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VENTILATION CONTROL WITHIN EXHAUST FAN VENTILATED HOUSES

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SYNOPSIS

Modern one-family houses in Scandinavia are often ventilated by an exhaust fan. Most of the outdoor air probably enters through whatever cracks and openings there are and only a small part enters through the supply vents in many of these houses. The overall supply of outdoor air might be adequate, but some rooms often do not get enough of outdoor air.

The constant concentration tracer gas technique was used to examine the supply of outdoor air. Fan pressurization combined with infrared photography were employed to characterize the air leakage of the building. A multi-zone network model was used to further evaluate the measurements.

A reasonable level of outdoor air, upstairs in an airtight two-storey house, can be ensured by locating the supply vents upstairs close to the floor. If that is not possible additional exhaust vents can be installed. If more than 3/4 of the outdoor air is to enter through the the supply vents, then the airtightness should be better than 1.0 air changes per hour at 50 Pa. The performance of an exhaust fan system is very much dependant upon the overall airtightness (including open supply vents) and the distribution of the airtightness of the building.

1. INTRODUCTION

A common ventilation system in modern Scandinavian one-family house is exhaust fan ventilation. An important issue for these houses is where the outdoor air enters and thereby how much outdoor air individual rooms gains. Does the outdoor air enter through the supply vents in the building envelope or does most of it enter through whatever cracks and openings there are in the building envelope? There are reasons to believe that supply vents can act as exhaust vents when it is cold. This is especially true for two-storey houses, where the total supply of outdoor air upstairs is reduced when the outdoor temperature is lowered.

The overall supply of outdoor air might be adequate, but are there long periods of time when too little outdoor air enters some rooms? The air exfiltration is often difficult to determine for a house with exhaust fan ventilation. It is usually given a constant value or neglected. Is that correct?

This paper is based on a report, where the relationship between ventilation and airtightness is examined (Blomsterberg 1990).

2. THE HOUSES TESTED

A group of 18 identical well-insulated experimental houses (Lättbygg 85) in Täby 30 km north of Stockholm, utilizing uncomplicated construction techniques, was built during 1984 and was monitored during 1985 and 1986 (Blomsterberg 1989). Two of the houses (No. 3 and No. 14) are examined in this paper .

The principle ideas governing the design of the houses were to build energy efficient, inexpensive, and uncomplicated houses with.

- a well-insulated and tight building envelope
- a resource efficient light construction technique
- an uncomplicated foundation
- an uncomplicated heating system with individual thermostats
- energy and water efficient appliances
- an instructive owner's manual
- an uncomplicated ventilation system

All houses are modern wood frame constructions employing I-beams made of wood and masonite throughout the construction. Wall, ceiling, roof, and floor elements are prefabricated. Space heating is provided with electric baseboards heaters. The houses are 119 m^2, with three bedrooms upstairs, a kitchen, and a living room downstairs (see figure 1 and 2).

The houses have an exhaust fan ventilation system. There are exhaust air terminal devices in bathrooms, laundry, and kitchen. This kind of system is common in modern one-family houses in Scandianvia. Nine of the experimental houses (e.g. house no 3) have additional exhaust air terminal devices in the bedrooms. Every house has seven special vents, in the exterior walls above the windows, for supplying outdoor air. The ventilation rate can be controlled by the user by adjusting a conveniently located three-way switch: no one at home = 0.1 air changes per hour, at home = 0.3 changes per hour, maximum = 0.5 air changes per hour (120 m^3/h) . The distribution of outdoor air within the house can to some extent be determined by opening and closing the supply vents.

The average mechanical ventilation rate during the heating season of 1986 was 0.35air changes per hourfor the experimental houses. During the summer the average ventilation rate was somewhat higher, 0.40 ach. These values are based on recorded values of run times for the different settings of the fan speed and one-time tests of the exhaust ventilation rates (Blomsterberg 1986). The recorded run times showed that the occupants did use the different fan speeds.

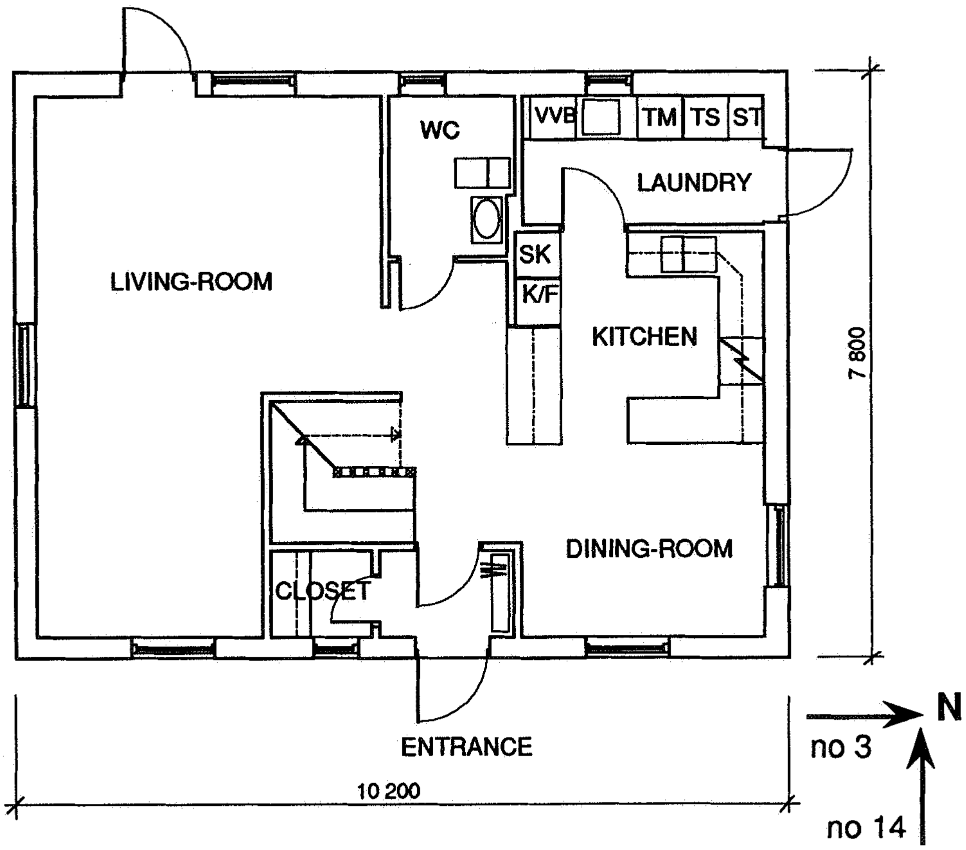


Figure 1. Plan of Lättbygg 85 house, downstairs.

