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IMPROVEMENT IN ENERGY EFFICIENCY AND INDOOR CLIMATE IN NATURALLY VENTILATED HOUSES

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1. INTRODUCTION

In Sweden there are close to 500000 one-family houses heated by electric baseboard heaters. Of them 90 % were built before 1980. In this group the most common ventilation system is natural ventilation. Half of all houses with electric baseboard heaters were built between 1971 and 1980. The Swedish Council for Building Research has been asked by the Swedish government to carry out a program concerning the efficient use of electricity in buildings. Consequently one-family houses with electric baseboard heaters and with a high consumption of electricity are an area where research and development and demonstration projects are needed.

Making the use of electricity efficient in one-family houses with electric heating includes measures to reduce the consumption and to reduce the power demand. In one project, which is carried out in four different cities (Umeå, Stockholm, Göteborg and Lund), 37 one-family houses have been investigated. The objective of the project is to show how electrically heated one-family houses can use electricty more efficiently employing existing techniques. The indoor climate is to be kept at the same level or improved. This paper deals with the investigation in Lund (Blomsterberg 1993).

2. THE HOUSES TESTED - BEFORE RECONSTRUCTION

Six detached one-family houses built in 1974 were tested, three 1½ storey houses and three one storey houses. Both types are very common in Sweden. The 1½ storey house is part of a group of 100 identical houses . The houses are 140 m^2, with a kitchen, laundry, bathroom, living room, bedroom downstairs and three bedrooms and a bathroom upstairs. The one storey house is part of a group of 120 identical houses built in 1974. The houses are 121 m^2, with a kitchen, laundry, bathroom, living room and 3 - 4 bedrooms.

The 1½ and the one storey houses are built on a slab on grade. Space heating is provided by electric baseboard heaters and an electric heating cable (1 kW) inside the slab along the perimeter of the house. There is an electric domestic hot water heater. The exterior walls are of traditional wood frame construction with 120 mm of mineral wool. The attic insulation consists of 150 mm of mineral wool. The windows have double panes. The window area is large, 28 % of the floor area. The houses are naturally ventilated with vertical shafts from bathrooms, kitchen and laundry. There are no supply vents for outdoor air.

3. MONITORING PROGRAM

3.1 Airtightness and ventilation

The standard method for finding the leakage function of a building is fan pressurization. According to the Swedish standard for fan pressurization all openings in the exterior envelope intended for ventilation purposes must be sealed before the test is performed. For the purpose of modelling air infiltration and exfiltration it is advantageous to also make a test with open supply vents part of an exhaust fan ventilation system and with open vertical shafts part of a natural ventilation system.

The most straightforward method of measuring the total ventilation rate i.e. the combined effect of mechanical ventilation and natural ventilation is to measure it directly (Blomsterberg 1990) using a tracer gas. In the houses tested a constant concentration of tracer gas was maintained in order to measure the ventilation rate. The outdoor air ventilation is obtained directly and it is possible to continuously monitor the supply of outdoor air to several individual rooms simultaneously, i.e. outdoor air which enters an individual room directly instead of first passing through an adjacent room.

3.2 ENERGY USE AND INDOOR CLIMATE

The houses were monitored continuously during 1989 (before recontruction) and 1992 (after). The following parameters were recorded as hourly values: electric energy use (measured separately for space heating, domestic hot water, household, heat pump, and a detached storage), solar radiation, indoor and outdoor air temperatures, and occupancy. The thermal comfort was measured with one-day tests of the air temperature (absolute level and gradient), the operative temperature, the air velocity, and the radiant temperature asymmetry.

4. IMPROVEMENTS IN INDOOR CLIMATE AND ENERGY EFFICIENCY

An important aspect of indoor climate is ventilation. The aim should be to improve upon the air exhange in individual rooms and the whole house. A ventilation system should be able to provide outdoor air to the whole house (Blomsterberg 1992).

Swedish one-family houses built during the seventies with natural ventilation are often reasonably airtight, although they usually do not meet the Swedish Building Code requirement for 3.0 ach at 50 Pa. This means that the ventilation rate (excl. airing) most of the time is too low i.e. below 0.5 ach (Lyberg 1989). Individual rooms, especially with doors closed, can have a very low ventilation rate. One improvement would be to install temperature controlled supply vents in the exterior walls. The advantages would be a less varying ventilation rate and a better distribution of outdoor air between individual rooms. The disadvantages would be sligthly raised overall ventilation energy losses due to somewhat increased ventilation and no possibility for heat recovery.

Another alternative of improving natural ventilation is to install supply vents in the exterior walls and a temperature controlled fan in the vertical shafts . When it is cold outside the fan will not run and the ventilation will be all natural. During warm and mild periods, when the stack effect is insufficient, the fan will increase the ventilation rate. The advantages would be a raised and more constant ventilation rate and a better distribution of outdoor air between individual rooms. The disadvantages would be raised ventilation energy losses due to increased ventilation and no possibility for heat recovery.

