SUPERINSULATION AND WARM-AIR HEATING IN SWEDEN

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ABSTRACT

Three well-insulated experimental houses in Sweden, utilizing warm air heating and exhaust air heat pumps, were monitored during 1983-1985.

The most energy efficient house has U-values below 0.10 W/m^2C. Four pane windows are used throughout the three houses. A balanced ventilation system is coupled with a very tight envelope. Heat recovery is provided for by an exhaust air heat pump.

The investigation has shown that the simplified warm air heating system led to a comfortable indoor climate, with fresh air, comfortable temperatures and little noise.

During one year, each of these three houses used between 10,000 and 13,000 kWh of electricity for space heating, domestic hot water heating and household use, compared with 20,000 kWh for a house that meets the current Swedish National Building Code. This energy savings was achieved by insulating and tightening the houses very well, and installing a heat pump.

INTRODUCTION

Three well-insulated experimental houses, utilizing warm air heating and exhaust air heat pumps, have been built in southern Sweden. They range from superinsulated to only somewhat better insulated than the average modern Swedish house, which is typically heated by electric baseboard heaters. In the average modern Swedish house domestic hot water is usually heated electrically and the ventilation system is equipped with an air-to-air heat exchanger. Two of the experimental houses, located in Skövde, were monitored during 1983 and 1984 and one, located in Stockholm, was monitored during 1984-1985, to assess both thermal performance and comfort conditions.

At 14 degrees longitude, and 59 degrees latitude, they are located slightly further north than Juneau, Alaska. Winter sun in southern Sweden rises to a maximum altitude of 8 degrees; in summer it reaches only 55 degrees. Because Scandinavia is warmed by the Golf stream, however, the climate is relatively mild, despite such low sun levels. While Minneapolis and Moscow, 13 and 7 degrees further south, respectively, experience extremely cold winters (-5.5 and -6.5 °C) southern Sweden's November through March temperatures average -1 °C.

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DESCRIPTION OF THE BUILDINGS

General Description

Two of the monitored houses (A and B) are located in Skövde and were designed to be houses of the future. They are identical except for the level of thermal insulation. The two houses are 110 m^2, with four bedrooms, a kitchen, and living room (fig. 1). They were designed and built by Rockwool AB. The houses surpass Sweden's rigorous standard for energy conservation.

The third house (C) was built in Stockholm and was designed according to the Swedish National Building Code, but with windows better than required. The house is 146 m^2, with four bedrooms, a study and two living rooms (fig. 2).

All three houses are modern wood frame constructions. They are heated with identical warm air heating systems incorporating an exhaust air heat pump. The warm air is blown into the individual rooms from registers located in the partitions up by the ceiling.

Energy Conservation

Insulation: Mineralwool insulation was installed throughout, in walls, ceilings, and floors (above a crawl space) in all three houses. Thermal resistance of the building envelope for house A and B is much better than in more conventional Swedish houses, like house C. The windows in house C are, however, atypically good (table 1). A special feature of house A and B is the box beam (fig. 3), which considerably reduces the thermal bridges compared with conventional studs. The box beam is used throughout the construction.

Tightness: As a moisture and air barrier, a continuous polyethylene sheet was employed between the insulation and the interior finished wall, ceiling and floor. The number of penetrations through the continuous polyethylene sheet was limited. The building envelope of all three houses meets Sweden's National Building Code requirement for airtightness, 3.0 air changes per hour at 50 Pa (table 2). Traditional modern Swedish construction (those buildings erected prior to Sweden's 1975 introduction of airtightness standards) commonly evidence 5.5 air changes per hour.

Heat recovery: All three houses have a balanced ventilation system, mechanically controlling both supply and exhaust air, and use an exhaust air heat pump to conserve heat loss. Ducts supply the houses with fresh air from the outside mixed with recirculated air and heated by the heat pump. The heat pump also heats domestic hot water. Back-up heating of air and water is provided for by an electric heater.