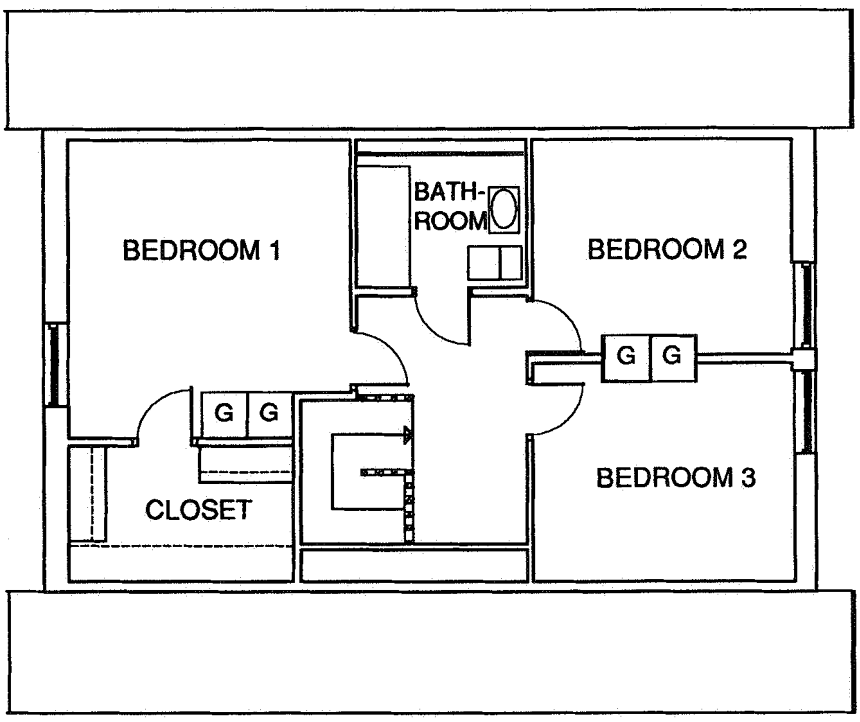


Figure 2. Plan of Lättbygg 85 house, upstairs.

3. TEST METHODS

3.1 Airtightness

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. Other openings are kept closed. 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. The exhaust fan is supposed to draw air through the supply vents and cracks and openings in the building envelope.

All rooms which are heated to more than 10 °C are included in the test. A doorleaf or a window is replaced by a sheet of plywood or airtight plastic film which is fixed to the frame and sealed. An air flow generating and metering system is connected through the sheet. The air flow rate is recorded at a number of pressure differences, positive and negative, and the test results are presented in a diagram with pressure difference and air flow/air change rate on the axes.

3.2 Ventilation

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). In a mechanical ventilation system the air flow in the ducts can be measured with different techniques for volume and mass flow rate measurements. There are many ways of measuring total ventilation, and almost all of them involve a tracer gas, which permits the indoor air to be labelled so that the outdoor air ventilation can be traced.

The tracer gas is injected into and mixed with the indoor air and its concentration is monitored. The mixing is assumed to be complete, which is probabaly the largest single source of error in tracer gas measurements. There are three different schemes; decay, constant concentration, and constant flow of a tracer gas.

All measurements are governed by the continuity equation. The single-chamber continuity equation is given here:

$$V \, dC/dt + Q \, C = F$$

where V is the effective volume, m^3
dC/dt is the time rate of change of concentration
Q is the outdoor air ventilation rate, m^3/s

C is the concentration and
F is the effective injected tracer gas flow rate, m^3/s

In the two houses tested a constant concentration of tracer gas was maintained in order to measure of the ventilation rate. One of the principle advantages with this tehnique is that it eliminates the problem of estimating the effective volume as the effective volume is eliminated from the continuity equation:

$$Q\,C = F$$

The outdoor air ventilation is obtained directly. The field of application for hte constant concentration technique is 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. The estimated inaccuracy in the measured outdoor air ventilation rate is ± 10 %.

4. MULTI-ZONE MODEL

A multi-zone model, which has been developed at the Royal Institute of Technology in Stockholm was used as a tool for further evaluating the measurements (Herrlin 1987). The PC research version of the program was used MOVECOMP-PC(R) (Bring 1988). In the program the building and its ventilation system is modelled. The model consists of pressure nodes connected to each other with flow paths. The nodes are different zones and duct components, while the flow paths are different leakage paths and ducts. The air flows are calculated by seeking a flow balance in each node. Mass balance has to be achieved.

The mass flow through leakage openings and ducts/ducts components, which is a function of the pressure difference, is throughout the model approximated with a power function. The flow through a leakage opening is calculated using the same flow exponent throughout the entire flow intervall. The Reynholds number correction of the air flow coefficient is done for the actual condition.

The system of simultaneous equations describing the flow balance is solved with a modified Newton-Rapson method. The method avoids on most cases otherwise common problems with convergence. As a result of a simulation all air flows and the pressure conditions within the simulated building are given.

How different ventilation systems work in different buildings can be studied. Almost any kind of combination of zones and leakage openings can be simulated.

The main disadvantage with the multi-zone approach is that it requires substantial inputs to describe the flow network. It is often also difficult to find reliable data e.g. wind pressure distributions and internal leakage characteristics (e.g. between rooms).

5. ANALYSIS

All tracer gas measurements of ventilation rates are only valid for the range of weather conditions, which prevailed during the measurements. The important questions are what happens if the weather conditions are changed, the building moved to another location or even the building itself modified. To answer some of these questions the two houses tested were modelled (Blomsterberg 1990).

The first step was to examine how good the agreement is, between predicted ventilation rates and ventilation rates measured using tracer gas. Each room was modelled as a separate zone, and each leakage path was modelled with the same air flow exponent.
As inputs were used:

- the results from the fan pressurization tests,
- the leakage function of the supply vents
- the distribution of leakage openings according to infrared photography scans,
- the actual locak shielding conditions,
- the measured indoor and outdoor temperatures (hourly averages),
- the on site measured wind velocity (hourly averages), not taking into account the fluctuations,
- the terrain roughness,
- the measured mechanical ventilation rates (i.e. air flows in ventilation system),
- the on site measured wind direction (hourly averages),
- wind pressure coefficients from windtunnel studies,
- the measured geometry of door crackage (which was converted to a leakage function),

The second step was to make predictions for an entire heating season (assumed to start on the 24th of September and end on the 8th of May). Weather data was taken from the reference year 1971 of Stockholm.

5.1 House no 3.

The prediction of the overall outdoor air ventilation rate (80 m^3/h) for house no 3 is close to the tracer gas measurement (70 m^3/h) (see table 1). One reason for the difference is that in the model the boundary between different zones is clearly defined, which is not the case in the measurements due to the fact that measurements in different rooms can influence each other. Only three interior doors were closed, the bathroom, the WC and the closet upstairs. As the house is very tight (1.3 air changes per hour at 50 Pa, 2.3 including supply vents) there is no air exfiltration during the measuring period according to the multi-zone model or the tracer gas measurements. The measured average air exfiltration was -10 ± 10 m^3/h i.e. the difference between measured mechanical air flow (80 ± 8 m^3/h) and tracer gas measurements (71 ± 4 m^3/h).

