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Low-energy residential housing – A case study

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SUMMARY

The aim of the study was to design and build a small house with 50% lower heating energy consumption than in typical existing Finnish small houses. Energy saving is based on three technologies: super insulation, airtight construction and ventilation heat recovery. The first monitoring results show the heating energy consumption of the house to be less than half of the measured consumption of typical small houses located in the same area. Also, the results show the air quality to be good.

1. INTRODUCTION

The Low-Energy Residential Housing Project /1, 2/, which is part of the Energy-Efficient Buildings and Building Components Research Programme, examined the various methods available to reduce the heating energy consumption of small houses. The results indicate, among others, that the consumption of heating energy in small houses can be halved without essentially changing the annual costs.

The results obtained from the research programme were applied to various experimental building projects. The aim of the study /3/ was to design and build a small house whose heating energy consumption was no more than 50% of the current average. Another important consideration was that the structural and HVAC systems of the building were to be produced using commercially available construction technology.

2. EXPERIMENTAL HOUSE

The heating energy consumption of the experimental house and the means to reduce consumption were analyzed computationally. A single-storey small house (living area 147 m^2) with an envelope similar to structures commonly used in Finland was selected as a reference. The annual heating energy consumption of the reference houses were estimated at 19,000 to 21,000 kWh (130 to 145 kWh/m^2). Thus the aim of the project was to achieve a consumption level of 9,000 to 10,000 kWh in conditions corresponding to a normal year. The theoretical heating energy consumption of the low-energy house was appr. 7,500 kWh/a (51 kWh/m^2, no basement).

The experimental house (Fig. 1) is located in Espoo (heating degree days 4,366 base 18C) near Helsinki, Finland. The location and the orientation of the house was not selected with a view of making use of free solar energy. The house has a living area of 147 m^2 and a heated area of 164 m^2, which includes a basement of 17 m^2 (temperature 17 - 20C). Total volume is 533 m^3 and heated volume, including the basement, 415 m^3.

The low-energy house has a direct electric heating system, roof heating in the living area, floor heating in the wet areas and an electric radiator in the basement. The house is equipped with a fully mechanical ventilation system with a heat recovery unit. The efficiency of the heat recovery system is about 75%, when the temperature increase caused by the fans is taken into account.

Fig. 1. The experimental house.

The external walls are build of prefabricated large units with 295 mm rockwool insulation. The thermal insulation for the roof consists of 500 mm thick loose fill rockwool laid directly on top of the vapour barrier.

The slab-on-ground floor is insulated with 150 mm polystyrene beneath the slab. The building is standing on a slope, with the basement walls fully exposed to outdoor air. The U-value of the basement walls is 0.75 W/m^2K.

The windows are triple-glazed, with the inner panes providing an evacuated window with a selective coating. The U-value of the windows is appr. 1.2 W/m^2K.

3. MONITORING

The monitoring of the house begun in November 1991. The energy required for heating, hot water, lighting, household electricity (appliances, wall sockets), HVAC equipment and sauna stove is being monitored. The temperatures, heat flows and moisture contents of the envelope structures are being measured. Air quality is being monitored by measurements and questionaries to the occupants.

3.1 Energy consumption

Table 1 shows the heating energy consumption of the building in the winter of 1991 - 1992. The table gives the actual measured consumption as well as corresponding figures for a normal year (1961 - 1990, standardized consumption), which were obtained on the basis of heating degree-day data for the months under consideration.

A study by Virtanen /4/ was used as a reference concerning the energy consumption by 10 buildings in Espoo equipped with direct electric heating. These houses had an average heated area of 156.6 m^2 and a volume of 405.9 m^3. According to the measurements, the heating energy consumption of the experimental house was appr. 47% of the consumption of the reference houses.

The consumption of other energy in the house during the months under review is shown in Table 2. The consumption of domestic electricity in the experimental house during the months monitored was appr. 40 kWh/m^2 and 1,313 kWh/person, if the gross energy taken by the water heater is excluded. The corresponding figures obtained from the reference study /4/ were 28 kWh/m^2 and 1123 kWh/person. The gross energy consumption by the hot water heater is fairly high because the average water consumption was only 57 litres/person/day.

