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Improvement of Mechanical Ventilation Systems Regarding the Utilization of Outdoor Air

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Synopsis

Nowadays it is rather common with demand controlled ventilation in public buildings and offices. The purpose of demand controlled ventilation is to adapt the ventilation to the varying needs of the occupations. In dwellings it is rather unusual with demand controlled system. The main reason for that is the high investment cost for the system. The outdoor air used for ventilation in dwellings is therefore not effectively used. For example in a mechanical exhaust ventilation system 50 % of outdoor air is leaving the house without being used of the people.

In a multi zone computer program simulations baced on tracer gas measurements were done for two modern typical houses. We did calculations for outdoor air flow for the whole and for a single room, during a heating season. Two different ventilation systems were simulated. The air flows between rooms and between inside and outside were calculated.

We found that we could utilize the outdoor air better if the systems were reconstructed. The reconstructed system contains the same amount of air inlets and outlets, but all outdoor air is supplied to the bedrooms. Further calculations show us the ratio between the interzonal air flow created by the fan(s) and interzonal air flow created by differences in temperature was 1 to 10.

The paper presents the results from calculations of air flows for two diffrent ventilation systems. Further on the paper discusses how a system should be constructed to utilize the outdoor air in an optimal way.

1. INTRODUCTION

An investigation into various ventilation principles employed in modern single-family houses has been carried out by, and on the initiative of, the Swedish National Testing and Research Institute (SP), financed by the Swedish Council for Building Research (BFR), the National Board of Housing, Building and Planning and the Swedish building industry's Development Fund. The investigation involved 40 single-family houses, built between 1988 and 1992.

One of the objectives of the project was to 'determine, by means of measurements and calculations, how well different types of ventilation systems ventilate individual rooms.' In addition, another objective has been to investigate the air source, i.e. outdoor air or transferred air (air flowing into one room from an adjacent room).

In order to obtain this data, outdoor air flows and transferred air flows to an individual room have been measured in 40 houses. These measurements were made over a period of a month in a large bedroom, using the passive tracer gas method. The MOVECOMP-PC program (Bring 1988, Herrlin 1987) has been used to generalise the results. The program allows air flows between rooms, outdoor air flows, infiltration and exfiltration to be simulated.

This paper describes the results from calculations and measurements of ventilation in two of the 40 houses having different types of ventilation systems. The measured results from the other houses have been described in a report (Blomsterberg, Carlsson, 1995).

2. DWELLING WITH MECHANICAL EXHAUST VENTILATION SYSTEM

2.1 General

In a house having a mechanical exhaust ventilation system (see Figure 2.1), the proportion of outdoor air entering an individual room depends on the number of outdoor air inlets, air leaks in the building envelope and the pressure difference across the building envelope. This pressure difference depends on the general airtightness of the building, the exhaust air flow rate, wind velocity, wind direction and the indoor/outdoor temperature difference.

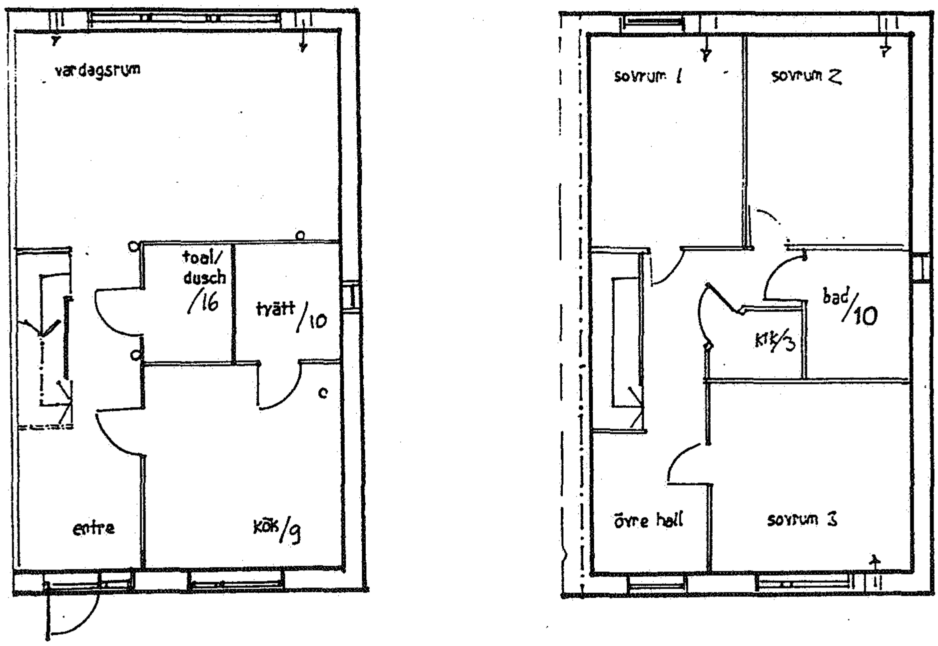

Figure 2.1 Positions of ventilation air inlets in a 1½-storey house with a mechanical exhaust system.

