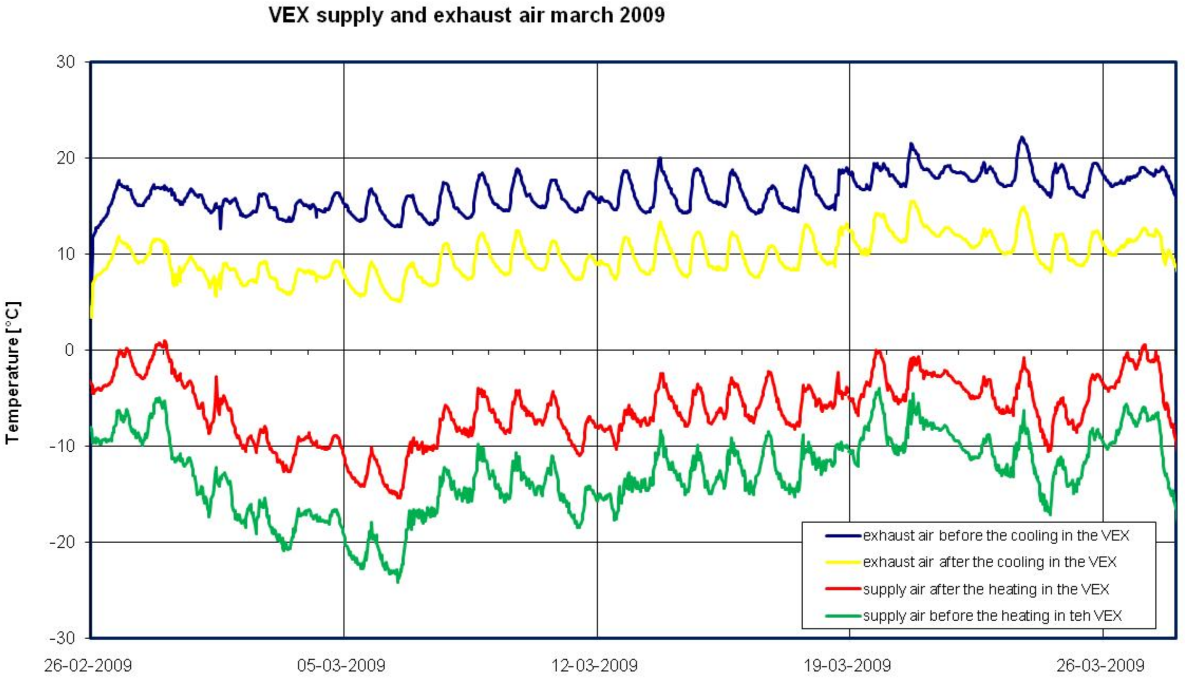

Figure 22 Measured temperatures immediately before and after the VEX

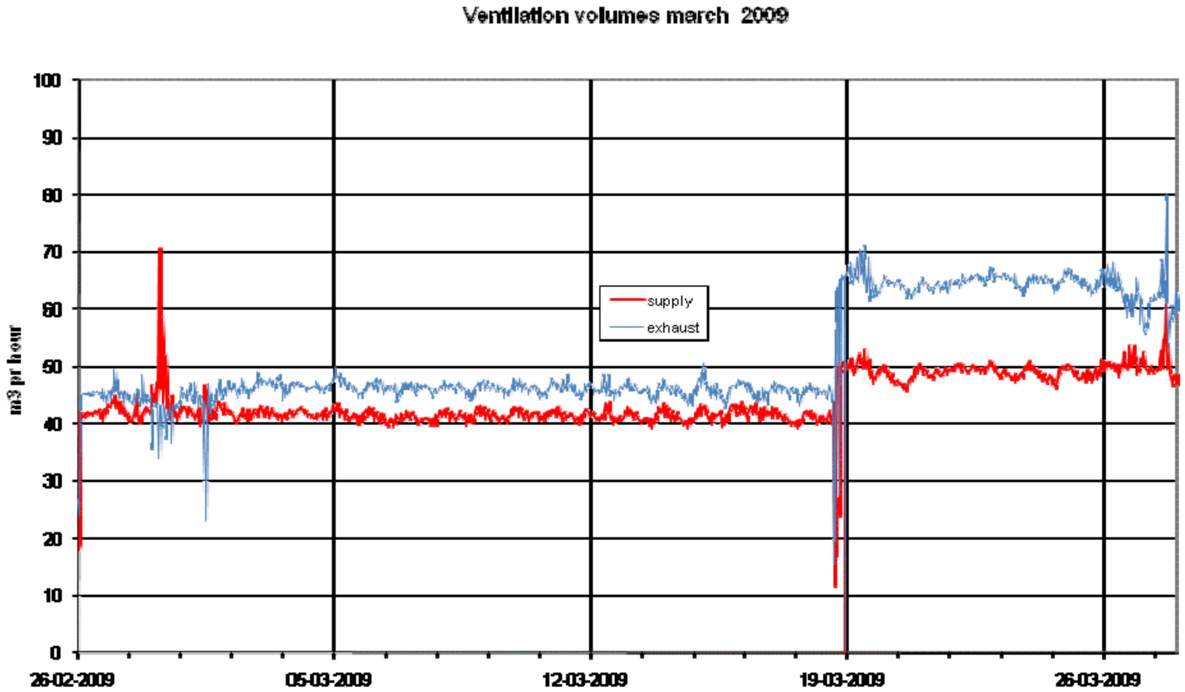

Figure 23 Measurement of the ventilation system volume flows in supply and exhaust (e.g. inlet and outlet)

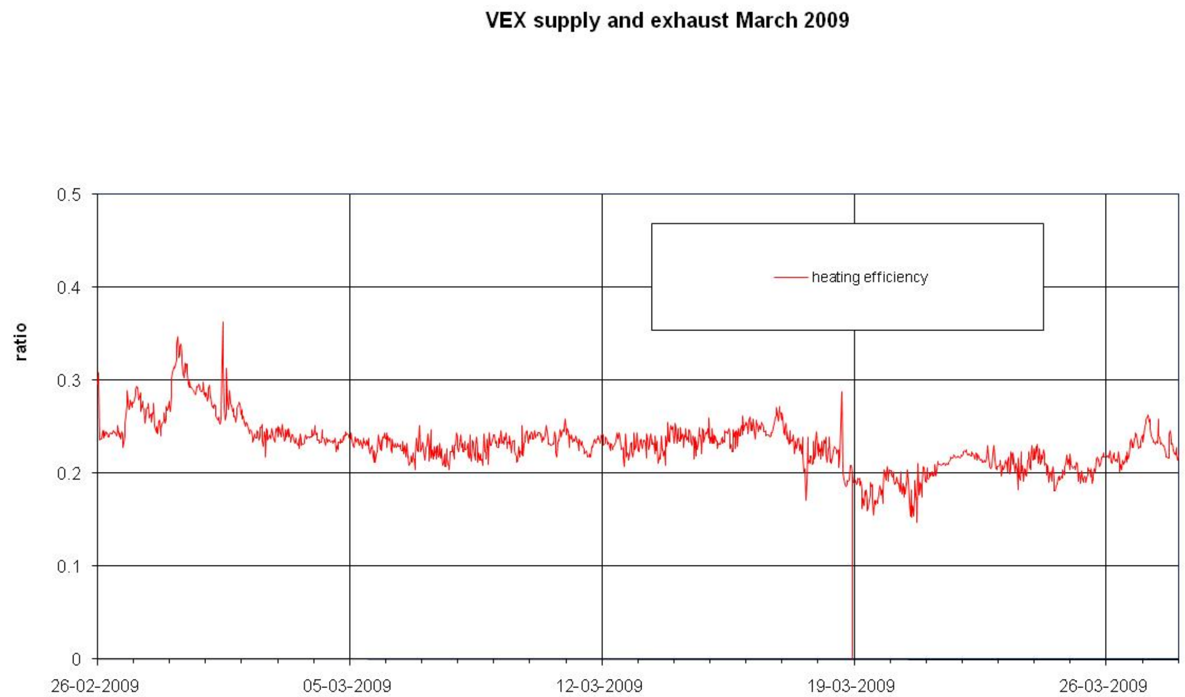

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Figure 24 Calculated temperature efficiency for the VEX in March 2009

Comment to the ventilation

Figure 22 shows that the outside temperature has been relatively low (-5 º C to -25 ° C), and that the temperature of the indoor air has decreased to 15-18 ° C before the air reaches the VEX. It should be noted that the room temperature during the same period has been measured to be about 23 °C, see Figure 4. So there is already a significant temperature drop, before the air reach to the VEX. For the period the VEX has calculated temperature efficiency about 22%, quite smaller than the approx. 80% which was measured in the laboratory at DTU BYG before the VEX was shipped for Greenland. The 22% calculated temperature efficiency was done only for one month period in March 2009 due malfunction of HOBO, therefore is the efficiency is low.