The multi-zone model also shows that only 40 % of the outdoor air enters the house through the supply vents during a typical winter day, the remainder enters through all the leakage openings. A similar result was obtained for similar weather conditions, when the pressure drop across the supply vents was measured and the air flow through them was calculated. The designer of the ventilation system presumably expected all air to enter through the supply vents. The air is mostly infiltrated through the facades and the floor. The higher above the floor the lower the air infiltration rates through the openings.

The discrepancy between prediction and measurements can partly be explained by the fact that the outdoor air supplied directly to the bathroom and the WC probably wasn't measured by the tracer gas technique. Adding these two air flows to the measured ventilation rate brings the overall outdoor air ventilation rate to 74 m^3/h.

Table 1 Multi-zone model predicitions vs tracer gas measurements for house no 3. Average air flows for a 15 hour period, m^3/h. For detailed information on air flows for individual rooms, see Blomsterberg 1990. The average outdoor temperature was 1 °C and the average wind velocity 0.5 m/s. The exhaust air flow was 80 m^3/h, 37 m^3/h upstairs and 43 m^3/h downstairs. There is no air exfiltration.

	Multi-zone model		Tracer gas measurement
	Supply vents	Total	Total
Overall supply outdoor air	33	80	71
Downstairs	22	61	52
Upstairs	11	19	19

During the heating season the variation in air exfiltration rate is very large according to the multi-zone model, if the exhaust air flow is 0.35air changes per hour(84 m^3/h) i.e. according to the measured average during the heating season. The maximum rate, 73 m^3/h, is very high and the minimum rate 0 m^3/h. The average rate is 9 m^3/h. The maximum value, 73 m^3/h, occurs at high wind velocities and is therefore uncertain, as high wind speeds never occured during the tracer gas measurements. If the ventilation is raised to 0.5 air changes per hour, then the average air exfiltration is lowered to 1 m^3/h (or 1 % of the total ventilation) and the maximum to 46 m^3/h. The house is obviously tight enough. With an airtightness level according to the Swedish Building Code 1980 (3.0 air changes per hour at 50 Pa) the average air exfiltration would have been raised very much, to 18 m^3/h (or 13 %).

In order to clarify where the outdoor enters house no 3 a parametric study was carried out using the multi-zone model. The following assumptions were made: the air flow through the exhaust fan is 0.5 ach, the airtightness of the house is equal to the fan pressurization result (1.3 air changes per hour at 50 Pa, 2.3 incl. supply vents) and the supply vents are adjusted according to the design by the HVAC consultant. The predictions show clearly how the outdoor air ventilation rate downstairs is increased from 60 m^3/h to 95 m^3/h and how the outdoor air ventilation rate upstairs is decreased from 60 m^3/h to 25 m^3/h when the outdoor temperature drops from + 20 °C to - 15 °C (see figure 3). A similar result was obtained during the tracer gas measurements in house no 14 (see section 5.2). Less than half of the outdoor air enters through the supply vents. When the outdoor temperature drops the pressure drop across the supply vents upstairs is reduced from 4 Pa to 1 Pa. A pressure difference of 1 Pa corresponds to a wind velocity of 1,5 m/s i.e. the direction of the air flow through the vent can easily change. A minimum air exchange rate is ensured in the bedrooms by the added exhaust air terminal devices there. When it is cold outside, part of the outdoor air to the bedrooms will sometimes be transfered air i.e. enter through the rooms downstairs.

A slight improvement in the distribution of outdoor air can be obtained by a better adjustment of the supply vents. The outdoor air ventilation rate upstairs will then vary between 63 m^3/h and 32 m^3/h , instead of between 60 m^3/h and 25 m^3/h (see figure 4). The pressure drop across the supply vents increases slightly and thereby the air flows are less sensitive to the influence of wind (see figure 4). The adjustment has been made in such manner that the house is depressurized at 4 Pa, when there is no wind and the indoor temperature is equal to the outdoor temperature. The adjustment was made using the air leakage function of the house and the supply vents. 4 Pa was chosen as being a representative value of the pressure difference caused by wind and temperature. The part of the outdoor air which enters through the supply vents is still almost the same.