Single-family houses generally have outdoor air inlets in bedrooms, the sitting room and in any general-purpose room. If these inlets are closed in the sitting room and the general-purpose room, the proportion of outdoor air entering via the bedrooms will increase.

By how much will the outdoor air flow rate to the bedroom increase if the outdoor air inlets in the other rooms are closed? What will be the effect on air change rate in the sitting room and general-purpose room when the outdoor air inlets in those rooms are closed?

2.2 Input data for simulation

One of the houses in the survey, having mechanical exhaust ventilation, has been simulated by the program. This is a 1½-storey house, with a conventional floor plan (see Figure 2.1), with bedrooms and bathroom on the upper floor and the remaining rooms on the ground floor. The ventilation system is typical of that in modern Swedish single-family houses with mechanical exhaust ventilation. The house fulfils Swedish Building Regulations requirements in respect of airtightness of the building envelope (3.0 air changes/h, 50 Pa).

The measured pressure/flow characteristics of the outdoor air inlets have been used in the simulations (Mellin, 1980). The house's wind pressure coefficients have been taken from wind tunnel investigations (Wiren, 1985). The actual airtightness of the house was measured during the diagnostic tests after construction (2.8 m^3/h, m^2). On the basis of our experience of leakage measurements through building envelopes in conventional single-family houses, we feel that the actual air leakage in a 1½-storey house can be regarded as being distributed as follows: 60 % through the floor/ceiling structure between the ground floor and upper floor, 20 % via penetrations, 10 % at the edges of floors, 5 % around the edges of the ceiling and 5 % through windows. The exhaust air flow rate used in the program (176 m^3/h) is that as measured for the house. Room temperatures and temperature gradients are based on measurements made when checking the performance of the system (see Table 2.2). Climate data for the 1971 reference year for Stockholm has been used when calculating heating and ventilation requirements for a heating season.

Table 2.2 Room temperatures and temperature gradients as used in the simulation.

Room	Room temperature, °C (at floor level)	Temperature gradient, °C/m (vertical)
Sitting room	18.4	0.6
Utility room	18.5	0.6
Kitchen	19.1	1.0
Hall, ground floor	19.1	0.6
Bedroom 1	18.8	0.5
Bedroom 2	19.1	0.5
Bedroom 3	19.8	0.3
Landing, upper floor	19.3	0.3

2.3 Comparison between measured and calculated values

The first computer run was performed in order to compare the actual measured results obtained from tracer gas measurements with the calculated outdoor air flow rate for bedroom 3 (see Figure 2.1). Simulation was performed for two different outdoor temperatures, with a wind velocity of 1 m/s. The model results were in good agreement with the measured values. The measured outdoor air flow rate to the bedroom was 3.9 l/s, while the calculated outdoor air flow rates to the bedroom at ambient temperatures of 0 °C and 10 °C were 3.4 l/s and 4.0 l/s respectively.

The computer model calculations were made on the basis of open bedroom doors and at two different ambient temperature levels in order to illustrate the effects of temperature. During the actual measurement period, the ambient temperature varied between 0 °C and 10 °C, while the indoor temperature was 20 °C. As indicated by the model simulation, the outdoor air flow rate to the bedroom increased when the ambient temperature increased, as a result of thermal driving forces.

2.4 Calculations for a whole heating season

The outdoor air flow rate is less than 8 l/s (the Swedish Building Regulations requirement for bedrooms with two persons) for most of the heating season (see Diagram 2.4.1). The reason for the variation in flow rate is partly thermal driving forces and partly the effects of wind.

The house used for the model contained two outdoor air inlets in the sitting room (see Figure 2.1). If these inlets are relocated to bedrooms 2 and 3, the outdoor air flow rate to these bedrooms will increase (see Diagram 2.4.2). The average outdoor air flow rate over the period increases from 2.6 l/s to 5.8 l/s in bedroom 3 if the sitting room air inlets are 'transferred' to the
bedrooms.