The ventilation system has not performed optimally. In periods the fans have been turned off due to unknown reasons. Often the people living in the house have not been aware that the ventilation has stopped.

As mentioned in connection with Figure 13 the further heating of the supply air after it has passed the VEX is not well controlled. The temperature of the air blowing into the rooms has been measured to be about 40 ° C and the regulation of the heater will hopefully soon be corrected.

4 Blower-door test

In February 2009 a blower-door test was performed to measure the air-tightness of the building envelope and to diagnose possible leakage. The results showed an average air change of 474 liters per second (V_{50}) and the average air changes per hour 3.22 h^{-1} (n_{50}) at 50 Pascal pressure, which is estimated to correspond to an infiltration rate of 0.32 h^{-1} at normal pressure state. The infiltration is calculated according to DIN 2003 where the estimated infiltration is approximately 10 % of n_{50} for tight houses.

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. According the Building Code if no blower-door was done, the value for infiltration is estimated to be 0.5 h^{-1} and used for possible calculation of energy balance.

For the initial calculation of the Low-energy house in BSim the ambitious value of 0.1 h^{-1} for infiltration was used. /1/

The test diagnosed problems with inner air-tight layer close to bedroom windows (windows on inclined wall). Also entrance window/door gives a significant leakage. The test also showed leakage between kitchen part and entrance part and crawl space under the furnace (e.g. shaft).