DESCRIPTION OF MONITORING PROGRAM

The houses were monitored continuously for 1.5 years, to assess both thermal performance and comfort conditions (1,2). Short unoccupied periods were used for special measurements and one-time tests which included the following:

- pressurization
- tracer gas measurements
- electric coheating (to assess the conduction coefficients. This was done only in houses A and B)
- infrared photography scans
- air flow and temperatures mesurements
- capacity testing of the heat pump

Those factors continuously measured and recorded throughout the monitoring period were the following:

- temperatures in the house, heat pump, ducts, and outside
- electric energy use, measured separately for space heating, hot water, compressor, fans, lights, and appliances
- total incident solar radiation, on the horizontal plane, and on the southern aperature (this was done only for houses A and B)
- run time for fans and heat pumps

RESULTS

Consumption and distribution

During one year, house A used 11,750 kWh of electricity, house B 9,900 kWh and house C 16,500 kWh (fig 4). These are actual measured consumptions, where house A and B experienced 10 % fewer heating degree hours and the indoor temperature during the heating season was 22 °C instead of 20 °C in house C. The main reason for the fact that the best insulated house (A) did not use the smallest amount of energy for space heating was that it was ventilated at a higher rate. The house had more available internal "free heat" than house B, most of which occured when there was no need for space heating. In a construction with more thermal mass some of this additional heat might have been stored.

Of the total consumption of electricity, space heating and domestic hot water heating consumed 25 % (3,000 kWh) in house A, 30 % (3,000 kWh) in house B and 50 % (8150 kWh) in house C. Fans and control equipment (part of the ventilation and heating system) consumed 20 % (2,500 kWh) in house A, 25 % (2,500 kWh) in house B and 15 % (2,000 kWh) in house C. Household electrical use (lights, washer, dryer, range, and miscellaneous) was responsible for the remaining 55 % (6,250 kWh) in house A, 45 % (4,400 kWh) in house B and 35 % (6,350 kWh) in house C. "Free heat" from people was 1,675 kWh in house A, 1,045 kWh in house B and 1,950 kWh in house C.

House A and B were modelled using a Swedish computer model (3). Inputs used were measured ventilation rates (m^3/h), measured conduction coefficients, measured internal generation of "free heat" and hourly weather data measured at the site. A close correlation (5 %) between the measured and calculated energy balances was obtained. The next step was to run the model using the same ventilation rates (0.5 ach), the same amount of internally generated "free heat" (5,000 kWh from household electricity and 1,400 kWh from people) for both houses. The model shows that house A compared with house B is supposed to consume 450 kWh/year less electicity, delivered to the heat pump for space heating (fig 5). The difference in delivered heat would have been 1400 kWh/year.

House C had to be modelled using a different model (4), as hourly values of the solar radiation at the C site weren't available. Inputs used were measured ventilation rates (m^3/h), measured internal generation of "free heat" and outdoor temperature measured at the site. A good correlation (11 % for the whole year, 2 % when excluding the summer) was obtained. The house was then modelled using a standard Stockholm climate, which is more similar to that of house A and B and using the same indoor temperature 20 °C as in house A and B (fig. 5).

Energy Comparison with a "Conventional House"

To understand these houses in their context, they were compared with a "conventional Swedish house", a carefully built house with the same area as house A and B, insulated according to the Swedish National Building Code (table 1). The yearly consumption of electricity for the comparison house was calculated using the same assumptions and the same model as for house A and B. The comparison house used 20,300 kWh, or 50 - 100 % more than the experimental houses. The "conventional house" is not equipped with a heat pump or a heat exchanger.

Sources of Energy Savings

Energy savings due to the improved thermal insulation was 6,300 kWh in house A and 4,900 kWh in house B (not taking the heat pump into account) compared with the "conventional house" (fig. 6). The heat pump decreased the energy consumption with an additional 4,600 kWh for house A, 5,500 kWh for house B, and 8,300 kWh for house C.

Indoor Temperatures

Occasionally the houses experienced high temperatures due to excess internal generation of "free heat" and solar gains. High temperatures can occur in the "conventional house" as well. The temperatures never went above 27 °C (fig. 7 and 8). No difference in the magnitude of the high temperatures between the three houses could be observed.

Looking at the heating season the warm air heating system keeps an even temperature distribution between rooms and within individual rooms. The largest temperature gradient experienced between the floor and 2.0 m above the floor in house A and B was 2.5 °C. Usually the gradient was much lower.