Sofar the suggestions have meant improving on the existing systems for natural ventilation. Another option is to install a completely new ventilation system i.e. mechanical ventilation. The advantages with a balanced ventilation system would be a raised and constant ventilation rate, a controlled distribution of outdoor air between individual rooms and the possibility to install a heat recovery system e.g. an air-to-air heat exchanger. The main disadvantage would be high costs. A balanced ventilation system should only be installed in a very tight building (Blomsterberg 1990).

If an exhaust fan ventilation system with supply vents is to be installed the house does not have to be as airtight as for the balanced ventilation system. The recommendation is 3.0 ach at 50 Pa (incl. open supply vents) (Blomsterberg 1991). The advantages would be a raised and constant ventilation rate, a fairly well controlled distribution of outdoor air between individual rooms and the possibility to install a heat recovery system e.g. an exhaust air heat pump. The main disadvantage would be high costs. With an exhaust air heat pump more heat can be recovered then by an air-to-air heat exchanger.

Another important aspect of indoor climate is thermal comfort. Many of the naturally ventilated houses built during the seventies have large window areas and therefore high indoor temperatures due to the sun can occur between april and september. In winter the radiant temperature asymmetry can be high.

To reduce the high indoor temperatures one can either prevent the solar energy from entering the building or lower the indoor temperature by e g increasing the ventilation. Installing exterior sun shading is the most effective way of preventing the solar energy from entering. It does however not improve upon the energy efficiency. The second most effective way is installing new windows, which transmitts less solar energy. These windows should then also have a low U-value in order to also reduce the termal losses during winter.

The radiant temperature asymmetry can be reduced by improvements in the heating system or the building envelope. The first improvement requires a heating system, which basically heats the inner pane of the window and is not going to reduce the heating demand. Most older houses have two pane windows. The radiant temperature asymmetry will be reduced if windows with a lower U-value are installed. This measure is usually too expensive compared with the energy savings that can be obtained, unless the windows have to be exchanged for other reasons.

5. THE HOUSES TESTED - AFTER RECONSTRUCTION

In all six houses a new ventilation system was installed, a mechanical exhaust fan ventilation system with outdoor air vents in the building envelope. The ventilation system includes an exhaust air heat pump, which delivers heat to domestic hot water and to two centrally located radiators. The reason for the choice of system was that the aim of the project was to make the use of electricity more efficient at the same time as the indoor climate is maintained at the same level or improved. The houses are not airtight enough (see also chapter 6.1) for a balanced ventilation system. In order to make maximum use of the two new radiators a new electronic control system was installed for the baseboard heaters.

From the measurements it was determined that during the spring, summer and fall high indoor air temperatures (see chapter 6.2) can occur and that during the winter the radiant temperature asymmetry might be a problem. The high indoor temperatures should be reduced by the installed mechanical ventilation system. The new electronic control system for the baseboard heaters should enable a better control of the indoor temperature. Instead of using the thermostats (bimetal ones) integrated into each heater the centrally located new control system uses room thermostats. The new control system should result in a more even indoor temperature.

The houses have already baseboard heaters located below the large windows, which should reduce the radiant temperature asymmetry. As after reconstruction part of the space heating will come from two centrally located hydronic radiators, the choice was made to improve the U-value of the windows. The old double-pane windows (U = 2.5 W/ m^2 °C) were exchanged for new quadruple-pane windows (U = 1.0 W/ m^2 °C). The new windows also result in a small reduction in the transmitted solar energy. It probably would have been enough to add a third pane to the existing window, but would have resulted in a lower reduction of the building heat loss coefficient. As the refrigerator/freezer was fairly old in the six houses they were exchanged for new energy efficient ones.

6. RESULTS

6.1 Airtightness and ventilation

In all six houses the airtightness has been tested before and after reconstruction. When these houses were built there was no official requirement on airtightness. All houses were pressurized and depressurized with open and closed vertical shafts (see table 6).

Table 6. Measured airtightness at 50 Pa, ach, before and after reconstruction.

House	closed vents before	closed vents after	open vents before	open vents after
# 1, 1 storey	2,5	2.1	4.4	2.9
# 2, 1 storey	2.9	2.4	5.3	3.0
# 3, 1 storey	2.9	2.4	4.5	3.1
# 4, 1½ storey	4.1	4.7	5.4	5.4
# 5, 1½ storey	3.7	3.8	5.3	4.6
# 6, 1½ storey	4.7	4.6	5.8	5.4
Average	3.2	3.5	5.1	4.3

All houses have a good level of airtightness already before reconstruction, the one-storey houses even meet today´s requirement in Sweden. The 1½ storey houses are leakier, generally due to the fact that it is difficult to achieve a good airtightness in the joints between ceiling and wall upstairs and the joint between the intermediate floor and exterior walls. The 1-storey houses have become even airtighter after reconstruction, mainly due to new windows. Two of the 1½-storey houses have unchanged airtightness and the third has become leakier.

Tracer gas measurements were performed in two houses, # 1 and # 4. House # 1 had a total outdoor air ventilation rate of 52 m³/h (0.17 ach) before and 151 m³/h (0.50 ach) after reconstruction (see table 2 for individual rooms). House # 4 had a total outdoor air ventilation rate of 71 m³/h (0.21 ach) before and 141 m³/h (0.41 ach) after reconstruction (see table 3 for individual rooms).