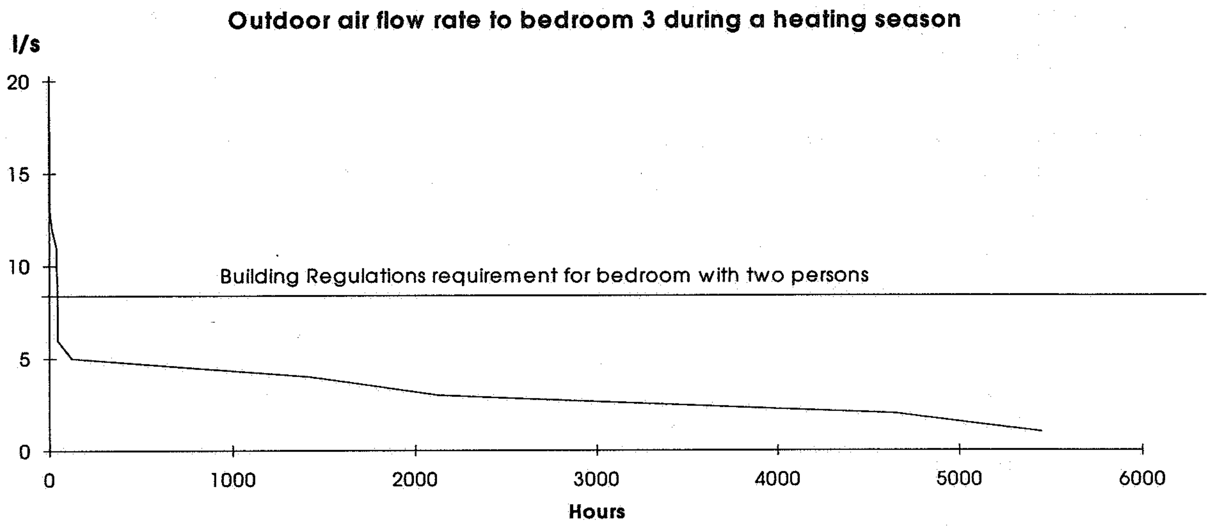

Diagram 2.4.1 Duration diagram (showing the Building Regulations requirement for 8 l/s outdoor air flow rate) for the outdoor air flow rate to bedroom 3 (standard type ventilation system, see Figure 2.1). Over the heating season, the average value of outdoor air flow rate is 2.6 l/s.

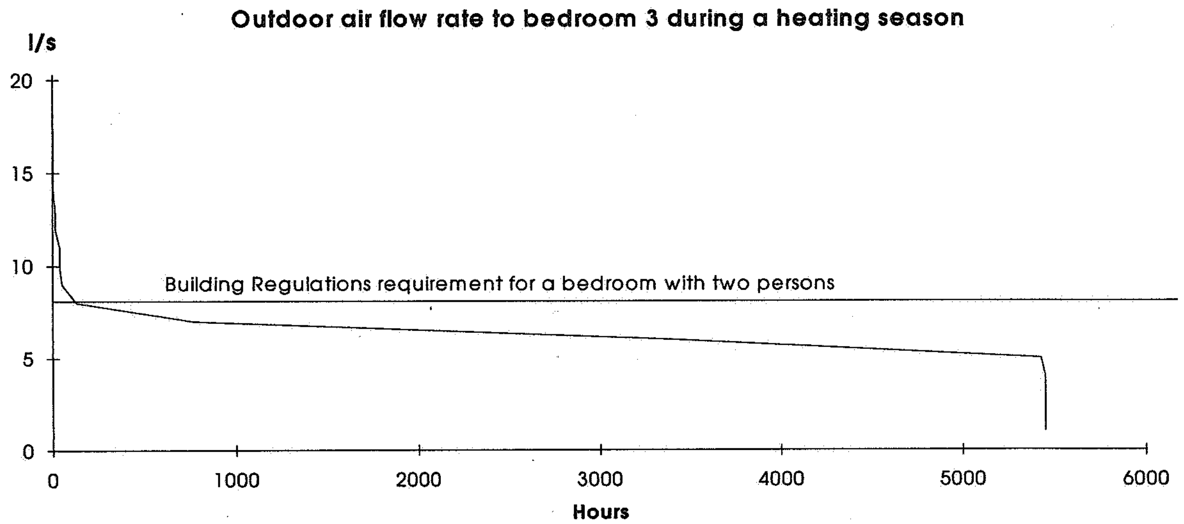

Diagram 2.4.2 Duration diagram (showing the Building Regulations requirement for 8 l/s outdoor air flow rate) for the outdoor air flow rate to bedroom 3 (with closed outdoor air inlets in the sitting room and an extra outdoor air inlet in the bedroom). Over the heating season, the average value of outdoor air flow rate is 5.8 l/s. With open bedroom door.

