Energy Project Villa – Main Report

Project Participants:

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Danfoss

Sekretariatet for Energimærkning

ROCKWOOL
FIRESAFE INSULATION

Preface

The Energy Project Villa report consists of two parts, Main Report as well as a Report of Appendices. In addition to this a separate report with modelling of energy consumption has been made by DTU (R-102).

The purpose of making two separate reports has been to make the report easily readable, also to people without thorough technical knowledge; thus, the technical specifications and details will be found in the report of Appendices.

The project partners would like to thank Anne & Niels Rasmussen, as well as Thomas Olsen & Lotte Rasmussen for making it possible to use the house in Køge for carrying out this demonstration project. We would also like to thank Bolius and Nykredit for their input to the project group throughout the process of the work.

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1. Introduction

Both the Technical University of Denmark (DTU) and Statens Byggeforskningsinstitut (SBi), as well as ECOFYS on European level (see literature list), have written reports about the potential energy savings (and equal CO_2 savings) by renovating the existing building stock.

The idea of the Energy Project Villa derived from discussions with decision makers realising that documentation of carrying out these improvements had not been made. A specific example of the cost saving effect by renovating a typical house was also thought to be of interest to the consumers (house owners). This energy saving potential is not reached through the Energy Performance of Buildings Directive (EPBD) demands since they apply only for major renovations of buildings.

The project focus has been to show the effect of the "easy to carry out" measures, which do not interfere with the aesthetic appearance of the house and for which solutions and products already exist. Some measures can be carried out by the house owners themselves at lower cost than in this project, since the renovation activities have here been subcontracted to professional contractors.

The goal has been to demonstrate the energy savings obtained by renovating a typical villa built before 1950. The total economy should be documented and the optimal result would be a saving from day 1 - even without taking into account the higher market value such measures might add to the house.

The purpose of the project is to get more attention and, via a marketing effort, to try to motivate and influence people to activate the energy saving potential in existing houses, using well known existing solutions.

A theoretical modelling of the energy consumption has been done for the same villa and subsequently compared with the values measured, in order to obtain an understanding of the difference between theoretical and measured results.

The Villa chosen for this project was one of the 284,000 houses certified through the energy certification secretariat in Denmark. Before the energy renovation the Villa had a C5 classification for heating - the poorest classification possible. Of all houses certified in Denmark, which are built between 1910 and 1950, 25% have a C5 classification for heating.

The house used for the energy renovation in this project was selected by "Energimærkningsordningens sekretariat". Through a search in the database of certified houses a number of houses were found, and the selected group of house owners were then contacted by phone. Subsequently four potential houses were visited for final selection.

The Villa was selected based on the following criteria:

- built before 1950 (segment with highest percentage of houses with low energy efficiency)

- a “typical” house (so solutions are transferable to other houses)
- not heated by a wood stove (difficult to measure energy consumption)
- no renovation carried out since the energy certification date
- location at Zealand (easiest access for project partners).

The cost saving effect was documented first by monitoring energy consumption and indoor climate, then by renovating the parts of the building found to be most cost-effective, and finally by monitoring the energy consumption again.

The energy consumption and the indoor environment of a building are closely related. Declaration of a building’s energy consumption without stating the related indoor environment is of no use. One follows the other; therefore energy consumption cannot stand alone. Obtaining low energy consumption in a building, e.g. by having very low temperatures, might be at the expense of increased risk of mould growth, thermal discomfort and other health risks, which is not recommendable. To eliminate the differences in indoor environment, the project deals with the measured values corrected to an indoor temperature of 20°C.

Due to the limited timeframe given to the project it was not possible to measure a full year of energy consumption before renovation activities started. The conclusions in this report are therefore made on basis of a measuring period of two Autumn months before renovation and one Winter month after the renovation, scaled up to the heating season of a full year. The energy consumption and indoor environment measurements in the house will continue throughout 2005.

Details of constructions and suggestions for energy renovating activities will be displayed at the Rockwool Scandinavia web-site www.rockwool.dk, as an inspiration to people searching to find solutions for the specific needs of their house.

2. Summary

In Energy project Villa the cost saving effect of renovating a typical existing villa built before 1950 has been documented. In this way the project can be regarded as a contribution to the documentation of the potential energy savings in the existing building stock.

The actual Villa used for the energy renovation and documentation in this project has been selected by “Energimærkningsordningens sekretariat” by searching in the database of certified houses.

The Villa is an old typical Danish master builder house of 161 m^2 with a C5 classification for heating before the energy renovation. It has a full basement (not heated), a ground floor and a first floor, and is occupied by four persons – a family with two small children.

Both before and after energy renovation a detailed monitoring of the indoor environment in terms of room temperatures, air change rates, and relative humidity has been carried out together with monitoring of air leakage and energy consumption.

In addition to the documentation of measured energy consumption and savings, theoretical predictions were made by use of building simulation modelling. A comparison between predicted and monitored results has thus been made possible, and shows larger savings when monitoring than when simulating.

The energy saving improvements carried out in the project are “easy to carry out” measures. The package of measures carried out consisted of: Improvement of the insulation level of the building envelope, amendments to the heating system and applying storm windows. The work was carried out by professional contractors and the total cost was DKK 157,000.

The specific master built villa from 1927 had a monitored gross energy consumption of 53,400 kWh per year (332 kWh/m^2) at an indoor temperature of 20°C before energy renovation.

The energy consumption and the indoor environment of a building are closely related. Declaration of a building’s energy consumption without stating the related indoor environment is of no use. It has been important for the project partners to see that the energy savings in the Villa are obtained without increased risk of mould growth, thermal discomfort and other health risks.

The project has shown that with the energy renovation it has been possible to reduce the gross energy consumption to 28,100 kWh per year (175 kWh/m^2) at an indoor temperature of 20°C. This equals a reduction of 2500 litre of fuel oil per year corresponding to almost 50 % .

The indoor environment seems to be improved by the energy renovation, according to the data collected so far. This will be monitored over a full year to get a picture of the yearly fluctuations.

Assuming a conservative energy price and a conservative way of financing the house owner will get a net saving the first year of DKK 7,500.

First year's cost of financing the building work equals DKK 8,500 and the energy saving equals DKK 16,000. Seen over a 30-year period the total savings in NPV (net present value) will be DKK 396,600.

It must be stated that if occupants for instance choose to improve their indoor environmental comfort after renovation, (or if they originally lived with a poorer indoor environmental comfort before energy renovation), then the actual energy savings in DKK will be less than stated above.

3. General Description of the Villa

The Villa is a typical Danish master builder house built before 1950. The front page picture of this report shows the front facade of the Villa facing south.

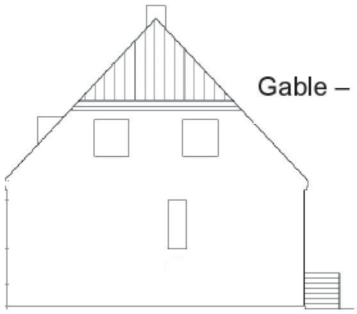
The Villa was built in 1927 and has a heated area of 161 m². It has a full basement (not heated), a ground floor with living room, dining room, kitchen and toilet, and a first floor with bedroom, two children rooms and a bathroom. See sketches of the Villa below.