Ventilation

The ventilation rates were measured continuously during part of the monitoring periods using tracer gas (the constant concentration technique). The measurements show that the ventilation rate is almost constant with time, particularly in house A and B (fig 9)(5). This is due to the fact that the ventilation system is coupled with a very tight building enevelope. The ventilation rate of individual rooms depend only on how well the system is adjusted.

The ventilation rate for different parts of individual rooms was investigated using tracer gas (the decay technique). Although air is blown into the rooms from inlets located in the partitions up by the ceiling, fresh air is adequately distributed within individual rooms.

CONCLUSION

The Experimental Houses

The year's monitoring of the three experimental houses has shown that it is possible to build well functioning houses with very good insulation, very good airtightness and warm air heating. Apart from occasional high temperatures i.e. never higher than 27 °C, the warm air heating system led to a comfortable indoor climate, with fresh air, comfortable temperatures and little noise all year around.

During one year, each of these three houses used between 10,000 and 13,000 kWh of electricity for space heating, domestic hot water heating and household use, compared with approximately 20,000 kWh for a well-built house that meets the current Swedish National Building Code. This energy savings was achieved by insulating the houses very well, and installing a heat pump in the ventilation system.

It is questionable, with the current low price of electricity in Sweden ($ 0.03/kWh), whether the heat pump should have been used, particularly in house A and B, with their low energy load. A conventional air-to-air heat exchanger (combined with electric heating) would probably have been the best solution. Improving the thermal insulation from house B to house A, i.e. lowering the U-values (W/m^2 °C) of the walls from 0.18 to 0.13, of the ceiling from 0.11 to 0.09, of the floor from 0.20 to 0.11, doesn't pay off today in southern Sweden.

Toward Better Performance of the Experimental Houses

Performance of the three houses could be improved. Suggestions include the following:

- Install energy conservative appliances

- Install energy conservative fans

It is more efficient to heat a low energy house by reducing the "uncontrolled" internal gains and relying more on a "controlled" heating system .

Future Swedish Low Energy Houses

In designing low energy houses, experience with the experimental houses points to the need, to try to predict the energy balance of the house elements properly. Most important of all is the impact from combinations of components as opposed to their individual effects. The house has to be a well functioning system.

The house itself should be tight, well-insulated, and mechanically ventilated. The vented air should pass through a heat recovery system. A mechanical ventilation system makes it possible to recover heat from the necessary vented air. It also makes perfect sense to use the duct part of a balanced ventilation system to distribute heat to the building, i.e. employ warm air heating. A warm air heating system in a low energy house doesn't require large air flows or very high temperatures, which can create discomfort. In a well-insulated and tight house the warm air can even be blown into the individual rooms from registers located in the partitions up by the ceiling, without creating any discomfort.

By whatever means, whether using additional mass in the walls or creating storage elesewhere, the design should guard against overheating due to excess solar gains. Finally, the house should be equipped with appliances that are, themselves, energy efficient, so that the heat they contribute to the house does not exceed its demand.

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REFERENCES

1) Solar Energy Research Institute, 1980. "Program Area Plan: Performance of Passive/Hybrid Solar Heating and Cooling Systems." Denver, Colorado, USA.

(2) International Energy Agency 1985. "Monitoring and Performance Evaluation: Procedures and Guidelines." Draft.

(3) Ståhl, B., Wader, K., 1982. "Energy Calculation Program STAWAD," Lund Institute of Technology, Lund, Sweden (in Swedish).

(4) Lawrence Berkeley Laboratory, 1982. "CIRA - Reference Manual." Berkeley, California, USA.

(5) Blomsterberg, Å, 1984. "The Influence of Climate and Ventilation System on Airtightness Requirements." Proceedings of 5th AIC Conference in Reno, Nevada, USA.

TABLE 1

U-values, conduction coefficients (CC), and building load coefficients (BLC) for the experimental houses A, B, and C, and for house A or B modified to be built exactly according to the Swedish building code (SBN 80). The conduction coefficients for houses A and B were measured using the electric coheating technique.

House	A	B	SBN 80	C
U-value W/m2°C				
Exterior wall	0.13	0.18	0.30	0.27
Ceiling	0.09	0.11	0.20	0.17
Floor	0.11	0.20	0.30	0.18
Window	1.40	1.40	2.00	1.40
CC W/C	57	72	114	95
BLC W/C	103	118	160	160

TABLE 2

Airtightness for the experimental houses A, B, and C, and for house A or B modified to be built exactly according to the Swedish building code (SBN 80), number of air changes per hour at 50 Pa.