Both the simulations were performed assuming an open bedroom door. If the door is closed, the outdoor air flow rate is reduced as a result of the pressure drop across the door. A further simulation was performed without air inlets in the sitting room, but with a closed bedroom door. This indicated that the average outdoor air flow rate during the heating season fell from 5.8 l/s to 4.9 l/s. Moving the outdoor air inlets from the sitting room to the bedrooms thus greatly increases the proportion of outdoor air to the bedrooms.

3. THE EFFECT OF INDOOR TEMPERATURE ON INTERNAL AIR CHANGE RATES

Three simulations were performed in order to investigate the effects on air change rates in individual rooms with different types of ventilation arrangements. Airtightness parameters were assumed to be in accordance with Swedish standard requirements for the building envelope. The temperature difference between indoor and outdoor temperatures was taken to be about 20 °C, with a wind velocity of 1.0 m/s.

1. Air change rate in the room, as powered by mechanical ventilation only, i.e. no temperature difference between the rooms (standard ventilation system).
2. Air change rate in the room, as powered by mechanical ventilation and temperature differences (see Table 8.1) between the rooms (standard ventilation system).

3. As simulation No. 2, but with outdoor air inlets only in the bedrooms.

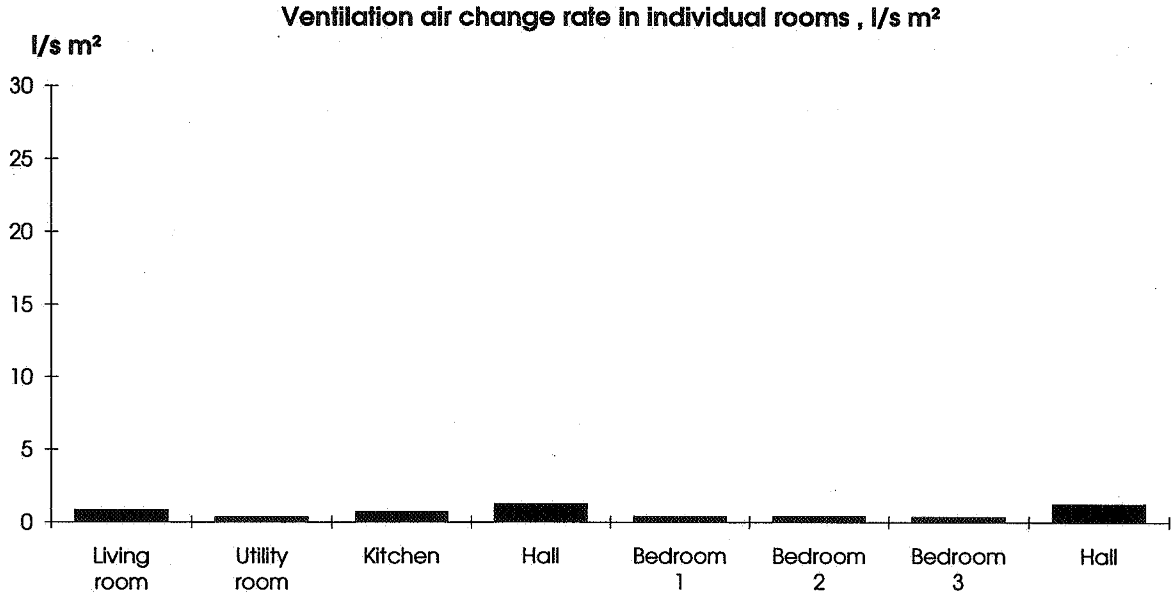

Diagram 3.1.1 **Simulation no. 1.** Ventilation air change rates (l/s, m² of floor area) as generated by mechanical ventilation only. Simulation results based on the standard design of ventilation system. Rooms as shown in Figure 2.1.