Velux windows in facade

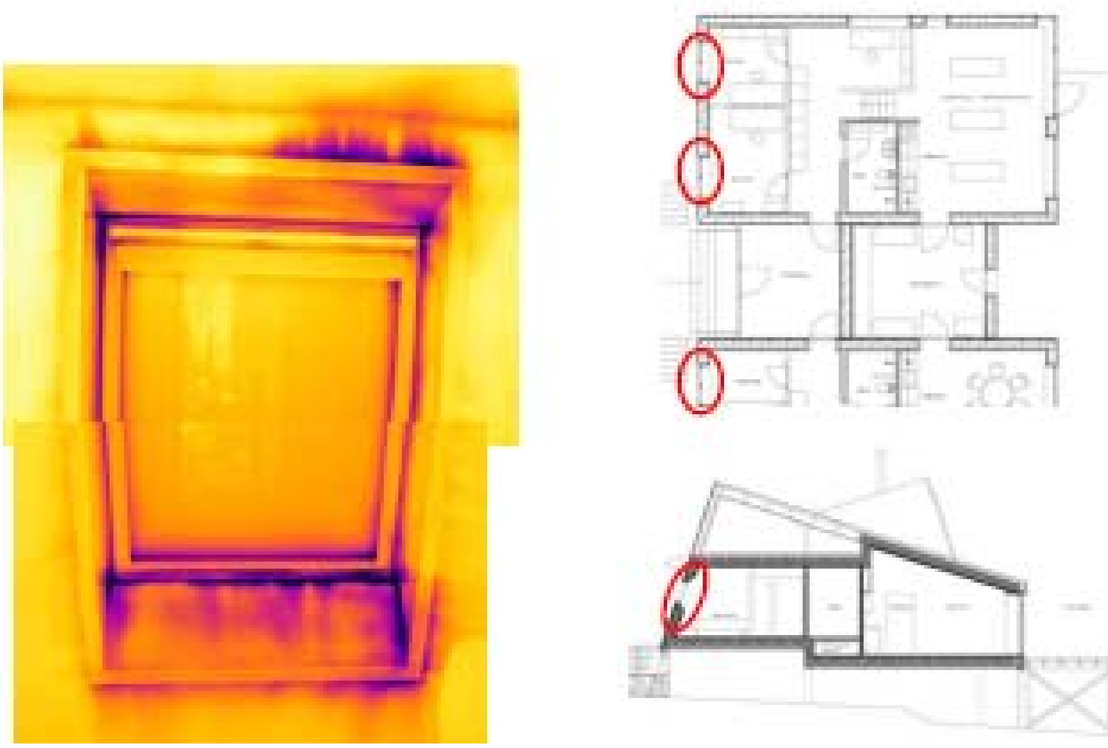

Figure 25 Windows on the inclined wall and leaking of air-tight barrier

Entrance hall where there are leaking areas both inside of the windows, but also in the surrounding construction and seal in window panels.

Figure 26: Entrance door and leakage

Some leakage in the corner between kitchen and crawl space (shaft) beneath the kitchen.

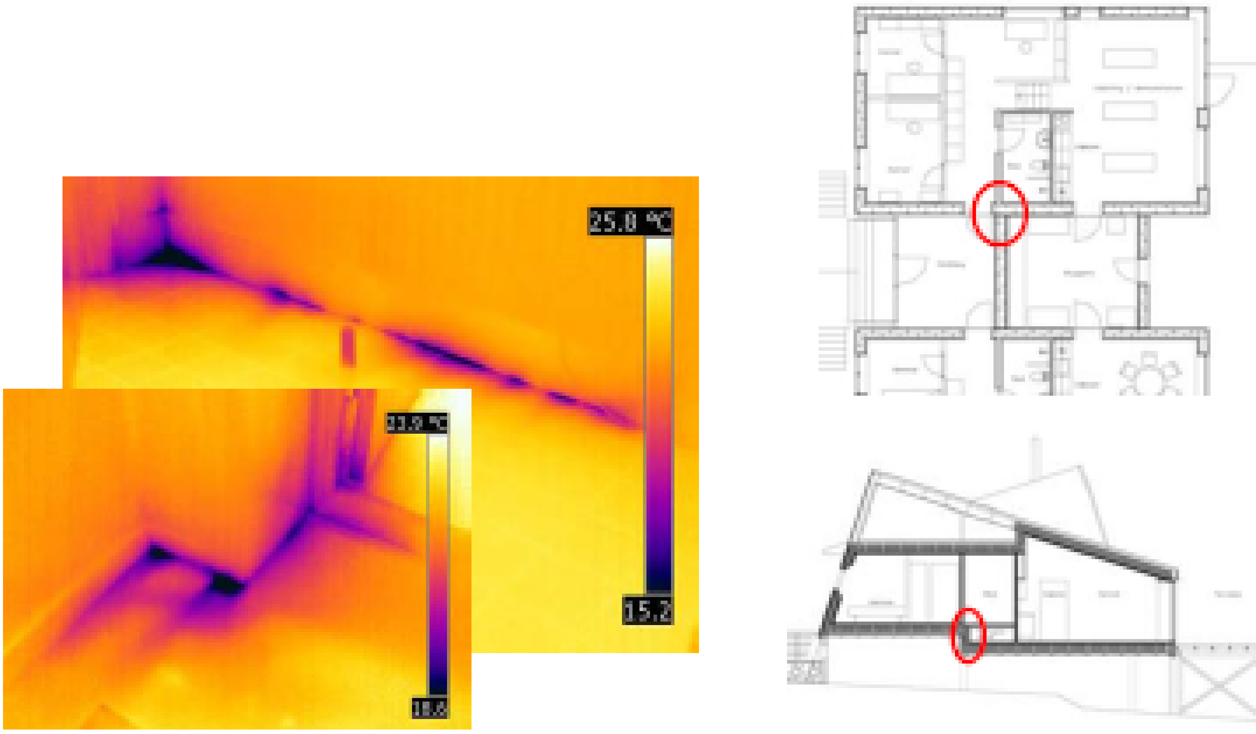

Figure 27 Leakage between entrance area and crawl space (shaft) beneath the kitchen

Large air flows from the crawl space beneath the kitchen cabinets and ventilation shaft.

Figure 28 Leakage between kitchen unit and crawl space (shaft)

Commenting on air tightness

The air tightness of the low-energy house is an important issue. The results of blower-door and thermo graph tests show that there was not enough attention given to tightness of building when the house was constructed. Leakages around windows in bedrooms have been repaired this summer and the work is going on fixing the leaks between kitchen, entrance area and ventilation shaft beneath the house. 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.