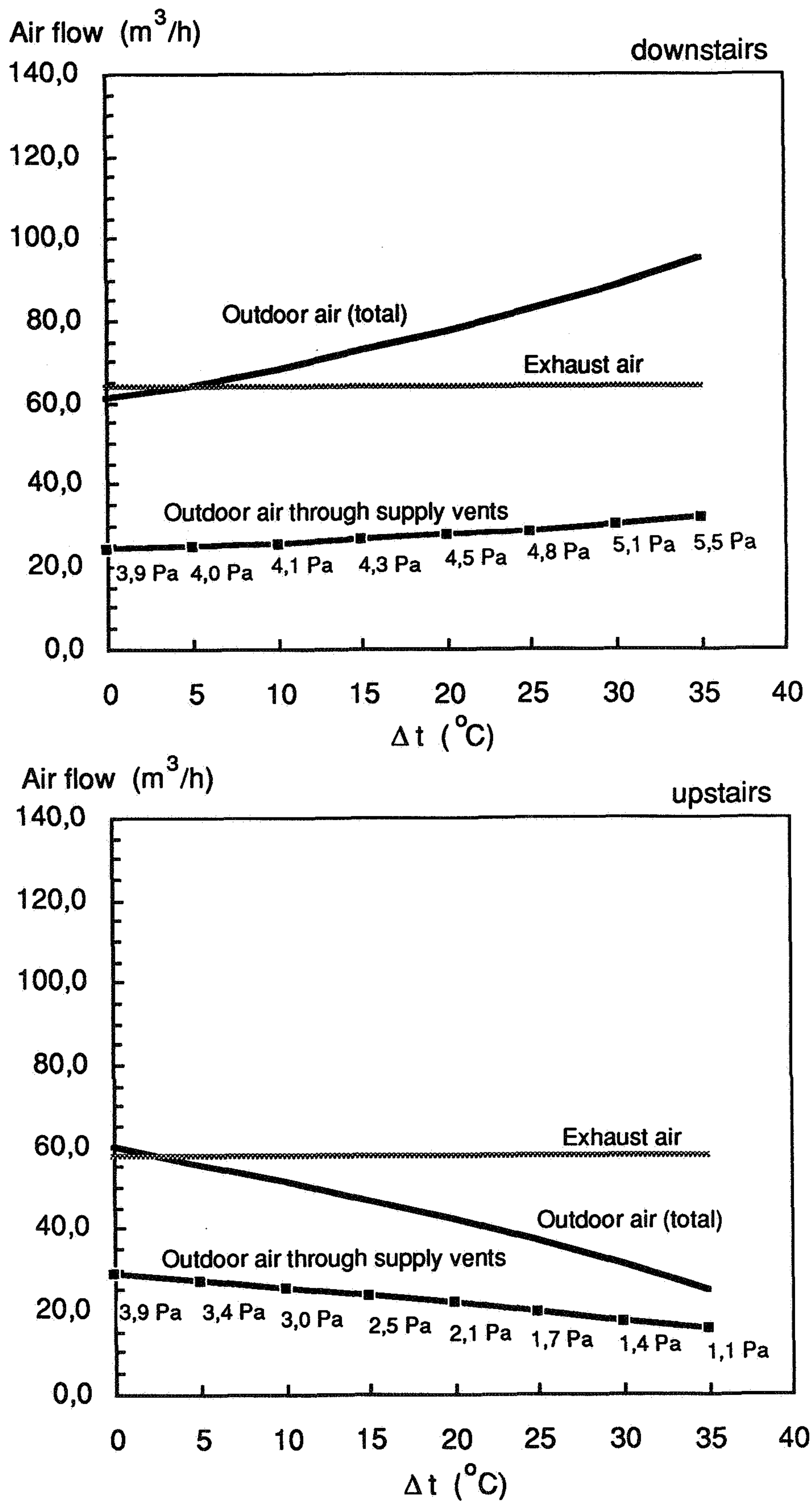


Figure 3. Predicted outdoor air ventilation rate as a function of inside-outside temperature difference, downstairs and upstairs in house no 3. For the supply vents the pressure drop is given. Airtightness = 1.3 ach at 50 Pa. Adjustment, HVAC-consultant. Wind = 0 m/s.

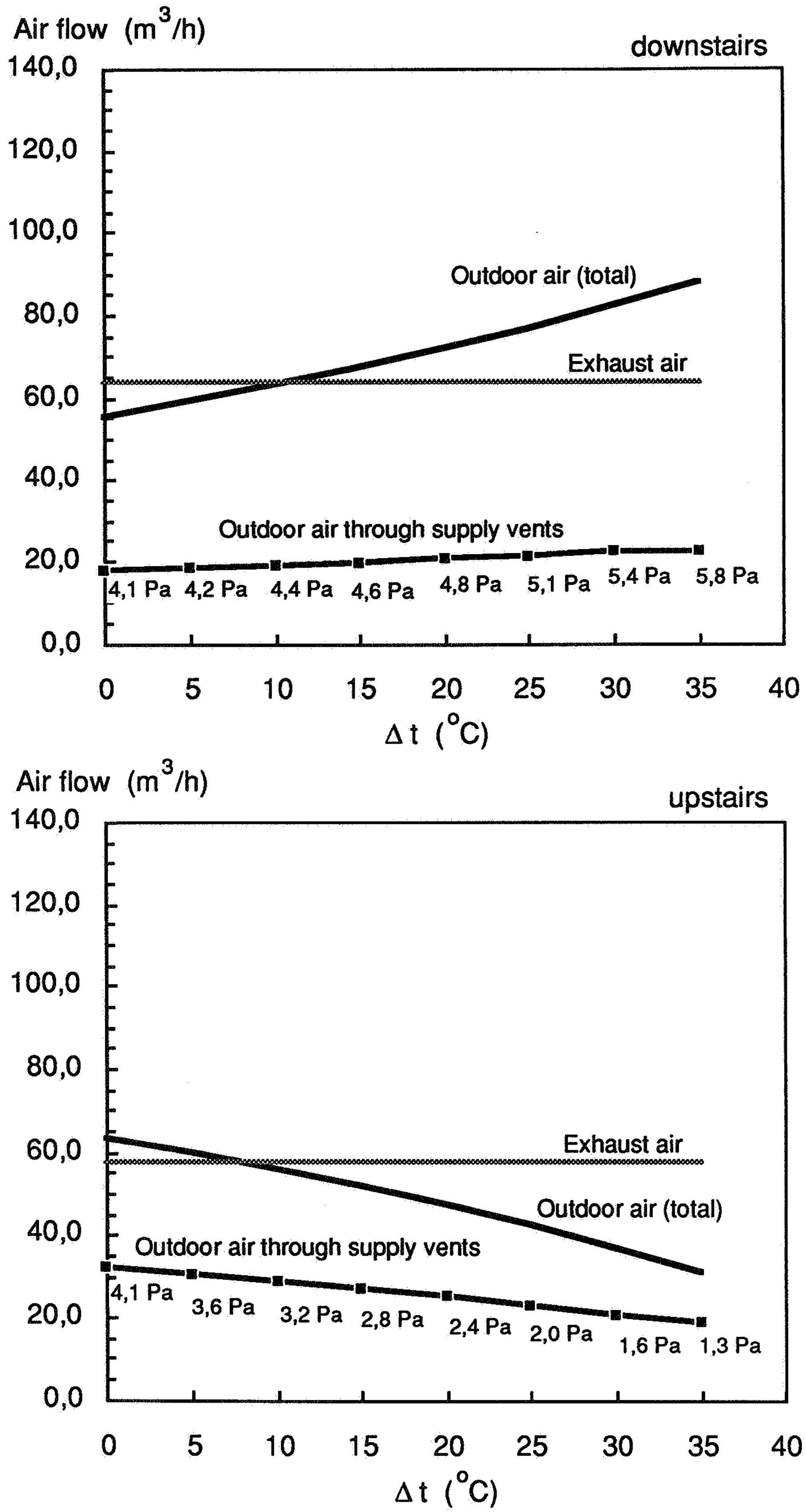


Figure 4. Predicted outdoor air ventilation rate as a function of inside-outside temperature difference, downstairs and upstairs in house no 3. For the supply vents the pressure drop is given. Airtightness = 1.3 ach at 50 Pa. Adjustment at 4 Pa. Wind = 0 m/s.

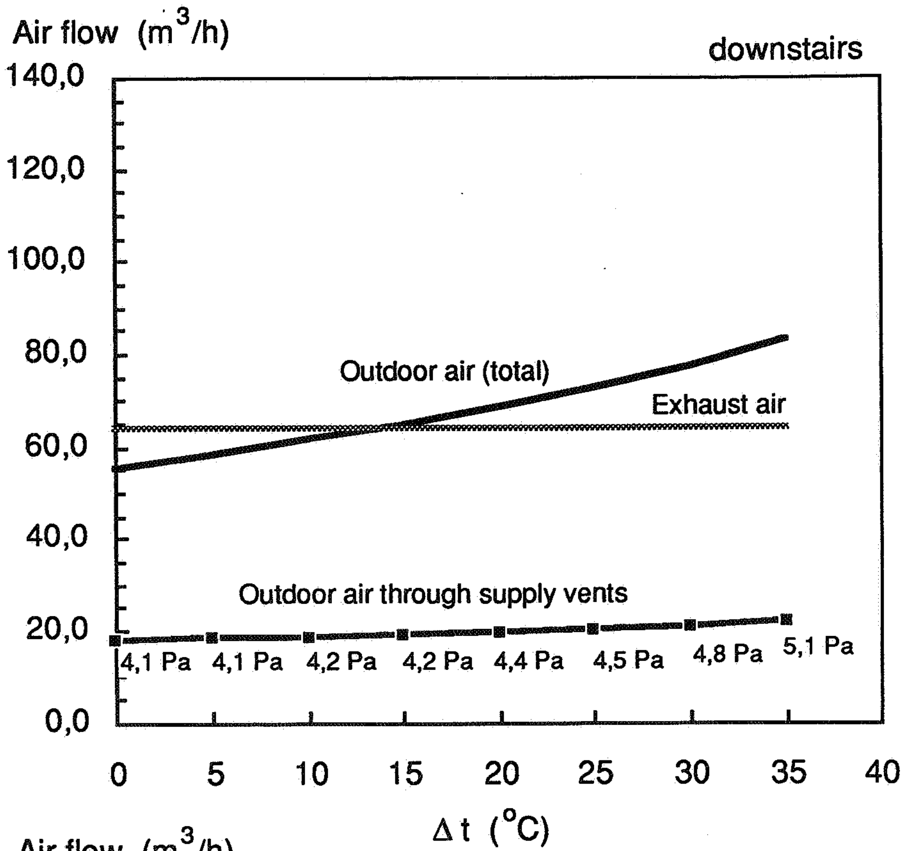
In order to further improve the distribution of outdoor air the house has to be tightened. If the house was as tight as some experimental houses e.g. 0.8 air changes per hour at 50 Pa and the adjustment was made at 4 Pa, then more than 3/4 of the outdoor air would enter through the supply vents. The total outdoor air ventilation rate upstairs will increase with 20 % (at + 20 °C) to 60 % (at - 15 °C), but will still be reduced when the outdoor temperature drops. The pressure drop across the supply vents is slightly increased by the tightening of the house.