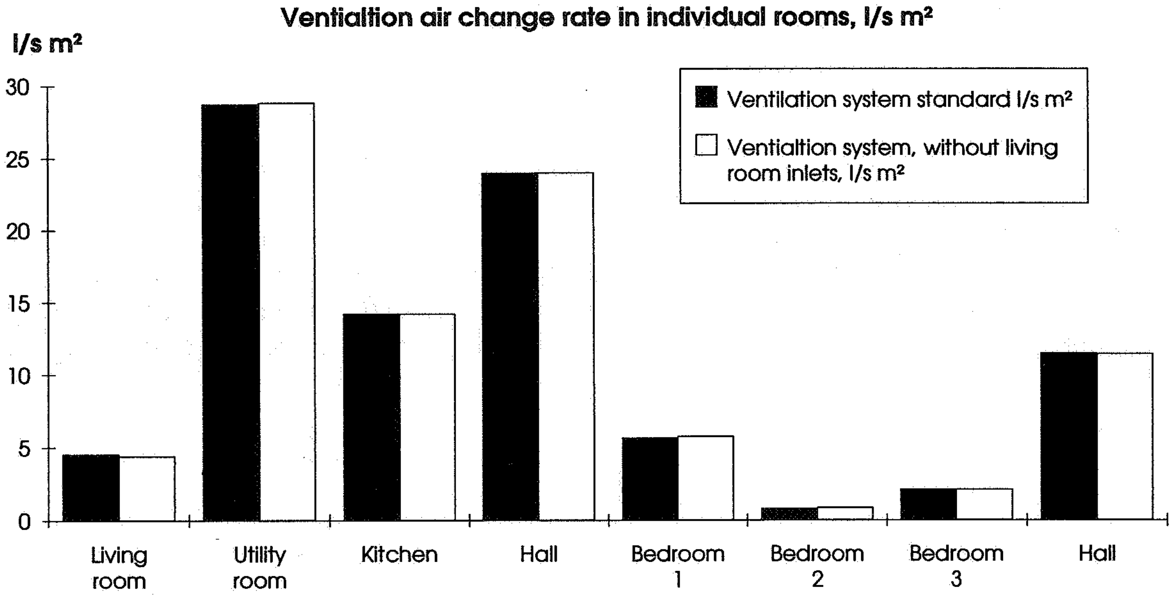

Diagram 3.1.2 **Simulations 2 and 3.** Ventilation air change rates (l/s, m² of floor area) as generated by mechanical ventilation and thermal driving forces. Simulation results based on the standard design of ventilation system and as modified with inlets in the bedrooms only. Rooms as shown in Figure 2.1.

The model simulation calculations assumed that all doors were open between all rooms. If the door to a room is closed, air change will not be affected by thermal drive forces between the rooms. Modern houses generally have no internal doors between the hall, sitting room, general-purpose room and kitchen.

The earlier simulations showed that the outdoor air flow rate to the bedrooms increased substantially, from 2.6 l/s to 5.8 l/s (see Diagrams 2.4.1 and 2.4.2) if the outdoor air inlets in the sitting room were closed. Air change in the rooms is strongly affected if temperature differences between the rooms arise when the internal doors are open (see Table 2.2, Diagram 8.4 and Diagram 8.5). If the internal doors are open, air change in the rooms is affected only insignificantly by whether or not there are outdoor air inlets in the rooms. The proportion of air change between rooms that can be affected by the fans when the doors are open is of the order of 10 %.

Further simulations that we performed showed that if the outdoor air inlets in the sitting room are closed and the total exhaust air flow rate is reduced from 178 m³/h to 88 m³/h, the outdoor air flow rate to the bedroom investigated increases to 2.8 l/s instead of 2.6 l/s (the mean value for the heating season). In other words, the bedrooms can be ventilated just as effectively with only half the exhaust air flow rate if there are outdoor air inlets in the bedrooms only.

4. DWELLING WITH BALANCED MECHANICAL VENTILATION SYSTEM

4.1 General

One of the houses in the investigation, a 1½-storey house having a balanced mechanical ventilation system combined with air heating, has been simulated by the computer program. The house had a relatively conventional layout, with bedrooms and bathroom on the upper floor and with the remaining rooms on the ground floor (see Figure 4.1). The ventilation system, shown in Figure 4.2, is of a type commonly employed in Swedish houses with air heating systems. The house complied with Swedish standards in respect of airtightness.