House	A	B	SBN 80	C
Pressurization at 50 Pa, h-1	1.2	1.1	3.0	2.0

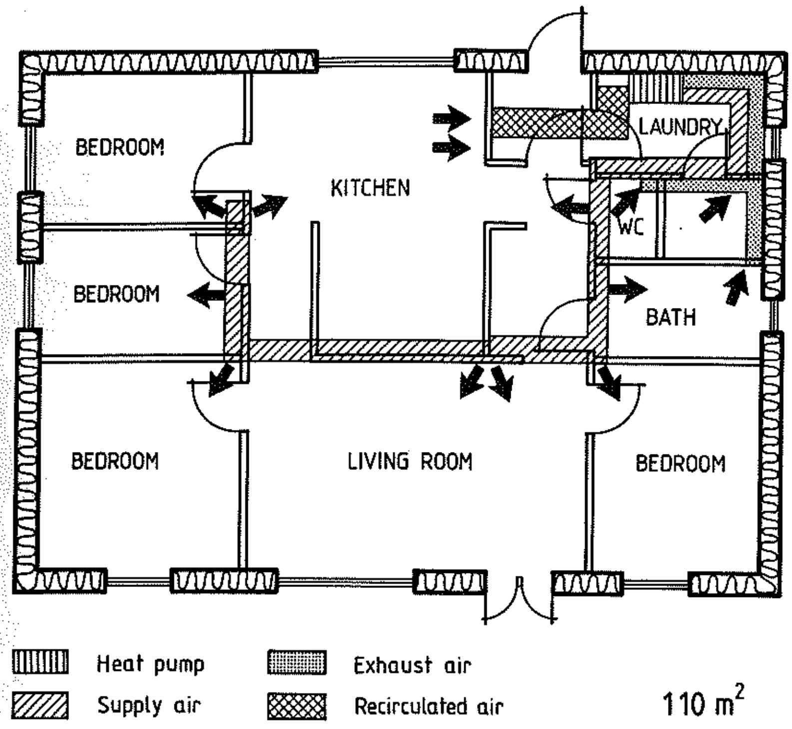

Figure 1. Plan of experiment house in Skovde. Experiment houses A and B in Stockholm are identical except for the level of thermal insulation