There are two techniques of reducing the dependance upon the outdoor air temperature of the distribution of the outdoor air flow between upstairs and downstairs. One alternative is to increase the pressure drop by choking the supply vents. With this technique the air flow through the vents will be reduced. Another alternative is to move the openings vertically by locating the supply vents upstairs close to the supply vents downstairs (see Fahlén 1991). If the supply vents upstairs are located close to the floor level and the supply vents downtairs close to the ceiling level, then the distribution of the outdoor air flow will be less affected by the outdoor air temperature and will be almost constant (see figure 5). The total outdoor air flow upstairs will vary between 63 m^3/h and 41 m^3/h. In the real house the calculated minimum was 25 m^3/h. Furthermore the pressure drop across the supply vents will be higher than 4 Pa, i.e. the air flow will be less sensitive to wind. The calculations are based an airtightness equal to the fan depressurization result and an adjustment at 4 Pa.

5.2 House no 14

Predictions were also made for house no 14. This house is identical to no 3 with a few exceptions, it is less airtight (2.2 air changes per hour at 50 Pa, 3.1 including supply vents), it has a slightly different ventilation system and the weather during the measuring period was much colder. There is a large discrepancy between prediction and measurement. The overprediction is close to 70 % (see table 2). There are reasons to believe that there was a constant background leakage of tracer gas from the equipment located on the first floor during the tracer gas measurements. This would mean that the measured ventilation rate would be too low with almost a constant amount, as the overall ventilation rate is dominated by the exhaust air flow, which can be assumed to be constant over time.

The overall predicted and measured ventilation rate varies almost to the same extent over time. During the measuring period the variation is between 92 and 129 m^3/h (± 11 %) resp. 60 and 73 m^3/h (± 9 %). Based on these findings and the findings for house no 3, the multi-zone model was used for predictions for the heating season.



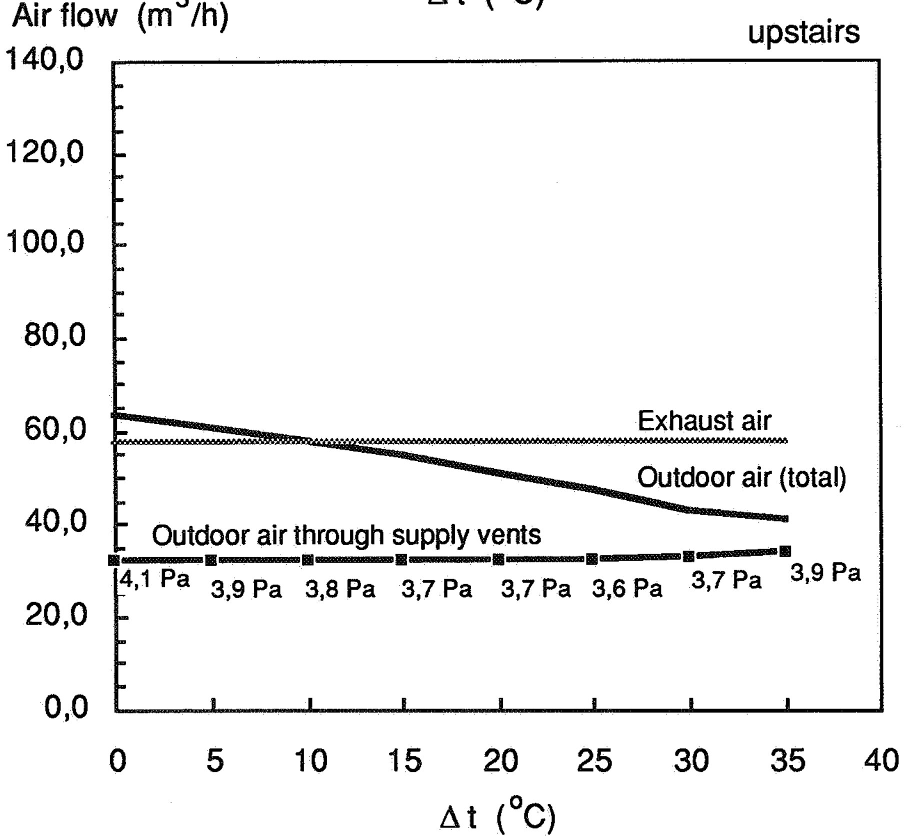


Figure 5. Predicted outdoor air ventilation rate as a function of inside-outside temperature difference, downstairs and upstairs in house no 3. For the supply vents the pressure drop is given. Airtightness = 1.3 ach at 50 Pa. Adjustment at 4 Pa. Wind = 0 m/s. The supply vents upstairs are located 0.2 m above the floor level.

As can be determined from the prediction there is an air exfiltration rate of between 2 and 39 m³/h in house no 14, while there was no air exfiltration in house no 3. This can partly be explained by the fact that house no 3 is tighter and was subject to a milder climate. One might also believe that the upstairs of house no 14 doesn't get very much air. Air is leaving the house through the supply vents, when the outdoor temperature drops below the freezing point. In both houses air is exhausted through the exhaust air terminal devices located upstairs. The upstairs of both houses gets replacement air from downstairs. The amount of replacement air to the bedrooms upstairs in house no 14 would have been larger, if there had been exhaust air terminal devices in the bedrooms as in house no 3. Close to 50 % of all air entering the house enters through the envelope below the windows downstairs. Particularly during the measuring period it might create some discomfort as it is cold air entering. Most of the exfiltration takes place through the ceiling.