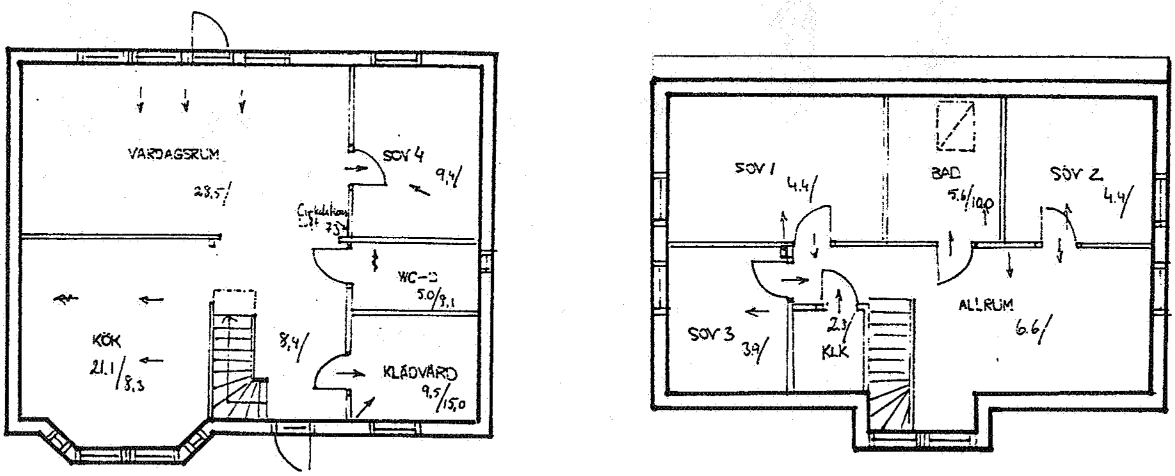

Figure 4.1 A plan of the house, showing positions of inlets and outlets for a balanced ventilation system. Supply and exhaust air flow rates are shown in l/s.

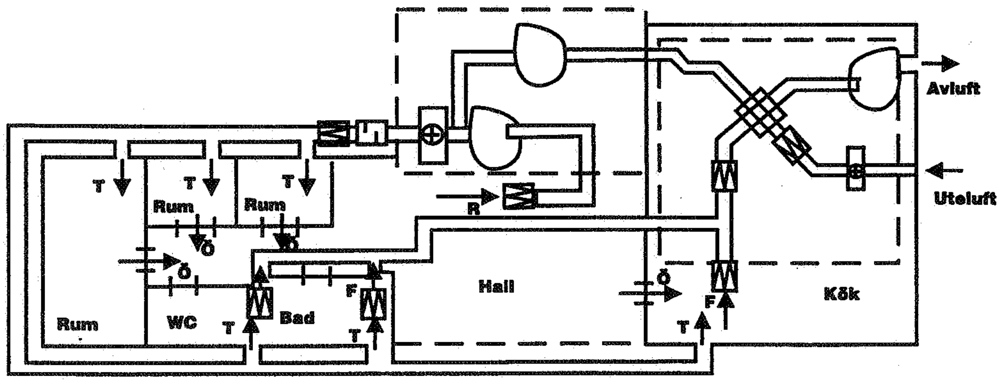

Figure 4.2 Schematic diagram of ventilation system for a single-family house with air heating. R = circulated air, T = supply air, F = exhaust air.

4.2 Input data for simulation

The house's form factors have been taken from wind tunnel investigations (Wiren, 1987). The actual airtightness of the house was measured during the diagnostic tests after construction (2.6 $m^3/h, m^2$). Leakage has been assumed to be distributed as follows: 60 % through the floor/ceiling structure between the ground floor and upper floor, 20 % via penetrations, 10 % around the edges of floors, 5 % around the edges of the ceiling and 5 % through windows. The measured air flow rates were 149 m^3/h of exhaust air flow, 95 m^3/h of outdoor air flow and 300 m^3/h of circulated air flow. Room temperatures and temperature gradients are based on measurements made when checking the performance of the system (see Table 4.2). Climate data for the 1971 reference year for Stockholm has been used when calculating heating and ventilation requirements for a heating season.

Table 4.2 Room temperatures and temperature gradients as used in the simulation.

Room	Room temperature, °C (at floor level)	Temperature gradient, °C/m (vertical)
Sitting room	20.0	0.5
Utility room	20.0	0.5
Kitchen	20.0	0.5
Hall, ground floor	20.0	0.5
Bedroom 1	19.9	0.5
Bedroom 2	19.7	0.2
Bedroom 3	20.0	0.3
Bedroom 4	19.7	0.4
General-purpose room	20.0	0.3

4.3 Comparison between measured and calculated values

The first computer run was performed in order to compare the actual measured results obtained from tracer gas measurements with the calculated outdoor air flow rate. Simulation was performed for two different outdoor temperatures, with a wind velocity of 1 m/s. The model results were in good agreement with the measured values. The measured outdoor air flow rate to the bedroom was 1.9 l/s, while the theoretical outdoor air flow rates to the bedroom at ambient temperatures of 0 °C and 10 °C were 1.2 l/s and 1.4 l/s respectively.