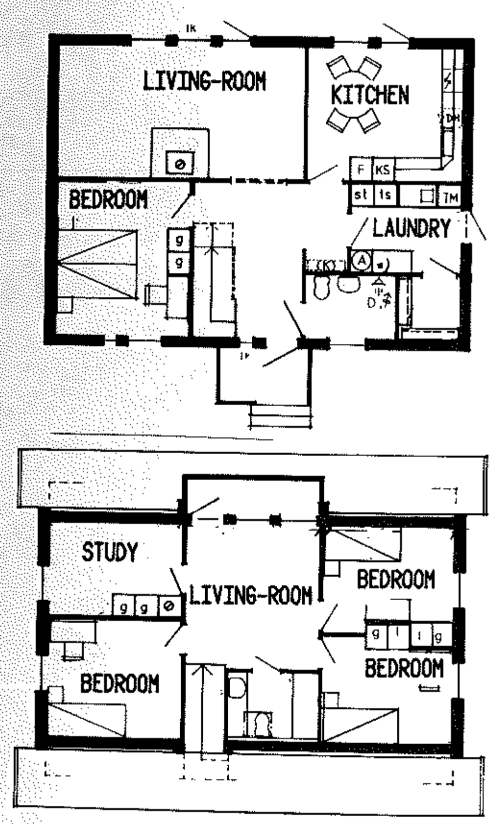

Figure 2. Plan of experiment house C in Stockholm

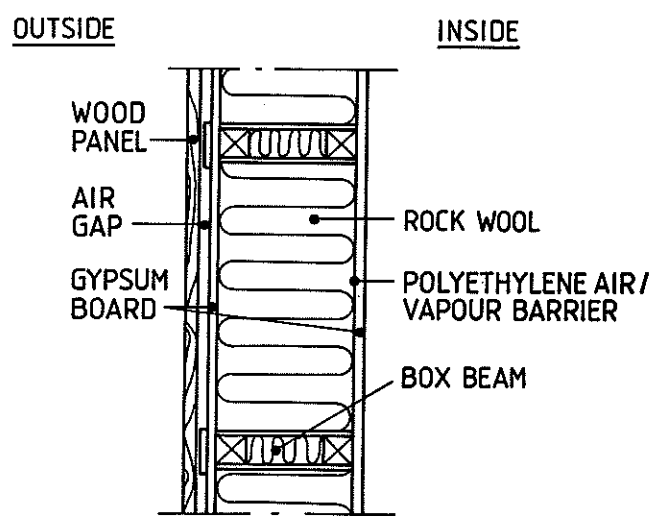

Figure 3. Cross section of wall in house A or B

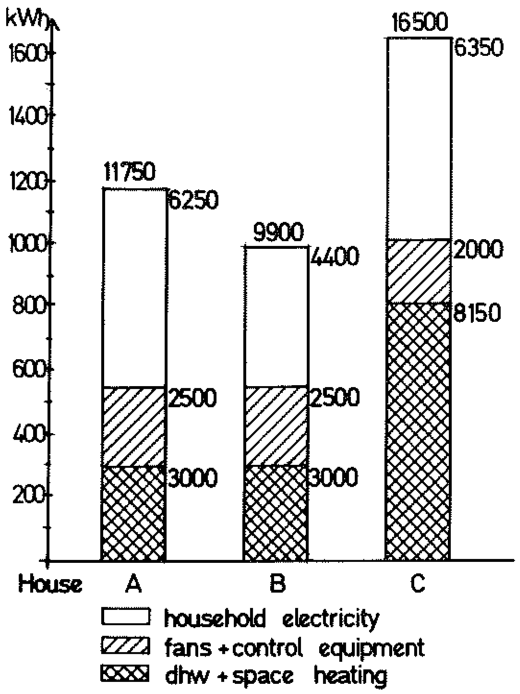

Figure 4. Histogram showing measured electricity consumption for one year. Houses A and B experienced 10% fewer heating degree hours

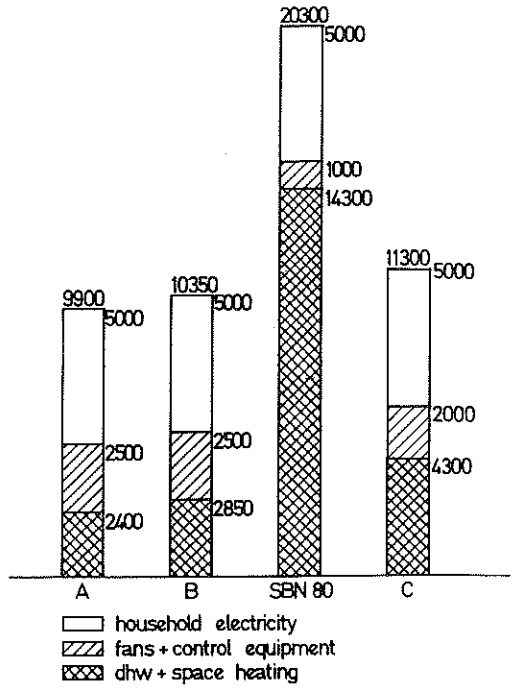

Figure 5. Histograms of corrected electricity comsumption for one year. Figures for houses A and B are corrected for differences in ventilation rates and "free heat". House C was corrected for differences in indoor temperature and climate