If during the measuring period the exhaust air flow is raised from 0.4 air changes per hour to 0.5 air changes per hour, then the air exfiltration is reduced from 29 m³/h to 13 m³/h and air enters through all supply vents.

Table 2 Multi-zone model predictions vs tracer gas measurements for the house no 14. Average air flows for a 108 hour period, m³/h. For detailed information on air flows for individual rooms, see Blomsterberg 1990. The average outdoor tempe- rature was -14 °C and the average wind velocity 0.2 m/s. The exhaust air flow is 90 m³/h, 24 m³/h upstairs and 66 m³/h downstairs. Inside parenthesis is given the air exfiltration.

	Multi-zone model		Tracer gas measurement
	Supply vents	Total	Total
Overall supply outdoor air	16	118 (-28)	69
Downstairs	24.4	109	61
Upstairs	-8.3	9 (-28)	8

The variation in air exfiltration rate during the heating season is larger for house no 14 than for house no 3. The main reason is that house no 14 is less airtight. The maximum air exfiltration rate is almost two times higher, 136 m³/h com- pared with 73 m³/h. The average rate is two times higher, 21 m³/h (or 20 % of the total ventilation) vs. 9 m³/h. The maximum values occur at high wind velocities and are therefore uncertain, as high wind speeds never occured during the tracer gas measurements. If the air flow through the exhaust fan was the required 0.5 air changes per hour, then the average air exfiltration is reduced to 10 m³/h (or 8 % of the total ventilation). The maximum rate is reduced to 116 m^3/h. The house needs tightening to arrive at an air exfiltration rate of 5 % (6 m^3/h) of the total ventilation . The air leakage at 50 Pa has to be lowered by 15 % from 2.2 air changes per hour to 1.9. The house would have experienced an average air exfiltration rate of 15 % (20 m^3/h), if the air leakage had been as in the Swedish Building Code 1980.

In order to clarify where the outdoor enters house no 14 a parametric study, like the one for house no 3, was carried out using the multi-zone model. The following assumptions were made: the air flow through the exhaust fan is 0.5 ach, the airtightness of the house is equal to the fan pressurization result (2.2 air changes per hour at 50 Pa, 3.1 incl. supply vents) and the supply vents are adjusted according to the design by the HVAC consultant. The predictions show clearly how the outdoor air ventilation rate downstairs is increased from 63 m^3/h to 128 m^3/h and how the outdoor air ventilation rate upstairs is decreased from 58 m^3/h to 7 m^3/h when the outdoor temperature drops from + 20 °C to - 15 °C (see figure 6). A similar result was obtained during the above mentioned tracer gas measurements (see figure 7). Less than 1/3 of the outdoor air enters through the supply vents. When the outdoor temperature drops the pressure drop across the supply vents is reduced from 2 Pa to 0 Pa. A pressure difference of 1 Pa corresponds to a wind velocity of 1,5 m/s i.e. the direction of the air flow through the vent can easily change. A minimum air exchange rate is not ensured in the bedrooms as in house no 3, as there are no added exhaust air terminal devices there.

A slight improvement in the distribution of outdoor air can be obtained by a better adjustment of the supply vents. The outdoor air ventilation rate upstairs will then vary between 60 m^3/h and 12 m^3/h , instead of between 58 m^3/h and 7 m^3/h (see figure 8). The pressure drop across the supply vents increases slightly and thereby the air flows are less sensitive to the influence of wind (see figure 8). The adjustment has been made in such manner that the house is depressurized at 4 Pa, when there is no wind and the indoor temperature is equal to the outdoor temperature. The adjustment was made using the air leakage function of the house and the supply vents. 4 Pa was chosen as being a representative value of the pressure difference caused by wind and temperature. The part of the outdoor air which enters through the supply vents does not change very much due to the better adjustment.

In order to further improve the distribution of outdoor air the house has to be tightened (see house no 3).

There are two techniques of reducing the dependance upon the outdoor air temperature of the distribution of the outdoor air flow between upstairs and downstairs. One alternative is to increase the pressure drop by choking the supply vents. With this technique the air flow through the