Table 1. Heating energy consumption in winter 1991 - 1992 /3/ and consumption by reference houses /4/.

Time	Heating energy consumption					
	Low-energy house				Reference houses	
	Measured		Standardized		Standardized	
	kWh	kWh/m2	kWh	kWh/m2	kWh	kWh/m2
Nov.	955	5.8	1165	7.1	1928	12.3
Dec.	1090	6.7	1261	7.7	2552	16.3
Jan.	1340	8.2	1727	10.5	2906	18.6
Feb.	1065	6.5	1296	7.4	2813	18.0
Mar.	805	4.9	997	6.1	2412	15.4
Apr.	765	4.7	709	4.3	1767	11.3
Total	6020	36.8	7155	43.1	14378	91.8

Table 2. Consumption of other energy during November 1991 - April 1992 /3/.

Type of consumption	Consumption, kWh					
	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
Hot water	656	596	660	620	582	587
HVAC eq.	87	127	151	151	140	144
Household	428	435	405	407	350	387
Sauna stove	12	44	77	124	163	150
Total lighting	299	608	647	530	369	229
indoor lights	-	368	369	-	-	-
outdoor lights	-	240	278	-	-	-
Total consumption	1582	1810	1940	1832	1604	1497
- kWh/m2	9.7	11.1	11.8	11.2	9.8	9.1
- kWh/person	316	362	388	366	321	300

3.2 Indoor climate

A summary of the indoor air quality measurements is shown in Table 3. The quality of indoor air was found to be good.

According to the people living in the house, the indoor climate is draught-free and comfortable.

Table 3. Results of the indoor air measurements

Item	Period	Measured value	Recommended value
Temperature 1)	11/91-4/92	19.7-22.3°C	19 - 21°C2)
Relative humidity	11/91-4/92	25 - 55%	
Total air change rate	4/92	0.8 1/h	0.5 1/h
CO_2	4/92	350-1330 ppm	max.2500ppm
Formaldehyde content 3)	4/92	≈0	0.15 mg/m^3 max.
Total fibre content 4) 5)	4/92	0.03 $fibre/cm^3$ 4)	6)
Mineral wool fibre content	4/92	≈0 4)	6)
Radon content - bedroom - bedroom - living room - basement	3/92-4/92	 70 Bq/m3 110 Bq/m3 150 Bq/m3 760 Bq/m3	200 Bq/m3 7)

1) Variation of monthly averages at 10 points
2) Recommended value depends on use of the room
3) Accuracy of measurement 0.02 mg/m^3
4) Scanning electron microscope, accuracy 0.01 $fibre/cm^3$ of sample
5) Building materials contain no asbestos
6) No recommended value for artificial fibres in Finland, recommended value for asbestos fibre in indoor air max. 0.05 $fibre/cm^3$
7) Target design value for new buildings.

3.3 The performance of the building envelope

Air leakage tests were carried out at the various stages of construction. The total air leakage rate of the building envelope is less than 2 1/h (50 Pa). According to the observations, installation and sealing techniques for a timber house built from prefabricated units should be improved when the thermal insulation layer is to be made thicker.

At its highest, the moisture content of the outermost section of the external wall timber frame was about 20% of dry weight. In spring, the structures dried quickly to moisture contents of 10 to 14%.

4. CONCLUSIONS

For the experimental house project, a small house with a conventional building envelope and heating and ventilation systems was built using current construction techniques to achieve a building whose heating energy consumption was less than half of the average level in Finland. This was accomplished by a well insulated and sealed building envelope and efficient heat recovery from the ventilation system. Other objectives included a high- quality indoor air and comfort, which were also achieved. The monitoring will continue until the autumn of 1993.

The thick thermal insulation did not affect the moisture content of the external wall timber frame. However, the installation and sealing techniques for timber houses made of prefabricated building units should be improved, if the thickness of the external wall thermal insulation is to be increased.

REFERENCES

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