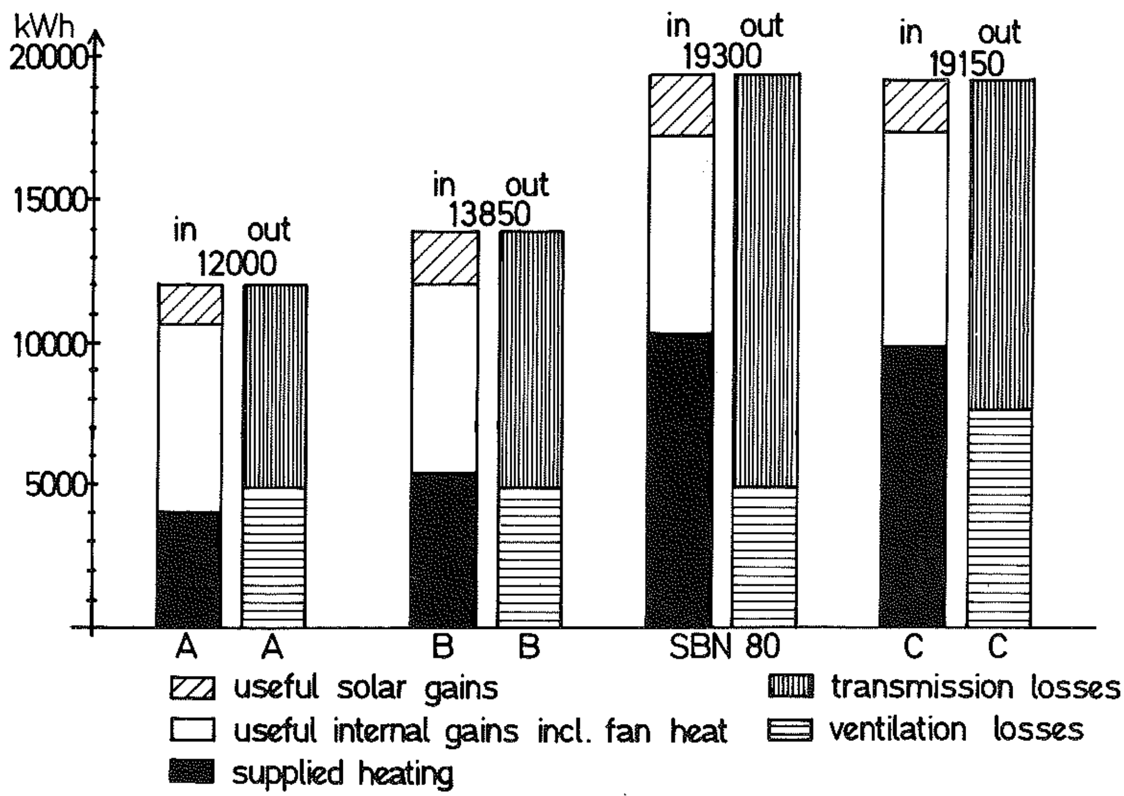

Figure 6. Histograms showing heating energy balance including corrections for differences in ventilation rates, internal gains, climate, indoor temperature

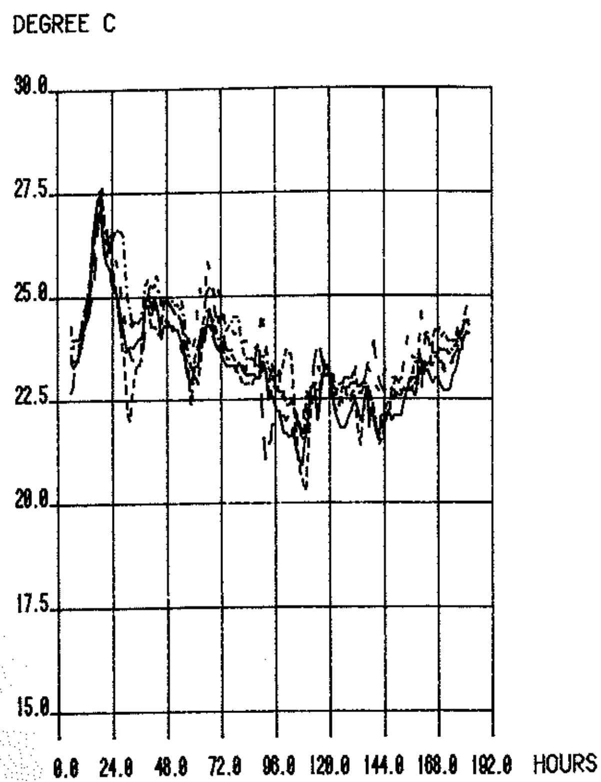

Figure 7. Graph of measured indoor temperatures for different rooms in house A during a summer week. Average outdoor temperature was 17°C, the maximum 27°C, and the minimum 12°C