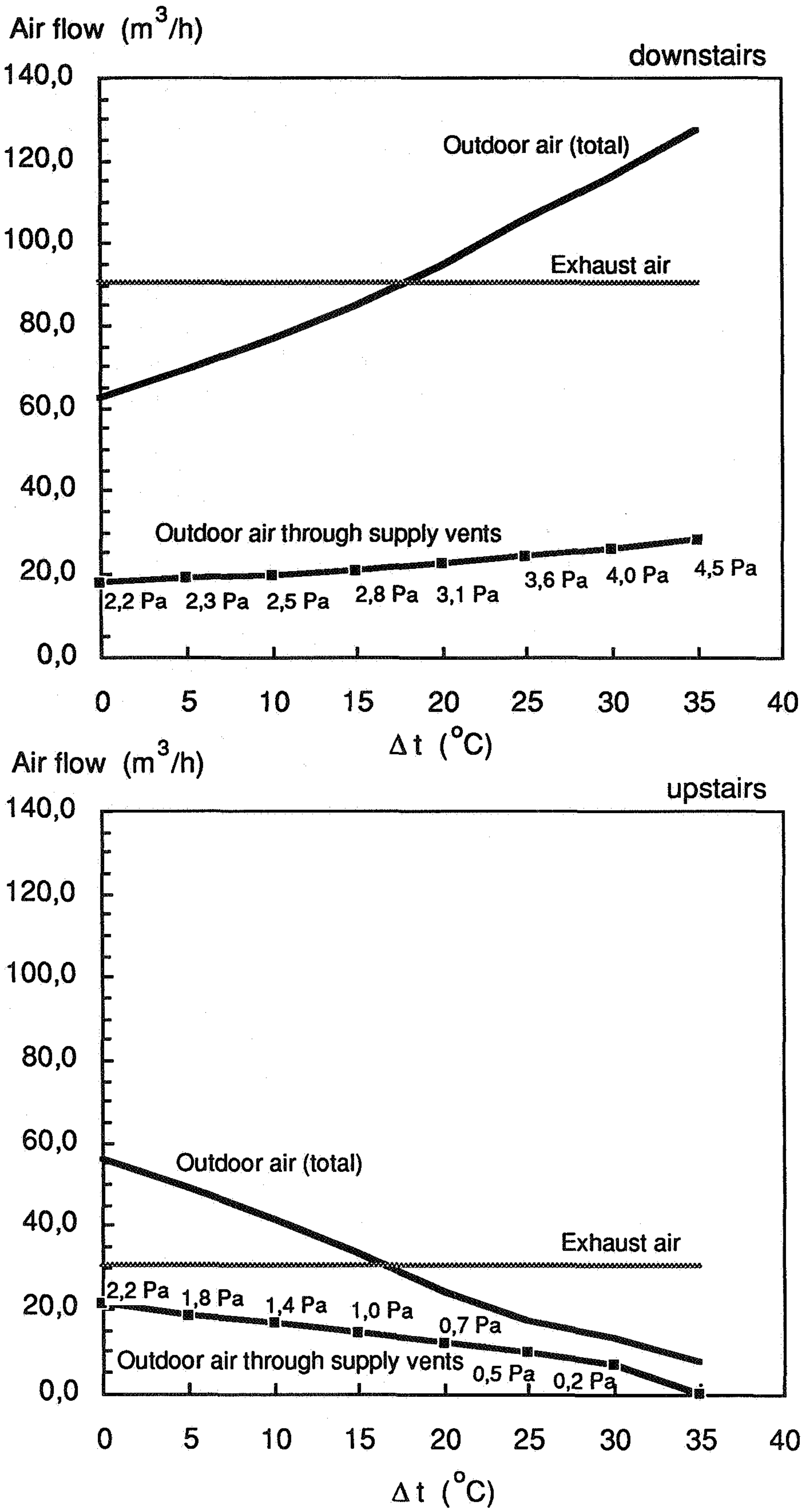


Figure 6. Predicted outdoor air ventilation rate as a function of inside-outside temperature difference, house no 14 downstairs and upstairs. For the supply vents the pressure drop is given. Airtightness = 2.2 ach at 50 Pa. Adjustment, HVAC-consultant. Wind = 0 m/s.

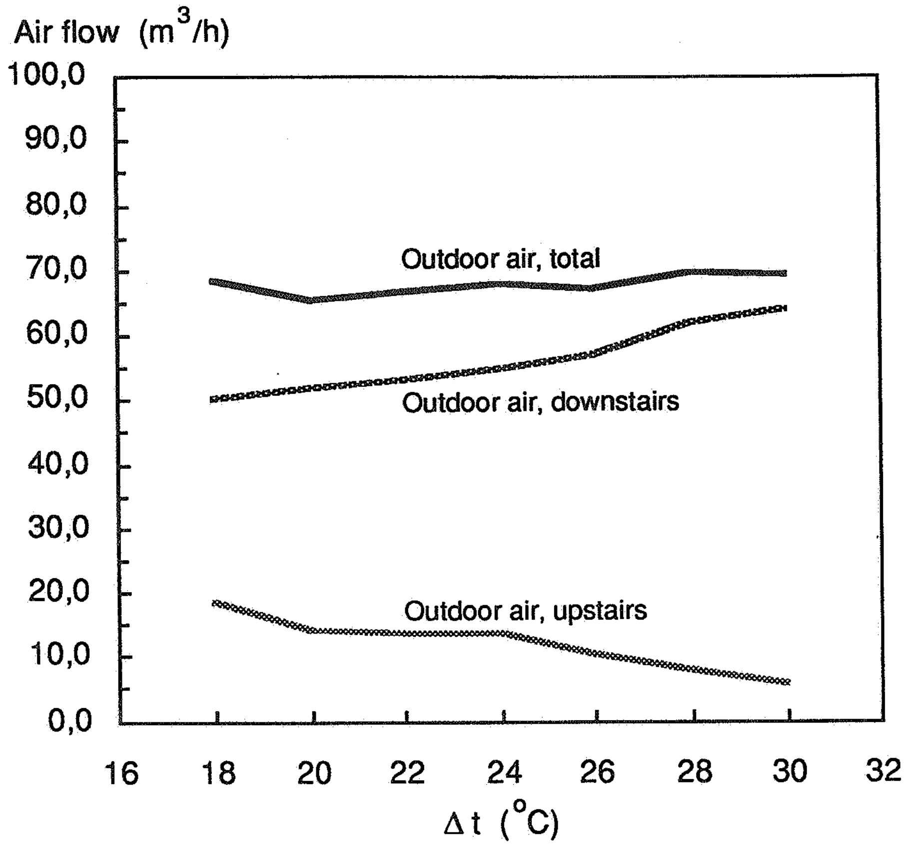


Figure 7. Measured outdoor air ventilation rate as a function of inside-outside temperature difference, for house no 14. The wind speed was 0.5 m/s. The exhaust fan was set on "at home" position. The constant concentration tracer gas technique was used.

vents will be reduced. Another alternative is to move the openings vertically by locating the supply vents upstairs close to the supply vents downstairs (see Fahlén 1991). If the supply vents upstairs are located close to the floor level and the supply vents downtairs close the ceiling level, then distribution of the outdoor air flow will be less affected outdoor air temperature and will be almost constant (see figure 9). The total outdoor air flow upstairs will vary between 63 m^3/h and 41 m^3/h. Furthermore the pressure drop across the supply vents will be higher than 2 Pa, compared with 4 Pa in the tighter house no 3. The calculations are based an airtightness equal to the fan depressurization result and an adjustment at 4 Pa.