Table 2. Measured outdoor air ventilation rates in house # 1 before and after reconstruction, m³/h.

	Before	After
Measuring period, h	6	6
Outdoor temperature, °C	6	6
Wind speed, m/s	0.7	4
Bedroom 1	7	20
Bedroom 2	26	12
Bedroom 3	3	10
Kitchen/living room	1	42
Study	1	25
Bathroom	10	9
Laundry	0	26
Hallway	0	7

Table 3. Measured outdoor air ventilation rates in house # 4 before and after reconstruction, m³/h.

	Before	After
Measuring period, h	3	6
Outdoor temperature, °C	9	4
Wind speed, m/s	1.4	3
Laundry	46	32
Kitchen	13	21
Bedroom	2	24
Living room	6	25
Bedroom upstairs	0	1
Bedroom upstairs	0	5
Living room upstairs	0	10
Bedroom upstairs	0	13
Bathroom upstairs	4	10

In both houses the overall ventilation and the ventilation of individual rooms have been improved after the reconstruction. The new ventilation system will of course have the problem that the colder the weather the lower the outdoor air and the overall ventilation of the bedrooms and the living room upstairs will be. The pressure caused by the stack effect is larger than the one cuased by the exhaust fan. To counteract this effect the building envelope has to be airtighter (Blomsterberg 1991).

In order to determine the change in ventilation rate not only for a couple of hours but for a heating season calculations were made. For this purpose the LBL-modell was used (Blomsterberg 1990). The calculations were first checked against the tracer gas measurements (Blomsterberg 1992 and 1993). The agreement between modell and measurement was found to be reasonable for a winter day with mild weather. Estimates for a heating season during a reference year shows an improvement in overall ventilation (see table 4).

Table 4. Estimates of the overall ventilation before and after reconstruction for a heating season during a reference year, air changes per hour (volume of house # 1 = 305 m^3 and of house # 4 = 345 m^3).

House	Before	After
# 1	0.2	0.5
# 4	0.35	0.5

6.2 INDOOR CLIMATE AND ENERGY USE

The improvement in indoor climate due to ventilation was discussed in the previous chapter. A comparison of calculated ventilation heat losses for an entire year show reduced (actual) and further reduced (theoretical) ventilation energy losses (see table 5). The calculated heat losses after reconstruction are based on the measured exhaust air temperatures and the electricity use of the heat pump. Degree day values were used. It should be possible to achieve a result closer to the theoretical possible. Then the hydronic radiators have to be bigger and in a better position to spread their heat to the building.
The control system for space heating and heat pump has to be improved.

Table 5. Calculated ventilation heat losses before and after reconstruction, kWh, for the reference year of 1971 from Stockholm.

House	Before	After (actual)	After (theoretical)
# 1	2200	1200	-500
# 4	4800	3300	200

The measurements before reconstruction showed that during spring, summer and fall high indoor air temperatures can occur. The problem with high indoor temperatures was reduced after reconstruction. According to the measurements during the period april - september the number of hours with an indoor temperature above 24 C is appr. 750 before and after reconstruction in the six houses. After reconstruction there is however hardly any hours above 26 C, although the summer of 1992 was warmer than the summer of 1989. Before there was appr. 250 hours.

The average overall use of electricity was 20650 kWh during 1989 (before reconstruction). If the overall use is corrected for the use in the detached storage the average value is 19300 kWh, with a lowest value of 17000 kWh and a highest value of 20650 kWh. After reconstruction the average overall use (ecxl. detached storage) of electricity during 1992 was 16500 kWh with a maximum of 18000 kWh and a minimum of 14700 kWh. The outdoor temperature during the winter was colder 1992 than 1989. The same people lived in the houses.

7. CONCLUSIONS

The monitoring of the six one-family houses built in the seventies before and after reconstruction has shown that it should be technically possible to improve the energy efficiency and the indoor climate in Swedish naturally ventilated houses built before 1980. The best way of improving upon both ventilation and energy efficiency in these houses is probably to install a mechanical exhaust ventilation system incorporating a heat pump. It is obvious from the tested houses that the overall ventilation and the ventilation of individual rooms were improved. The indoor climate was improved and the use of electricity was reduced. Thermal comfort and energy efficiency are improved by installing windows with a low U-value. The realized improvements in the six houses are however too expensive, if based on the electricity price of today. The improvements have to be carried out, when measures are needed because of normal maintainance e. g. windows being worn out.

The energy performance of the six houses could be improved. Suggestions include the following:
- Increase the size of the hydronic radiators.
- Locate the hydronic radiators in a better position to spread their heat to the building.
- Improve upon the control system for space heating and heat pump.

For mechanical ventilation with heat recovery to really make sense the house has to have a good level of airtightness. Older houses with natural ventilation are often not airtight enough. There are also practical problems in installing new ventilation systems in existing houses.

Less expensive and simpler systems for the impovement in energy efficiency and indoor climate in electrically heated and naturally ventilated houses are needed.

8. REFERENCES

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