Front facade - South

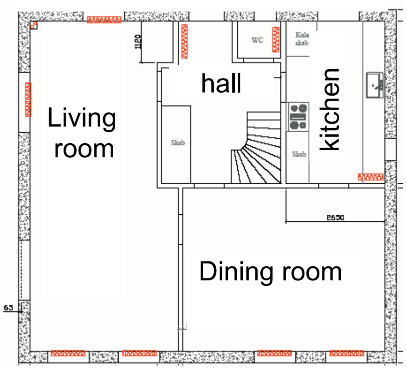
Back facade - North

Gable – West

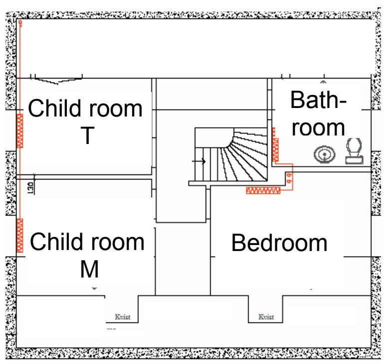
Gable – East



Floor plan – ground floor



Floor plan – 1st floor



3.1 Building constructions

The original structures of the house were composed of external walls of 30 cm un-insulated cavity walls with steel ties. The windows were traditional, old windows with small wooden glazing bars, which, on the ground floor, were partly equipped with storm windows with ordinary glass. The space under the roof slope, the sloping walls and the collar-beam roof were insulated with old 50 mm insulation mats. See detailed description of building constructions in Appendix G.

3.2 Heating and ventilation

Room heating was originally provided by old cast iron heaters with manually operated on/off valves. The room heating system was water-based, buoyancy driven, and two-stringed. Domestic Hot Water (DHW) was stored in a 200 l horizontal hot water tank placed in the unheated basement. The heating was produced by an old un-insulated cast iron boiler with an oil burner placed in the basement. See pictures below.

As the heating system was buoyancy driven, pipe thicknesses were between 3/4″-2½″. The general insulation thickness of the pipes was around 30 mm.

3.3 Ventilation and air-change rates

The necessary ventilation, i.e. fresh air supply in the Villa was provided by means of manually opening and closing of windows combined with use of air shafts in external walls (i.e. natural ventilation). Besides this intended and controlled ventilation, an uncontrolled infiltration/ventilation of the building took place through various air leakages in the building envelope. Especially around the original window frames, the air leakage was significant, leading to cold draught near windows.

There is no cooker hood in the kitchen. Originally, a small exhaust ventilator was mounted in the kitchen window; however, it was not functioning.

3.4 Residents/users/occupants

The Villa is occupied by a family with two small children at the age of 3-5 years. Since the two children suffer from asthma and allergy, the occupants are fairly careful about ventilating through opening and closing of windows every morning in bedroom and children rooms.

Laundry, including hang drying of clothes is done in the (unheated) basement.

4. Renovation measures carried out on the Villa

The building envelope was analysed to the extent possible without using destructive methods and possible solutions for improving the energy efficiency of the villa were designed. Some of these solutions were chosen not to be carried out because - although technically possible - they were, from a cost-effective point of view, found not to be as feasible as other measures.

The following measures were carried out at site.

- Facades (Insulation of cavity walls)
- Retrofitting of ”space under the roof slope”(horizontally and vertically)
- Retrofitting of sloped wall
- Retrofitting of loft
- Heating system (6 new radiators, thermostats, pump)
- Insulation of wall under windows (not cavity)
- New storm windows with energy glass

Pictures from the on-site work can be found in Appendix H.

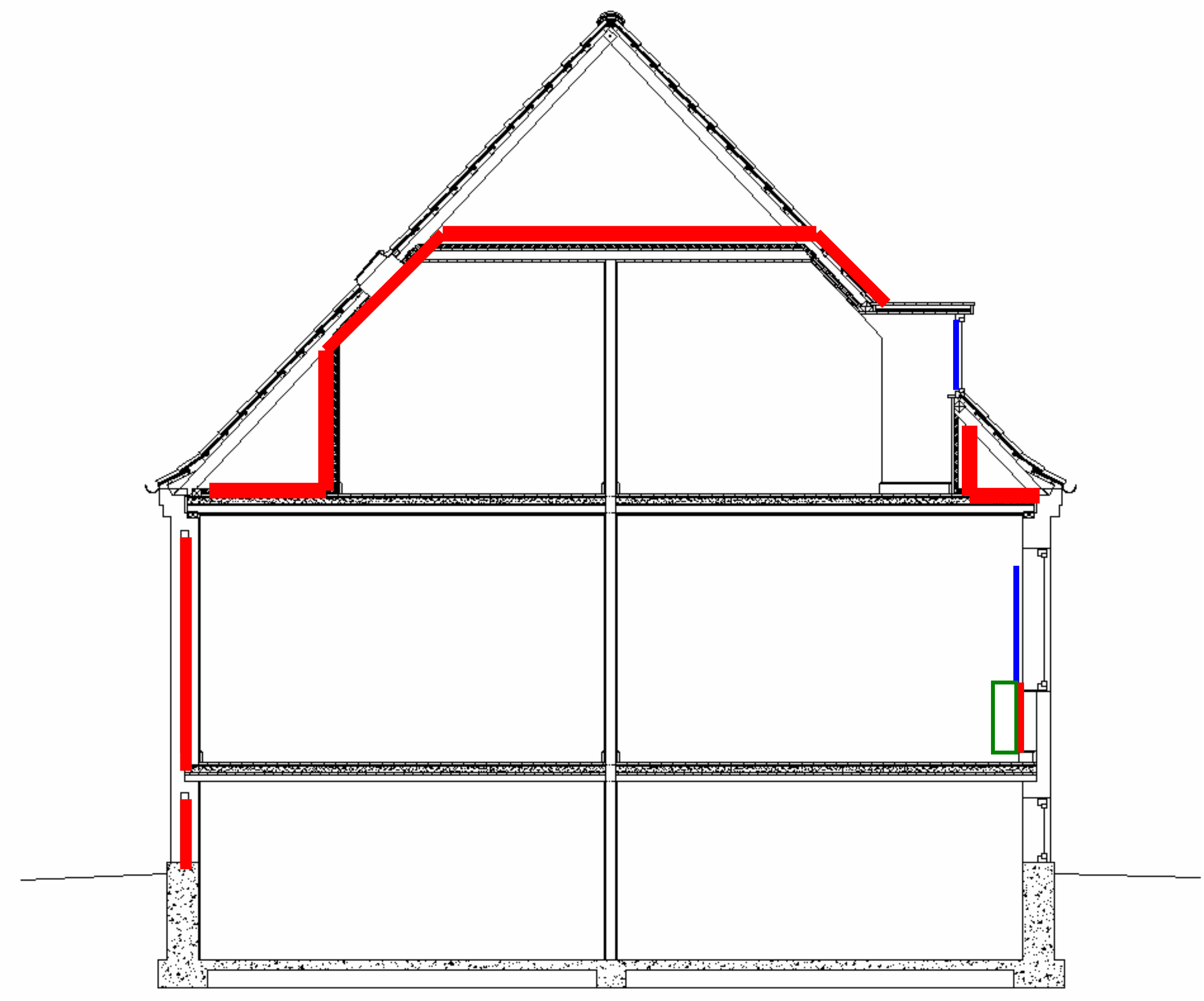


Figure 4.1 Location of energy efficiency improvements to the building envelope

Some additional measures had to be carried out as a result of the retrofitting although they had no energy saving effect. These are: Insulating exhaust from boiler through loft space, replacing exhaust ventilator in kitchen, and installing exhaust ventilator in bathroom.