The computer model calculations were made on the basis of two different ambient temperature levels in order to illustrate the effects of temperature. During the actual measurement period, the ambient temperature varied between 0 °C and 10 °C, while the indoor temperature was 20 °C. As indicated by the model simulation, the outdoor air flow rate to the bedroom increased when the ambient temperature increased, as a result of thermal driving forces.

The low outdoor air flow rate to the room is due to the use of a combined heating and ventilation system (see Figure 4.2). Bedroom 1, which was studied is on the upper floor (see Figure 4.1). Most of its heating demand is met by heat from the ground floor. This means that there must be a lower outdoor air flow rate to the upper floor than to the lower floor in order to prevent excessive temperatures.

4.4 Calculations for a whole heating season

Both the computer simulation and the measured values indicate a low value of outdoor air flow rate. The requirements in the Building Regulations for a ventilation air flow rate of 8 l/s are fulfilled in the master bedroom for only a few hours during the period (see Diagram 4.4.1). One way of improving the outdoor air supply to the bedrooms with this type of ventilation system would be to divide the system up into two zones. The supply air to the bedrooms would then consist solely of outdoor air, while the supply air to other rooms would consist of recirculated air (see Figure 4.4).

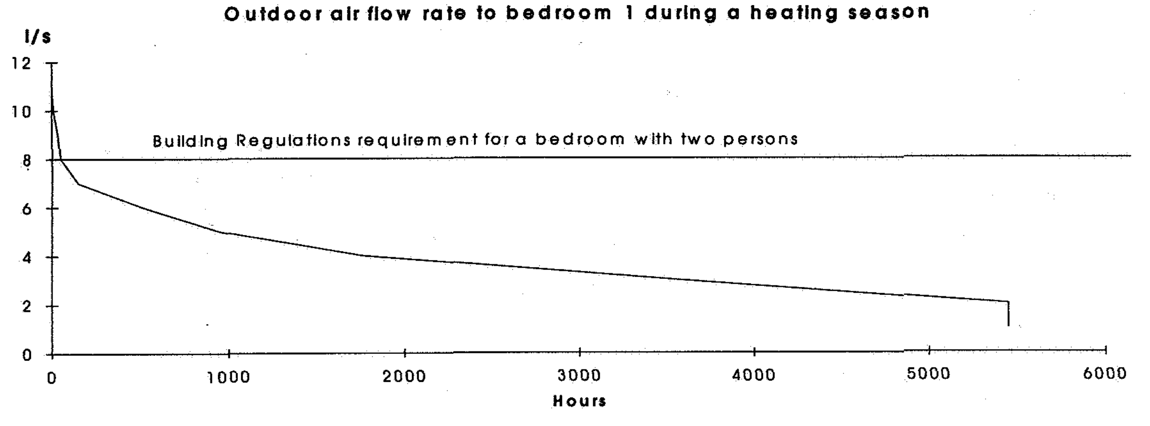

Diagram 4.4.1 Duration diagram for outdoor air flow rate to a two-person bedroom during a heating season. The diagram above is based on an open bedroom door. The average air flow rate during the period is 3.3 l/s (of which 2.3 l/s are infiltration).

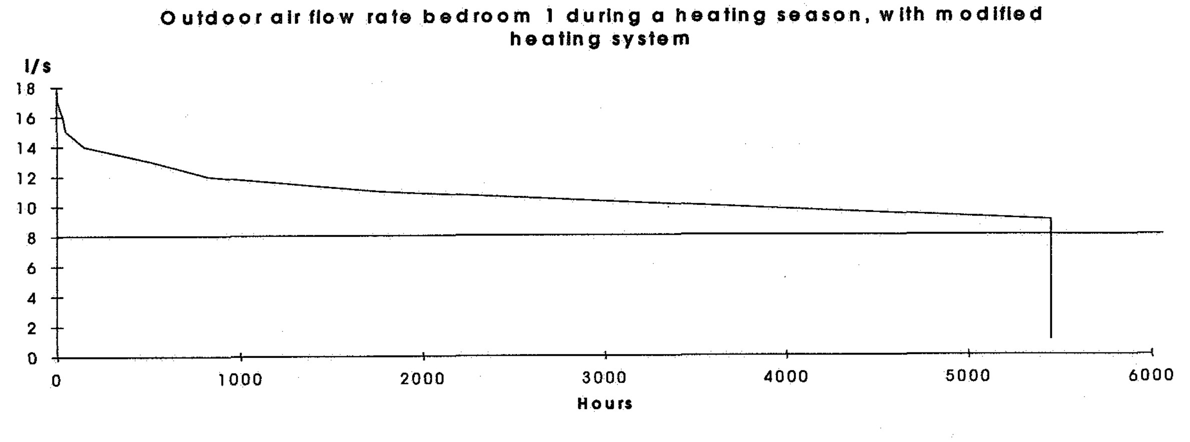

Diagram 4.4.2 Duration diagram of outdoor air flow rate to bedroom 1, with the heating and ventilation system modified as shown in Figure 4.2. The average air flow rate during the period is 10.3 l/s (of which 1.7 l/s are infiltration).