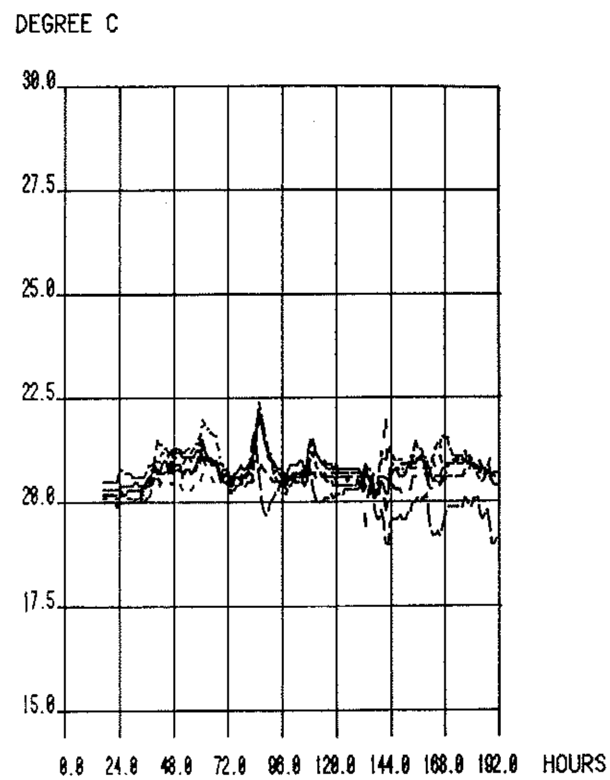

Figure 8. Graph of measured indoor temperatures for different rooms in house A during a winter week. Average outdoor temperature was -2°C, the maximum 1°C, and the minimum -6°C

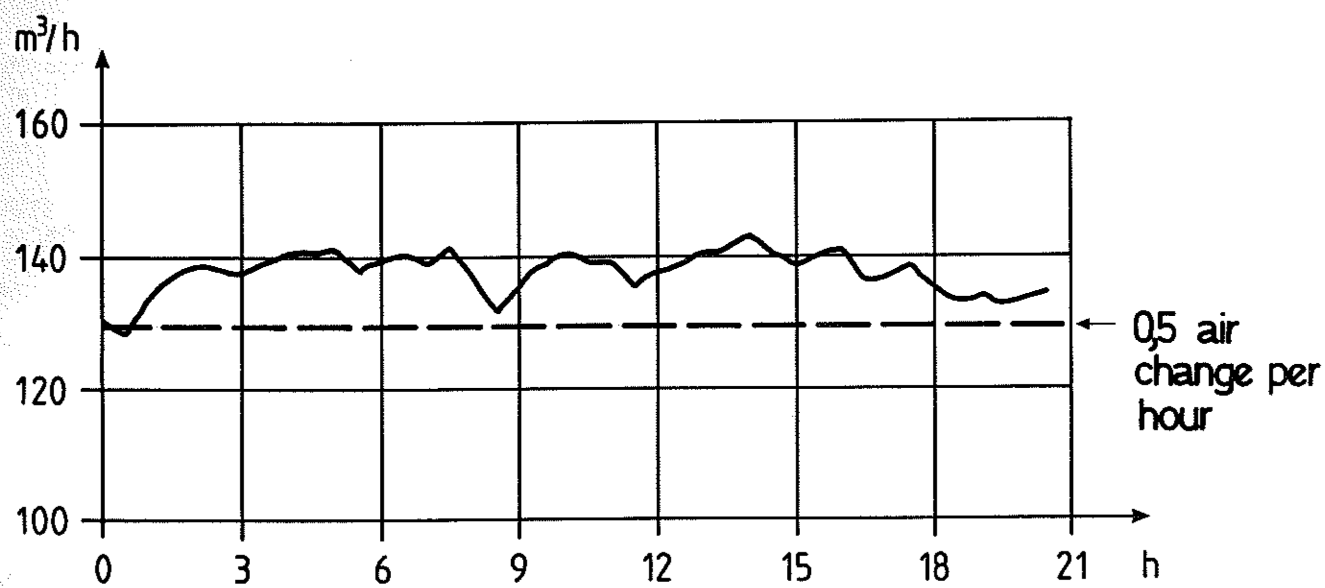

Figure 9. Graph of measured ventilation rate (air infiltration + mechanical ventilation) for house A. Average wind speed was 2.8 m/s, and average temperature was -1°C