Measures that were not found to be feasible from a cost-benefit point of view, due to the specifics of the villa, were: Work on the dividing floor to basement, dormers, and boiler.

4.1 Description of measures

Facades: Granulate insulation was blown into the cavity wall according to the general Rockwool work description. The cavity was measured to approx. 90 mm.

Space under the roof slope (Skunk): Old insulation was removed. To make sure that air cannot penetrate underneath the floor boards of the space under the roof slope, granulate was blown into the small cavity. Slaps were applied on top of the floor boards and vertically to the "outside" of the wall.

North side of house:	Vertically: 75 mm Super-A batt + 200 mm Flexi A batt
	Horizontally 100 mm super-A batt + 200 mm Flexi A batt
South side of house:	Vertically: 75 mm Super A batt + 200 mm Flexi A batt
	Horizontally: 250 mm super-A batts

Sloped walls: Old insulation was removed. A new 75 mm Flexi A batt was slid into place on the "outside" of the sloped wall in the cavity underneath the roof. This was done from the loft and downwards. (Cavity was approx. 100 mm)

Loft: Old insulation was removed. 100 mm Super-A batts and 200 mm flexi-A batts were applied horizontally.

Insulation of walls under windows: There are no cavity walls under the windows and therefore insulation was applied on the inside of the external wall. The existing heaters had to be dismounted in order to apply this insulation. 75 mm flexi-A batts and 16 mm MDF-board were applied.

Heating system: After dismounting the heaters at six places in order to apply insulation, six new heaters (thinner) were installed. Thermostats were applied to all heaters in the house (12 new ones, one heater already had a thermostat). At first floor (4 rooms) the Danfoss type RA-plus was installed, in remaining rooms Danfoss type RA was installed. A pump had to be added to the system to compensate for the higher resistance in the heating system.

Storm windows (extra frame + glass mounted on interior side of existing window): Existing, not airtight, storm windows were dismounted. New storm windows of the type "Trehøje Dannebrog" with 4 mm energy glass were installed at ground floor and first floor.

***Necessary additional measures*:** Exhaust pipe from boiler was insulated through the loft space with 2x50 mm Rockwool wired mats. Existing ventilator in kitchen window (not connected) was removed and a new one was installed, type Punto M 120 AT. Ventilator type Punto M 100 AT-HCS was installed in the bathroom wall.

5. Indoor environment and energy consumption <u>before</u> renovation

The energy consumption and the indoor environment of a building are closely related. Declaration of a building's energy consumption without stating the related indoor environment is of no use. One follows the other; therefore energy consumption cannot stand alone. Low energy consumption in a building can be obtained through compromising on temperature levels, on air quality, on damping levels, etc., i.e. by increasing the risk of mould growth, thermal discomfort and other health risks, which is not recommendable.

In this chapter the monitored energy consumption in relation to the actual indoor environment in the villa <u>before</u> the energy renovation is described.

The indoor environment is described through measured room temperatures, air leakage levels, ventilation rates, and relative humidity levels.

5.1 Temperature levels

The measured temperature levels in the Villa before the renovation are characterised by:

- **Being generally low**. The average room temperature in the villa before renovation is measured to 19.4 °C. Whereas standard temperature is minimum 20 °C. The measured minimum temperatures are down to 13-15 °C in several rooms for longer periods.
- **Varying considerably from room to room** with average room temperatures varying from 17-22 °C.
- **Varying considerably over the day.** This could be due to the fact that the existing cast iron radiators were provided with on/off valves only.

Average, minimum and maximum of measured temperatures and in the different rooms of the villa before renovation (from 9/9-7/11 2004) are shown in Table 5.1 below:

Temperatures measured from 9/9-7/11 2004	**Average [°C]**	**Minimum [°C]**	**Maximum [°C]**
Room (air) temperatures			
Living room	20	17	24
Dining room	22	19	25
Bed room	18	13	24
Children room - Mille	19	13	25
Children room – Tilde	18	14	22
Kitchen	21	17	27
Bathroom	18	15	24
Boiler room in basement	22	20	25
Basement – unheated room	19	18	21
Entrance hall	18	15	21
Toilet	17	14	20
Entire house*	**19**	**16**	**22**
External temperature	12	4	21

Table 5.1: Overview of temperature levels in the villa before energy renovation.

* The overall temperature of the entire house is determined as a weight average. See Appendix B, par. B.2.

Figure 5.1 shows a typical example of how the temperatures vary throughout the day. Especially in the living room and dining room, the maximum temperatures occur around midnight and minimum temperatures early in the morning. This is probably due to the fact that the existing cast iron radiators had manually controlled on/off valves only. If the valves are left on while the residents are not at home, the temperatures get too high. Therefore, the residents leave the radiators off while not at home. As the heating system and the building constructions in the villa are thermally heavy/slow, it typically takes 1-2 hours before the temperatures are at comfort level again.

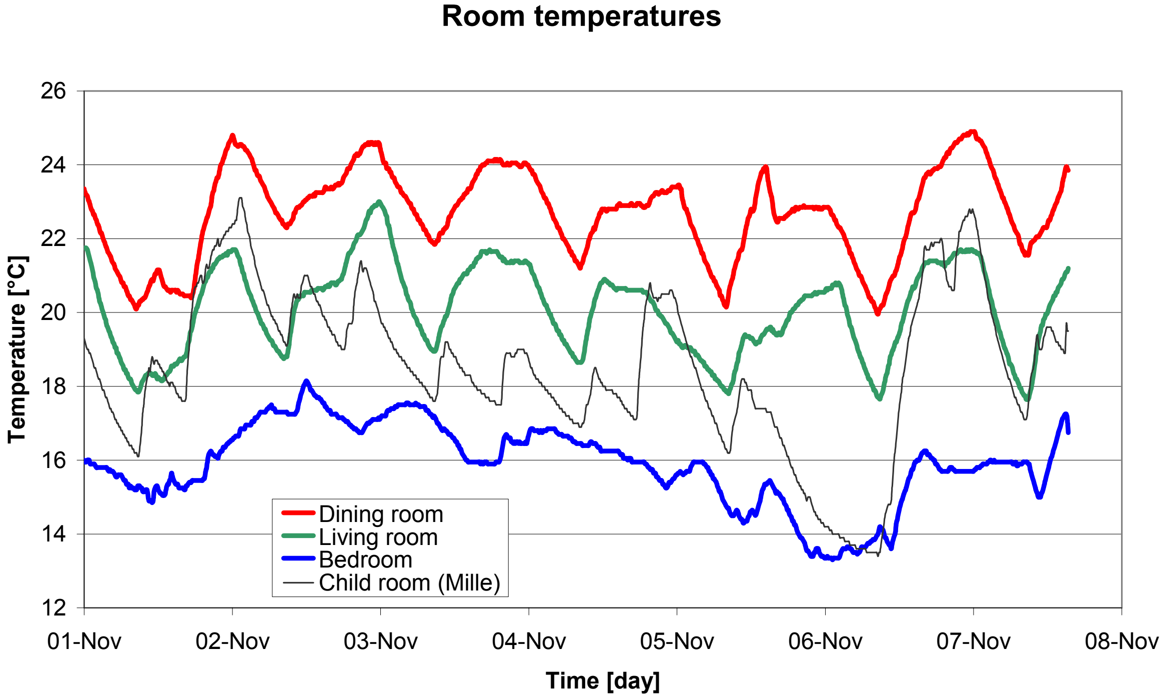


Figure 5.1 Room temperatures in the Villa before renovation. November 1-7 2004. Typical winter week.