5 Comments on Low-energy performance in year 4

Low-energy house in general

The low-energy house has been inhabited during the whole fourth year, e.g. the South-western apartment was inhabited, and the North-eastern apartment was used as occasional guest house during the year.

Ventilation
The set up of ventilation system has to be solved where the air blowing into rooms has a high temperature, ant the speed of air flow needs to be managed more carefully. The efficiency of VEX heat exchanger is still not as expected and there are problems with defrosting function.

The solar heating system and its measured results in year 4 have generally been satisfactory, but the measurements show that there are still problems with either the control of the system, or the operation of a return valve (reverse circulation). This is being investigated and the magnetic valve will be installed.

Windows are still in good condition, but certain fixing of leakage around the windows has been done after the blower-door and thermo graphic test. To fix the frosting between panels in terrace windows the holes have been drilled to avoid frost and condensation (executed in November 2006). See photos in Annex 1 - Pictures from the low-energy house 2008/2009.

Further repair of the house will be done during autumn 2009 to get one more year of functioning of house and to complete a 5-year trial period. The repair and energy improvements could lead to possible improvement on heating consumption as follows:

Estimates of maximum possible energy improvements

Heat consumption today	140 kWh/m^2
Possible saving by air tightening the house (estimate)	45 kWh/m^2
Possible saving by insulating the heat recovery unit (estimate)	25 kWh/m^2
Possible saving by mending the control of the supply air’s heating coil (estimate)	20 kWh/m^2
Possible saving by insulating the ducts and units in the attic (estimate)	10 kWh/m^2
Possible saving by various other improvements, e.g. user behaviour (estimate)	10 kWh/m^2

/4/
It is not realistic to assume that all these savings can be achieved simultaneously.

The planned actions will be executed after summer 2009 and therefore have no effect in this report:

- Extra insulation on ventilation ducts in attic, plan for 100 mm of extra insulation, total 150 mm of insulation
- Leaking windows in bedrooms have been repaired and air-tight barrier have been checked
- Mending of ventilation system
- Outlets from technical room to ventilation systems and inlets to user parts of the house.
- Electricity system will be revised and checked to see possible “escapes” of electrical energy, e.g. electrical antifreeze of sewage piping. (When the house is occupied, the antifreeze is off, therefore no electricity leakage.)

6 Low-energy houses´ technical journal

Below are listed dates and descriptions of major changes that could affect the registration of Low-energy house performance.

Date	Description
April 2005	Inauguration of low-energy house
16. Jan 2006	Three meters coupled to keep focus system
Marts 2006	Insulation of pipes in technical room
August 2006	Internal regulation of solar heating
August 2006	Logging of ventilator inoperative
October 2006	Insulated box around the exchanger
November 2006	Measuring the differential in the fan and the air temperature at home and take at vex'en. Measurements made with Hobo data logger,
November 2006	To fix the frosting between panels in terrace windows the holes have been drilled to avoid frost and condensation
Forår 2007	Logging of Sensirion system inoperative for long periods.
1 July. 2007	1. rents of low-energy house move out
Dec. 2007	Setting up the wall in front of washroom facilities
Feb – Mar 2008	Renovation wood flooring
1. April 2008	2. tenant moves in. (Larseraaq - switching)
February 2009	Blower-door test
March 2009	Replacement of parts in the air heating system
July 2009	Fixing of leaking windows in inclined wall
August 2009	Current 30 mm was increased for extra 50 mm of insulation on ventilation ducts in the attic (total thickness of insulation is 80 mm)
December 2009	Extra 70 mm of insulation on top of the 80 mm (total thickness of insulation is 150 mm)
December 2009	Mending of after-heating

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Annex 1 – Photos of Low-energy house 2008/2009

Pictures were taken in August 2009.

Figure 29 Window toward South

Figure 30 Solar collectors and South facade

Figure 31 Low-energy house and fixing of windows in inclined wall

Figure 32 Fixing of skylight windows

Figure 33 Heat exchanger in insulated box

Figure 34 Holes in windows to prevent freezing in winter