The measured results for the individual bedroom indicate low outdoor air flow rates (1.9 l/s). By modifying the system so that outdoor air is supplied via the bedrooms, the outdoor air flow rate increases from 3.3 l/s to 10.3 l/s, although the total air flow rate to the house remains unaltered. In the existing system, most of the fresh air is supplied to the ground floor.

When the bedrooms are occupied, all outdoor air supplied to the house will benefit those in the rooms. When the bedrooms are unoccupied, the outdoor air will pass through them and benefit the rest of the house.

The result is that better use would be made of the outdoor air than with the present system design. With the same outdoor air flow rate to the house, but with the modified system arrangement, the outdoor air flow rate to bedroom 1 would exceed 8 l/s throughout the entire heating season, as shown in Diagram 4.4.2.

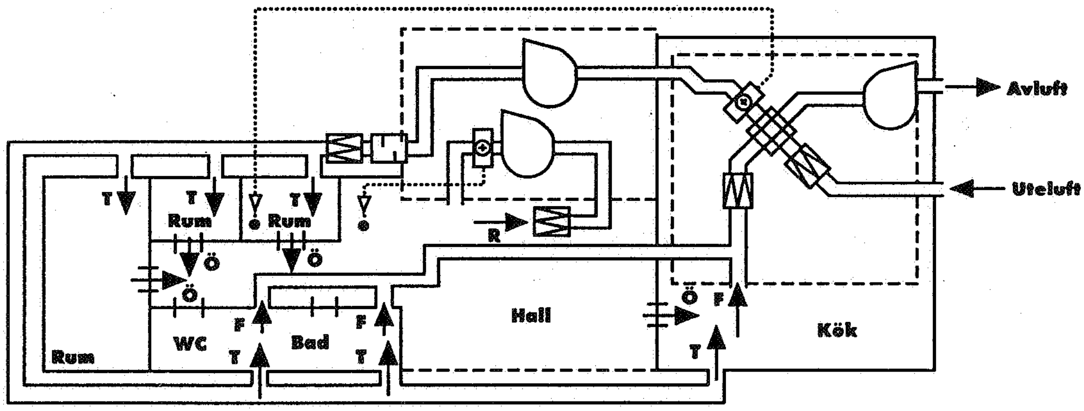

Figure 4.4 Modified air heating system

5. Conclusions

Ventilation systems in Sweden have generally been designed so that outdoor air is supplied to the bedrooms, sitting room and general-purpose room. This means that when the bedrooms are occupied, the fresh air supplied to the sitting room and general-purpose room eventually leaves the house without having ventilated the bedrooms: it is effectively wasted.

If, instead, all the incoming fresh air is supplied via the bedrooms, it will be utilised more effectively. When the bedrooms are unoccupied, the air will flow through them without being contaminated by recirculated air and will then benefit the other rooms.

The general conclusion to be drawn from these measurements and calculations is that all outdoor air should be supplied via the bedrooms, regardless of which of the types of ventilation systems investigated is used. This would mean that the outdoor air flow rate to the bedrooms will increase (c.f. Diagrams 2.4.1 and 2.4.2 and Diagrams 4.4.1 and 4.4.2). Diagram 3.1.2 shows that the incoming fresh air will benefit the rest of the house when the bedrooms are unoccupied.

If it is felt that the quantity of outdoor air supplied by the present system design is sufficient, the proportion of outdoor air can be reduced using the suggested system design. As described in Section 3.1, the outdoor air flow rate can be reduced by 50 % in a system in which outdoor air is supplied only to the bedrooms, and yet still provide the same quantity of outdoor air to the bedrooms. A reduction in outdoor air flow rate will result in reduced energy use and a quieter system. When the building is new increased ventilation might be necessary during 0,5-1 years to remove emissions from new serface materials.One important condition is that there are no harmful emissions from building materials and furniture.

Maintenance of a ventilation system in a house with lowered ventialtion rate is very important, as the marginal to too low ventilation rate is reduced.

6. REFERENCES

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