It appears from Figure 5.1 that especially in the bedroom, but also in the children's rooms, temperatures have been extremely low. One explanation might be the daily airing routines of the residents. Every morning they open windows and ventilate all bedrooms thoroughly - these can possibly have been left open for longer periods. Another explanation might simply be that the residents prefer very low temperatures in their bedrooms and thus more or less keep them unheated.

See appendix A for description of monitoring program and appendix C for further details on measured temperatures in the building before the energy renovation.

5.2 Measured air change rates and relative humidity before renovation

Before the energy renovation the Villa is characterised by having no mechanical ventilation, and a very leaky building envelope, resulting in increased risk of cold draught near external walls, especially near windows.

5.2.1. Air leakage

The air leakage of a building envelope describes the uncontrolled infiltration/ventilation of a building, which strongly affects the heat losses of a building. The air-leakage of a building should not be mistaken for the controlled and necessary ventilation of the building.

The air leakage of the building before energy renovation was measured to be19 air changes per hour at 50 Pa. In comparison, air-leakages in low-energy houses in DK with very tight building envelopes are measured to be 0.2-0.6 air changes per hour at 50 Pa. [Source: Kolding+HjorteKær].

See Appendix D for further information on the measurement of air leakage in the Villa.

5.2.2. Ventilation rates/fresh air supply

The necessary ventilation, i.e. fresh air supply in a building can be provided by means of mechanical or natural/manual ventilation. Before the renovation, the necessary ventilation of the Villa is provided by manually opening and closing of windows.

The typical ventilation rates at normal use of the residents of the Villa were measured through a period of 11 days from October 21 till November 1st. By “normal use” means normal opening and closing of external and internal doors as well as normal ventilating through opening and closing of windows. The air change rate was measured to be 0.4 air changes per hour in the living rooms (i.e. living room, dining room, and bedrooms). In comparison a new built house in DK typically has an air change rate of 0.4-1.0 air changes. [Source: “Byg boligerne bedre” page 80+81].

See appendix E for further information on the measurement of ventilation rates.

5.2.3. Relative humidity

The relative humidity in the Villa before (and after) energy renovation is measured in order to give an indication of damping levels and mould growth risk

As can be seen from the table below, the measured relative humidity in the villa before energy renovation generally varies from 40-60 % on average in most rooms. In the bedroom where the room temperature is generally kept very low - the average relative humidity is 65%. In the bathroom it is 70%.

Relative Humidity measured from 9/9-7/11 2004	**Average [%]**	**Minimum [%]**	**Maximum [%]**
Indoor Relative Humidity (RH)			
Living room	53	41	74
Dining room	41	26	58
Bed room	65	36	90
Children room – Mille	58	35	77
Kitchen	53	35	71
Bathroom	70	48	98

Table 5.2: Measured relative humidity before energy renovation.

5.3 Energy consumption

The energy consumption in the villa before energy renovation in the period from 9/9 to 7/11 2004 is measured to:

Total heat production from boiler:	3143 kWh
- Part for domestic hot water (DHW):	<u>- 693 kWh</u>
Total energy consumption for room heating:	<u>2450 kWh</u>

Since the general room temperature in the Villa in the "before-situation" has only been 19°C, compared to normal room temperatures of 20°C, the measured energy consumption for room heating has to be corrected according to this lower comfort level. (See detailed description of correction method in appendix B).

With corrections for room temperatures and degree-days, this measured value equals the following total energy consumption for room heating in the Villa <u>before</u> energy renovation:

Net energy consumption for room heating, BEFORE: <u>29,900 kWh per year</u>

The measured energy consumption for room heating includes pipe heat loss in pipes from boiler to room heaters and from room heaters back to boiler. However, boiler loss (due to burner efficiency, heat loss from boiler surface, heat loss from boiler hatch, as well as flue gas loss), are not included.

The total gross energy consumption for room heating - including energy consumption for domestic hot water preparation (4300 kWh) and taking account of boiler efficiency (64 %) - sums up to:

Gross energy consumption (room heating + DHW), BEFORE <u>53,400 kWh per year</u>

This equals around 5300 l of fuel oil per year.

See detailed description of boiler efficiency in Appendix C par. C.6.

6. Indoor environment and energy consumption after renovation

In this chapter the monitored energy consumption in relation to the actual indoor environment in the Villa after the energy renovation is described and compared with the situation before the energy renovation.

6.1 Temperature levels

The measured temperature levels in the Villa after renovation are characterised by:

- **Being generally higher than before the renovation**. The average room temperature in the Villa after renovation is measured to 20.6 °C. The corresponding temperature was 19.4 °C before the energy renovation. The measured minimum temperatures in the heated rooms after renovation are generally around 17-19 °C, - they were typically 13-15 °C before the renovation. All together, the measured temperatures indicate a significant rise in the thermal comfort level after the energy renovation of the Villa.

- **Varying from room to room** with average room temperatures varying from 18-24°C.

- **Varying less over the day than before the renovation**. See Figure 6.1.

Measured average temperatures and absolute minimum and maximum temperatures in the different, heated rooms of the Villa after renovation (from 3/12-3/1 2004/05) are shown in Table 6.1 below:

Temperatures measured from 3/12-3/1 2004/05	**Average [°C]**	**Minimum [°C]**	**Maximum [°C]**
Room (air) temperatures			
Living room	21	19	24
Dining room	23	21	25
Bed room	18	13	21
Children room – M	20	17	24
Children room – T	20	17	24
Kitchen	24	20	28
Bathroom	21	19	23
Boiler room in basement	23	19	25
Basement – *unheated room*	*16*	*15*	*18*
Entrance hall	20	14	22
Toilet	20	18	22
Entire house*	**21**	**19**	**23**
External temperature	3	-3	9

Table 6.1: Overview of temperature levels in the villa before energy renovation.

The overall temperature of the entire house is determined as a weight average. See Appendix B, par. B.2.

Figure 6.1 compares typical examples of how the temperatures vary during the day before and after the renovation.

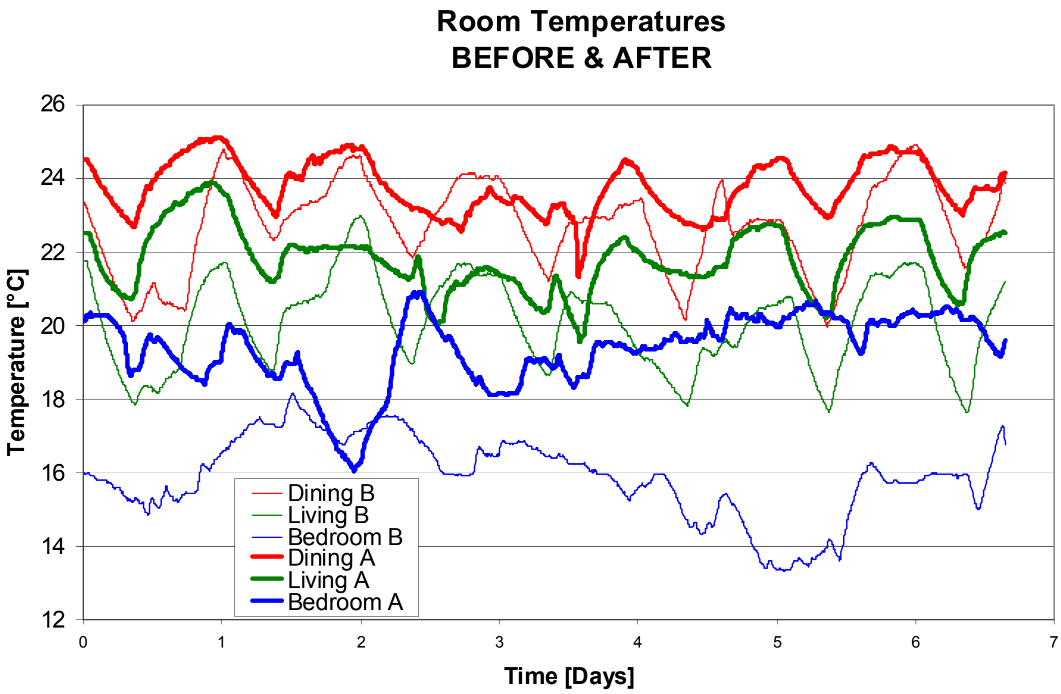


Figure 6.1: Room temperatures in the Villa after renovation. December 4-11, 2004. B indicates before renovation and A indicates after renovation.

See Appendix A for description of monitoring program and appendix C for further details on measured temperatures in the building before and after the energy renovation.

6.2 Measured air change rates and relative humidity after renovation

The building is still being mainly manually ventilated through opening and closing of windows. However, two small exhaust ventilators in bathroom and kitchen are installed in order to increase comfort level for the habitants through the possibility of ventilating these rooms without having to be at home.

6.2.1. Air leakage/ risk of cold draught

After the energy renovation the villa is characterised by having a building envelope which is only half as leaky as before, resulting in decreased risk of cold draught near external walls, especially near windows.

The air leakage of the building after energy renovation was measured to 9 air changes per hour at 50 Pa. This corresponds to less than half of the air leakage before energy renovation which was 19 air changes per hour at 50 Pa.

6.2.2. Ventilation rates/fresh air supply

The typical ventilation rates, at inhabitants' normal use of the villa, were measured during a period of 9 days from December 8-17 by means of tracer gas measurements. The air change rate **after renovation** was measured to **0.3 air changes per hour** in the living rooms, i.e. living room, dining room, and bedrooms. The measurement before renovation was 0.4 air changes per hour, corresponding to a reduction of ventilation rates of 30 %.

6.2.3. Relative humidity

The table below is listing the measured relative humidity in the Villa after renovation.

As can be seen from table 6.2, all measurements of average, minimum and maximum relative humidity are lower after the renovation than before the renovation indicating reduced dampness levels and thus reduced risk of mould growth after the energy renovation.

In spite of a decrease in ventilation rates of 30 %, the relative humidity is also decreased and thus reduced risk of mould growth.

Relative Humidity measured from 3/12-3/1 2004/05	**Average [%]**	**Minimum [%]**	**Maximum [%]**
Relative Humidity (RH)			
Living room	**46**	**38**	**54**
Dining room	**33**	**22**	**46**
Bed room	**56**	**39**	**76**
Children room - M	**42**	**33**	**62**
Kitchen	**41**	**28**	**78**
Bathroom	**54**	**43**	**87**

Table 6.2: Measured relative humidity after energy renovation.

It appears that the general indoor environment in the Villa has been improved after the energy renovation. Thermal discomfort caused by cold draught from air leakages (especially around windows) has been reduced and the relative humidity levels have been decreased; both resulting in a reduced risk of mould growth. Due to difference in outdoor conditions before and after renovation, final conclusions regarding the relative humidity levels can, however, not be made until further measurement data are available. A thorough discussion of influence of humidity levels and recommendations regarding good indoor environment can be found in "Indeklimaet i boligen, SBI anvisning 179".

6.3 Energy consumption

The energy consumption in the villa after energy renovation in the period of 3/12 - 3/1 2004/05 is measured to:

Total heat production from boiler:	2329 kWh
- Part for domestic hot water (DHW):	- 467 kWh
Total energy consumption for room heating:	1862 kWh

With corrections for room temperatures (20^{o}C) and solar corrected degree-days, this measured value equals the following total energy consumption for room heating in the Villa after energy renovation:

Net energy consumption for room heating, AFTER: **11,200 kWh per year**

See detailed description of correction method in appendix B.

The measured energy consumption for room heating includes pipe heat loss in pipes from boiler to room heaters and from room heaters back to boiler. However, boiler loss (due to burner efficiency, heat losses from boiler surface, heat losses from boiler hatch, as well as flue gas loss), are not included.

The total energy consumption for room heating - including yearly consumption for domestic hot water (4300 kWh) and taking account of the boiler efficiency (55%) - sums up to:

Gross energy consumption (room heating + DHW), AFTER: **28,100 kWh per year**

This equals around 2790 l of fuel oil per year.

See detailed description of boiler efficiency in Appendix C, par. C.6.

7. Comparison of monitoring results with building simulation predictions

As a part of the overall project, The Technical University of Denmark, DTU, have modelled the energy consumption in the Villa before and after energy renovation, using the Danish building simulation tool BSim2002. Detailed description of heat loss calculations and the simulation of the energy consumption in the villa can be seen in the separate report "Energirenovering af murermesterhus" (R-102 in Danish).

In this chapter the conclusions from the DTU report are given and a comparison is made with the monitoring results presented in chapter 5 and 6 of this report.

Comparisons are made between the following parameters before and after renovation:

- Overall thermal indoor environment in terms of room temperature levels
- Total air change rates (without distinguishing between intentional ventilation and unintentional infiltration through air leakages)
- Annual net energy consumption for room heating (including heat loss from pipes in the basement)
- Annual gross energy consumption

First, the summary of the DTU report with predicted annual gross energy consumption is given. Then points are listed where the building simulation prediction deviates from real life conditions. Finally a comparison between predicted and monitored results is given.

7.1 Summary from DTU report R-102 (BSIM2002 prediction)

In the following the calculated heat losses and modelled/predicted gross energy consumption by use of BSIM2002 is summarised. An un-edited version of the summary from the DTU report R-102 is given in Appendix F par. F.2.

7.1.1. Reduction of heat losses through energy renovation measures

Detailed calculation of transmission heat losses through the building envelope have been carried out by DTU as a part of the building simulation modelling.

According to the DTU modelling results, the chosen energy renovation result in a reduction of the dimensioning heat loss of 53% from 15.0 to 7.1 KW. This is provided that the air change rate is reduced from 1.0 air changes per hour to 0.5 air changes per hour primarily through sealing of windows.

The transmission heat loss itself is reduced by 54% and the thermal bridge part is increased from 11% to 25%. The relatively small share before the renovation is due to the generally poor insulation of the thermal envelope constructions, whereas the considerable share after the energy renovation reflects that thermal bridges generally become more important when the insulation rate is increased. In the renovated solution there are considerable thermal bridges, for instance outside the massive exterior wall parts around windows and doors.

7.1.2. Total gross energy consumption for heating (incl. DHW)

A detailed calculation of the transmission heat loss in the Villa has been carried out. However, factors such as internal heat gains, air change rates, and precise room temperature levels also influence the energy consumption for heating in a building. These parameters might vary significantly from villa to villa, depending on the actual users, but are typically not known at such a detailed level. Therefore a series of sensitivity analysis have been carried out, where these parameters have been varied and their influence on the predicted result evaluated.

Table 7.1 shows the predicted gross energy consumption for heating including space heating demand, heating for domestic hot water (DHW), non-utilized heat losses from heating pipes, hot-water tank, and boiler, plus the boiler efficiency. An average boiler efficiency of 70% before the energy renovation and 65% after is assumed, since the implementation of the energy saving measures will reduce the boiler effect necessary. Thus the loss from running idle will be a relatively larger part and as such the annual useful effect will be slightly reduced.

It appears from Table 7.1 that the predicted gross energy savings vary considerably from 21.7-24.0 MWh/year or 28-41%, depending on assumed air change rates and internal heat gains.

If an internal contribution of heat from persons and household electricity of 5 W/m², a natural air change rate of 1.0 times an hour, and a room temperature of 20°C is assumed, the gross energy consumption is predicted to be **67,800 kWh** per year **before** energy renovation and **44,200 kWh** per year **after** corresponding to a 35% reduction.

The reduction is 41% if the air change rate after the energy renovation is assumed reduced to 0.5 times an hour (VENT 0.5).

In other words, the total gross energy consumption for heating can be reduced significantly by implementing modest envelope related insulation improvements.

Model name	***Before***	***After***	***Savings***	***Reduction (p.c.)***
Basis model	*67.8*	*44.2*	*23.6*	*35*
IV3	*70.6*	*47.2*	*23.4*	*33*
VENT0.5	*59.0*	*35.0*	*24.0*	*41*
VENT1.5	*75.7*	*53.4*	*22.3*	*29*
WCS	*78.2*	*56.5*	*21.7*	*28*

Table 7.1: Predicted *gross energy consumption for heating [MWh/year] before and after the energy renovation.*

According to DTU, it will usually be possible to obtain additional energy savings through subsequent insulation of boiler, hot water pipes and hot water tank (typically placed in the basement).Insulation of building envelope (external) and mechanical ventilation with heat recovery are examples of effective measures, which will also be able to yield additional savings. It is estimated that in this way it would be possible to reduce the room heating demand by about 75%.

7.2 Understanding BSIM2002 as a building simulation tool

A prediction of the annual energy consumption for room heating has been made by means of the Danish building simulation tool BSIM2002 on the basis of a detailed model of the Villa. It is important to notice that a model used in a simulation tool will always be a simplification of the real house and situation only. Although BSIM2002 is one of the more advanced building simulation tools, parts of reality are not taken into account or modelled precisely in BSIM2002. The most important factors are:

- Varying room temperatures – both from room to room and over time
- Real life operation of heating systems
- Varying air change rates due to weather conditions and user behaviour
- Incoming solar radiation
- Pipe heat losses
- Internal heat gains
- Weather conditions
- Duration of heating season
- Insulation values after energy renovation
- Domestic Hot Water consumption
- Boiler efficiency

All these factors and their possible effect on the BSIM predicted result compared to the monitored result are described in details in Appendix F.

7.3 Comparison of monitored and predicted energy consumption

By comparing predicted results with the actually monitored results, we get an indication as to which extent the building simulation predictions represent the actual situation. Further, we get an indication of where possible differences occur and what might be the reason.

A comparison of the predicted and monitored gross energy consumption is shown in Table 7.2 below:

Gross energy consumption	BEFORE [kWh]	AFTER [kWh]	Energy saving [kWh]	Reduction [%]
Predicted, basis model	67.800	44.200	23.600	35
Monitored	53.400	28.100	25.300	47

Table 7.2: Comparison of monitored & predicted gross energy consumption before and after energy renovation.

It appears from Table 7.2, that the predicted energy consumption both before and after renovation is significantly higher than the monitored energy consumption. There appears to be a shift in level. The predicted energy saving potential, thus, is quite close to the actually monitored energy savings. A likely explanation might be that the predicted heat losses from pipes in the basement are overestimated (see appendix F for further explanation). Another likely explanation is that the predicted air change rates are overestimated.

The predicted energy consumption for Domestic Hot Water (DHW) and the predicted boiler heat losses and efficiencies also differ from the actually monitored consumption.

Finally, the assumed air change rates and internal heat gains differ from considerably from the actual ones monitored.

8. Economy

The calculation of the economic result of the energy renovation of the Villa, is based on the actual building cost as well as energy prices and financing expenses. These parameters - which are less specific when looking into the future - will be examined and discussed below.

All of the measures carried out on the Villa have a life expectancy of more than 30 years.

The work has been carried out by professional contractors, based on tenders submitted. Quotations were received from two contractors for each of the different measures, and the cheapest offer chosen.

8.1 Accounting report for retrofitting cost

	Cost	Incl. VAT [DKK]
Contract work for energy renovation		
Wall under windows	6,702	8,377
Cavity walls (exterior)	15,200	19,000
Storm windows + sealing of front door	42,475	53,094
Insulation in loft	6,185	7,731
Clearing away old boards (loft) + new walking area	3,400	4,250
Vertical and horizontal insulation in "space under the roof slope" (skunk)	7,810	9,763
Insulation of sloped wall	3,850	4,813
Heating system work (+ power for pump)	29,496	36,870
Total I	115,118	143,897
Necessary additional costs		
Re-insulation of pipes due to pump work a.m.	2,615	3,269
Ventilator in kitchen (existing power outlet)	2,323	2,904
Wall mounted ventilator in bathroom	3,347	4,184
Insulation of boiler exhaust pipe through loft space	2,100	2,625
Total II	125,503	**156,879**

Table 8.1: Cost of on-site energy renovation work

8.2 Energy prices

Below are shown three scenarios for the future increase of energy prices which can be used to extrapolate the development representative for the Danish consumer, as well as current oil price.

There are several factors affecting the price today. Both market and political factors could influence the price. First of all the Danish energy price is based on the world market price plus a major tax contribution. The energy supply is a compound of many sources with very different history and future, and the energy tax can be changed to regulate the prices. Oil and gas supply will decrease in the future, resulting in higher prices, whereas coal, biomass and wind power are expected to be more price stable.

Additionally, the Danish energy supply sector is about to be privatized. This might result in increased energy prices.

For this study three conservative assumptions for extrapolation are used:

1) EU- Scenario
2) Prices will follow world energy consumption
3) Extrapolation made by DTU*, corresponding to a sustainability scenario over 30 years. (* Eurosun 2000 conference)

	Yearly increase in fixed prices	Source	Scenario based on
Scenario 1	1.5 %	ECOFYS 3	Standard scenario for evaluation of energy savings in EU
Scenario 2	1.8 %	EIA 2004	USA- energy agency scenario of oil consumption increase until 2025
Scenario 3	2.34 %	DTU	DTU sustainability scenario (doubled price over 30 years)

Table 8.2: Scenarios for development in energy prices

In fixed prices (year 2005 DKK) - the price increase of 1.5; 1.8 and 2.34 % p.a. respectively for the three scenarios does not sound like much. But scenario 3 equals a doubled energy price for the consumer in 30 years measured in 2005 –DKK: from approx. 6.4 DKK/l heating oil to approx. 12.8 DKK/l heating oil. - For details on scenarios, see Appendix N.

8.3 Financing

Five different types of loans have been examined, and the expenses for establishing these loans are included in the costs below. For the detailed specification from Nykredit, see Appendix J.

The loans shown are for a net value of DKK 157,000 and based on a 30-year period except "boliglån" which has a maturity of 20 years. All calculations are made by Nykredit and interest rates are based on data as of 21.01.2005 (for loan up to 100%, 07.02.2005).

Type of Loan	Monthly cost before tax deduction [DKK.]	Monthly cost after tax-deduction [DKK]	Yearly cost after tax deduction [DKK]
"4% obligationslån" *1	930	708	8496
"Flekslån" *1 – payment	752	608	7296
"Flekslån" *1 -no payment *2	437	293	3516
"RenteMax" *1 – payment	804	640	7680
"RenteMax" *1 -no payment *2	506	339	4068
"Boliglån indenfor 80 %" *1 *3	1115	878	10536
"Boliglån indenfor 100 %" *3	1232	976	11712

Table 8.3: Loan types

*1 This types of loan has to be within 80 % total value of house.
*2 For the first 10 years only interest payment – no pay off on loan
*3 only 20-year maturity

The type of loan to be chosen for an energy renovation depends of the financial situation and acceptance of risk by the specific house owner.

8.4 Resulting money savings from day 1 derived from energy renovation

The energy savings obtained by the energy renovation of the Villa are 2510 litres of oil per year and the current oil price set to DKK 6.4 per litre.

With the cost of financing and extrapolation of energy prices for the next 30 years, the resulting savings and financing cost are collected in the table below. (Functions of the scenarios for energy price and type of loan chosen). For details from extrapolations in Net Present Value (NPV) see Appendix K.

	Scenario 1	Scenario 2	Scenario 3	Day price
Energy savings year 1	16,000	16,000	16,000	16,000
NPV Energy saving (30 years)	585,015	612,063	664,744	470,166

Table 8.4: Extrapolation of energy savings in DKK

	4% obligationslån	Flekslån med afdrag	Flekslån uden afdrag	"Rente Max" m/ afdrag	"Rente Max" u/ afdrag	"Boliglån indenfor 80 %"	"Boliglån indenfor 100 %"
Financing cost year 1	8,500	7,300	3,500	7,700	4,100	10,500	11,700
NPV financing cost (30 years)	188,400	156,325	154,165	167,033	168,290	182,086	190,202

Table 8.5: Extrapolation of financing cost in DKK

If the above parameters are chosen in a "conservative" way:

- Energy prices will increase by 1.5 % (in fixed prices) in the financing period of 30 years.
- A low risk loan type of "4 % obligationslån" is considered.

then the cost the first year of financing the building work equals DKK 8.500 and the energy savings equals DKK 16,000. The resulting extra money for the house owners to use for other purposes the first year is DKK 7,500.

Seen over a 30-year period the total savings in NPV will be DKK 396,600 (585,000 minus 188,400).

9. Energy Labelling - before / after Renovation

The house used for the project was selected from a database of all buildings labelled in Denmark, managed by the Energy Label Secretariat.

The criteria for the selection were that the house should:

- Be built before 1950 (segment w. highest percentage of houses w. low energy efficiency)
- Be a "typical" house (in order that solutions are transferable to other houses)
- Not be heated by firewood (difficult to measure energy consumption)
- No renovation carried out since the energy certification date
- Be located at Zealand (easiest access for project partners)

9.1 About energy labelling

In Denmark all houses of less than 1,500 m^2 must be energy labelled when offered for sale. The purpose is to inform the possible new owner about the expected annual costs for heating and for electricity for household and water, as well as to inform of any potential savings in energy and water consumption.

The Energy Label is granted each house based on a theoretical calculation of heating energy, electricity for the household, water as well as the environmental load. It is also stated which Energy Label could be obtained by carrying out the energy savings suggested in the Energy Label report.

The Energy Label for heating has 15 steps, from A1 to C5. The Energy Label is calculated based on the theoretical gross energy consumption per m^2 for heating and domestic hot water. Step A1 corresponds to 64 kWh/m^2. Step C5 corresponds to 367 kWh/m^2. Determination of the step for an individual house depends on the energy source, i.e. electricity, oil, natural gas, district heating, or solid fuel. In this way the individual steps are comparable, irrespective of different energy sources. For Energy Certification Scale, see Appendix M.

The Energy Label for the CO_2 environmental load has three steps, A to C, and is calculated based on the number of kg of CO_2 emission per m^2 as a consequence of the energy consumption for heating and electricity. The scale goes from 50 kg/m^2 to more than 90 kg/m^2.

Energy labels for electricity and water are based on the difference between a standard consumption and the consumption of the actual building. The calculation is based on the registered consumption of electricity and water consuming domestic appliances. The scale has three steps, from A to C.

9.2 Energy label for the specific house, used for Energy Project Villa

The Villa was first energy labelled on April 7th, 2003. The Energy Labelling Report at that time showed an Energy Label C5 for heating, which could be improved to A5 by implementing all the energy saving measures.

The Energy Label for environmental load was C, which could be improved to B. The Energy Label for electricity and water was B. This could not be improved.

The following measures were recommended in the report to be carried out for improving the heating:

> Insulation of the exterior wall cavity, insulation of the space under the roof slope, insulation of the loft and the sloped wall, air tightening of the windows and applying new storm windows or glass in existing frames, insulation of cavity in dividing floor to basement, insulation of water tank and boiler, adjustment of nozzle on oil burner.
> The corresponding estimated cost was: 138,600 DKK.

All of the above measures were implemented through the renovation except for:

> Insulation of cavity in dividing floor to basement (cavity already ‘insulated’ by clay), insulation of water tank and boiler, adjustment of nozzle on oil burner.
> The estimated cost in the report of the measures not carried out was: 33,500 DKK

After carrying out the energy saving measures in the building, a new Energy Labelling Report was prepared. Since the "original Energy Labelling Report" was made, the program used for the calculations of an Energy Labelling Report had undergone a revision. Also the analysis done by the Technical University of Denmark (DTU) of the Villa had added new knowledge about the construction of the building. Thus the Energy Labelling Report had to be adjusted according to the new data.

Before the energy renovating measures the annual consumption of oil was estimated to app. 6,000 l. According to the Energy Label Report a saving of app. 2,400 l oil/year has been obtained by insulating the external wall and the loft, and by applying storm windows with energy glass. Accordingly, the Energy Label for heating has been changed to B5.

As shown above, the Energy Label after carrying out the energy saving measures was B5 - and not A5 as calculated in the original Energy Labelling Report. The reason for the difference is that the floor between the cellar and the ground floor could not be insulated, and further the boiler/water tank was not insulated. In the new way of calculating the energy label it is not possible to obtain more than B1, and other measures than originally proposed would then have to be carried out.

Thus the Energy Label for heating was changed from C5 to B5 as a result of implementing the energy saving measures by renovating the villa. An average single-family house in Denmark from the 1930ies would usually carry an Energy Label C1.

See appendix L for copies of the original and new Energy Labelling Report.

10. Conclusion

The project has documented that it is possible to obtain large energy savings, compared to the necessary investments in a typical existing single family house built before 1950.

The specific Danish master builder villa from 1927 had a monitored gross energy consumption of 53,400 kWh per year (332 kWh/m²) at an indoor temperature of 20°C before energy renovation.

The package of measures carried out was: Improvement of the insulation level of the building envelope, amendments to the heating system and applying storm windows.
The work was carried out by professional contractors and the total cost was DKK 157,000.

With the energy renovation the gross energy consumption has been reduced to 28,100 kWh per year (175 kWh/m²) at an indoor temperature of 20 °C. This equals a reduction of 2500 litre of fuel oil per year corresponding to almost 50 %.

The indoor environment appears to be improved by the measures carried out, which will be monitored further to see yearly fluctuations.

Parameters may vary for energy price and way of financing. The assumption made is that energy prices will increase by 1.5 % (in fixed prices) and a low risk loan ("4 % obligationslån" for 30 years). With these conservative assumptions, the cost the first year of financing the building work equals DKK 8,500 and the energy savings equals DKK 16,000. The resulting extra money for the house owners to use for other purposes the first year is DKK 7,500.

Seen over a 30 year period the total savings in NPV will be DKK 396,600.

11. Dansk Resume

I ”Energy Project Villa” er dokumenteret besparelsen der er opnået ved at energirenovere en traditionel murermestervilla fra før 1950. Villaen som er brugt i projektet er udvalgt af ”Energimærkningsordningens sekretariat” fra deres database af energimærkede huse.

Huset er en typisk dansk murermestervilla på 161 m^2 der ikke har gennemgået renovering, med en C5 klassificering for opvarmning inden energirenoveringen. Huset har fuld kælder (uopvarmet), stueetage og 1. sal og bebos af fire personer, en familie med to mindre børn.

Både før og efter energirenoveringen er der gennemført en detaljeret registrering af indeklimaet, herunder rumtemperaturer, relativ fugtighed, friskluftskifte samt registrering af klimaskærmens tæthed (luftsprækker) og energiforbrug.

Ud over en dokumentation af det målte energiforbrug og besparelser, er der i projektet lavet teoretiske, skønnede beregninger ved hjælp af bygningssimulering. Derved har det været muligt at sammenligne de forventede og de faktiske resultater, og der har vist sig at være større besparelser med de registrerede data end med de simulerede.

De gennemførte energiforbedringer i projektet er tiltag som er ”lette at lave”. Energiforbedringspakken omfattede: Forbedring af isoleringsniveauet i huset generelt, forbedringer af varmesystemet og montering af energirigtige forsatsvinduer. Arbejdet blev udført af professionelle håndværkere og den samlede udgift beløb sig til DKK 157.000.

Inden energirenoveringen havde den aktuelle murermestervilla fra 1927 et registreret bruttoenergiforbrug på 53.400 kWh om året (332 kWh/m^2) ved en indendørs temperatur på 20^{o}C.

Energiforbrug og indeklima i en bygning hænger sammen og det giver derfor ingen mening, at angive en bygnings energiforbrug uden samtidig at specificere det tilsvarende indeklima. Det har været vigtigt for projektets deltagere at konstatere, at energibesparelserne i villaen er opnået uden at give termiske gener, øget risiko for skimmelsvamp og andre sundhedsrisici.

Projektet har vist, at det med energirenoveringen har været muligt at sænke bruttoenergiforbruget til 28.100 kWh per år (175 kWh/m^2) ved en indendørs temperatur på 20^{o}C. Det betyder en reduktion på 2500 liter fyringsolie om året svarende til næsten 50 %.

Ifølge de data der er indsamlet indtil nu ser det ud til at indeklimaet er forbedret ved energirenoveringen. Målingerne vil fortsætte gennem et helt år for at få et billede af de årlige udsving.

Baseret på en konservativt skønnet energiprisudvikling og en finansiering med lav risiko af renoveringsudgifterne, vil husejeren få en nettobesparelse det første år på DKK 7.500. Første års udgifter til finansiering svarer til DKK 8.500 og energibesparelsen er på DKK 16.000. Set over en 30-års periode vil den samlede besparelse i nutidsværdi være DKK 396.600.

Det bør bemærkes, at hvis beboerne f.eks. vælger at forbedre indeklimaet efter renoveringen, (eller hvis de faktisk havde et dårligt indeklima inden renoveringen) så vil de faktiske energibesparelser i DKK være mindre end nævnt ovenfor.

12. Glossary / Literature

Glossary ENGLISH	Glossary DANISH	Symbol	Explanation
Bar	Sprosse		
Basis temperature	Basis temperatur	t_b	Outdoor temperature at which no heating is needed in the building - typically set to 17°C.
Beam	Bjælke		
Calorific value of heating oil			10.08 kWh/litre
Clay pugging	Lerindskud		
Cooker Hood	Emhætte		
Crossbar	Tværpost		
Damping level	Fugtighedsniveau		
Degree-days	Graddage	G	
DHW	Varmt vand		Domestic Hot Water
Dormer	Kvist		
DRY	Reference år		Danish Design Reference Year based on long term climate obser-vations in Denmark.
Flooring plank	Gulvplanke		
Fully brick built	Fuldmure		
Glazing bead	Glasliste		
Gross Energy consumption for heating efficiency	Bruttoenergifor-brug til varme		Including boiler losses and effi-ciency
Joint	Fuge		
Joist	Gulvbjælke		
Lath	Forskallingsbrædt		
Loft above ashlar joist	Hanebåndsloft		
Mullion	Lodpost		
Net Energy consumption for room heating	Nettoenergifor-brug til rumop-varmning		Including pipe heat losses in basement
Occupant/user/resident	Bruger/beboer		
Outer leaf	Formur		
Point	Understryge		
Pugging board	Indskudsbræt		
Renovation/retrofit	Renovering		
RH - Relative humidity	Relativ fugtighed		
Rabbet	Fals		
Shingle	Singels		
Sloping wall	Skråvæg		
Solar hours	Sol timer	z	Number of solar hours per day ex-ceeding 0.5
Space underneath roof slope	Skunk		
Storm Window	Forsatsvindue		
Thrust	Drivtryk		

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