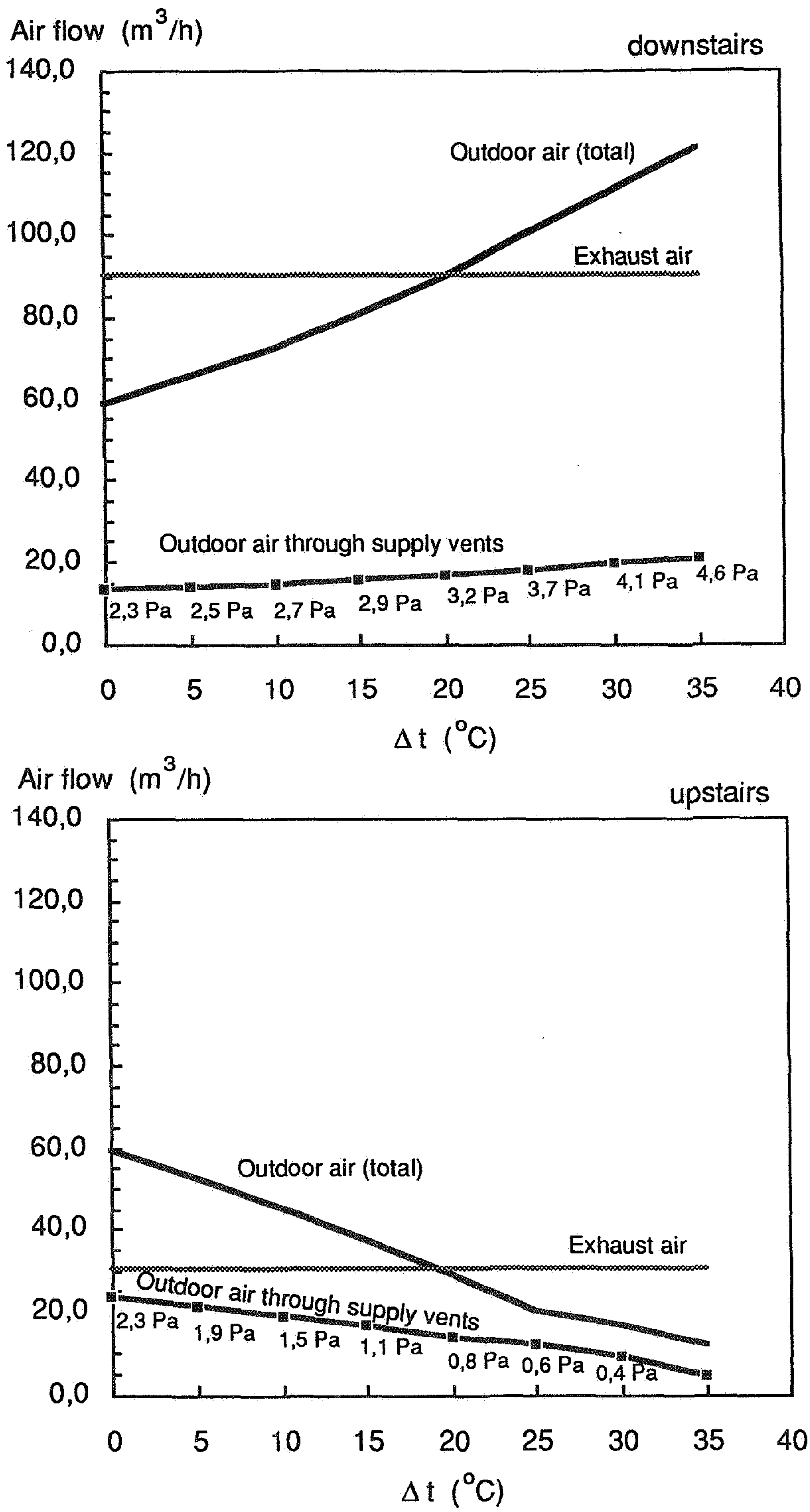


Figure 8. Predicted outdoor air ventilation rate as a function of inside-outside temperature difference, downstairs and upstairs in house no 14. For the supply vents the pressure drop is given. Airtightness = 2.2 ach at 50 Pa. Adjustment at 4 Pa. Wind = 0 m/s.

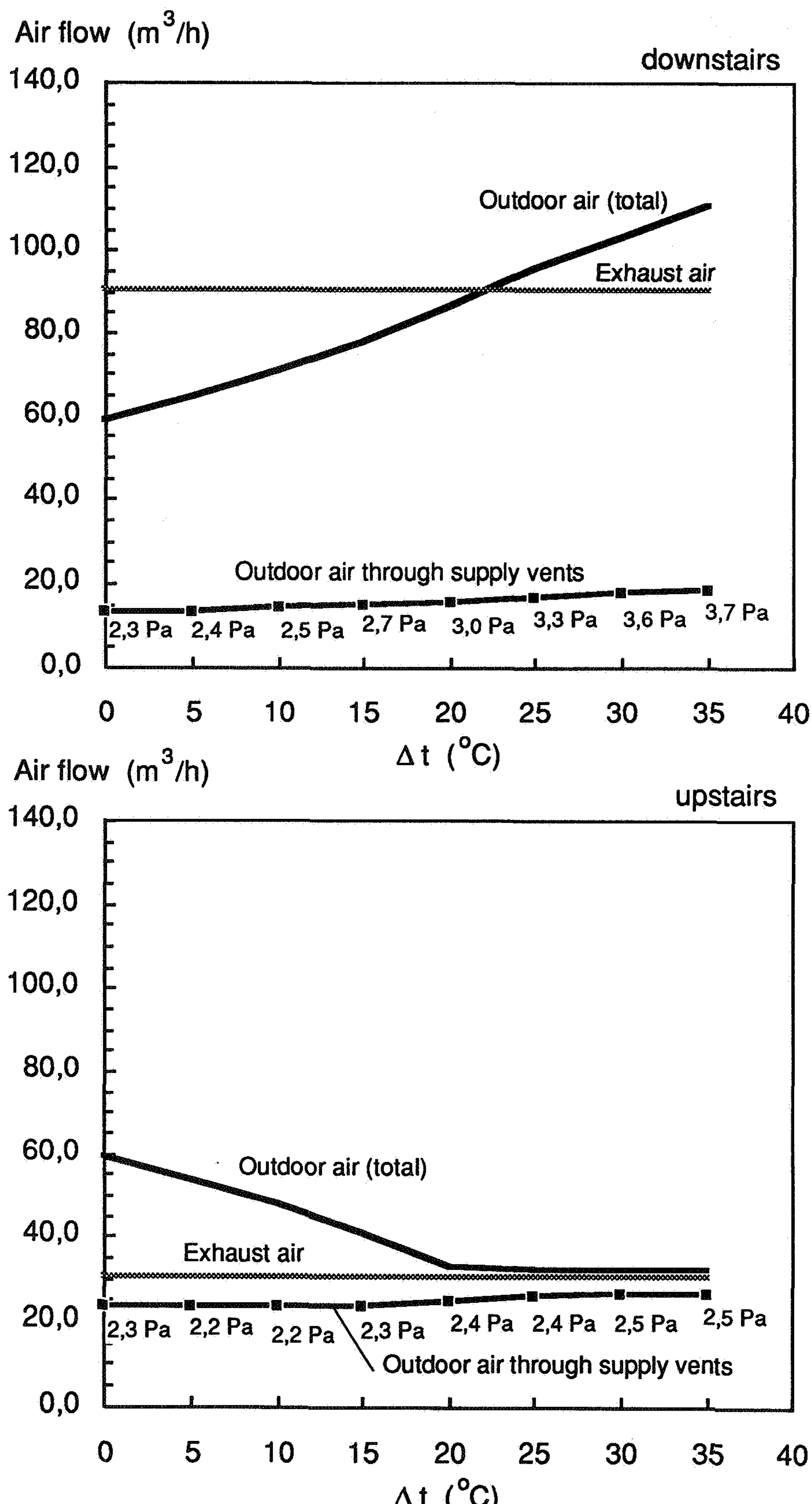


Figure 9. Predicted outdoor air ventilation rate as a function of inside-outside temperature difference, house no 14 downstairs and upstairs. For the supply vents the pressure drop is given. Airtightness = 2.2 ach at 50 Pa. Adjustment at 4 Pa. The supply vents upstairs are located 0.2 m above the floor level. Wind = 0 m/s.

6. CONCLUSIONS

The Lättbygg 85 houses had a correct distribution of air flows between the exhaust air terminal devices. One of the ideas behind the ventilation system in these houses was that the occupants should be able to control where the outdoor air enters the house. Vents which can easily be closed and opened were incorporated in the building envelope. Measurements and calculations show that although the two Lättbygg 85 houses tested are tighter than most modern houses only 1/3 of the air enters through the vents if all of them are open. The remainder of the outdoor air enters through whatever cracks or openings there are. If the cracks are located at floor level cold air can enter during the winter and impair the thermal comfort. An uneven distribution of cracks can cause an uneven distribution of outdoor air i.e. some rooms might get too little outdoor air.

For the least airtight house (2.2 air changes per hour at 50 Pa) the air is actually leaving the house through the supply vents in the bedrooms upstairs, when the outdoor temperature falls below the freezing point. The exhaust air flow was 0.35 air changes per hour. Raising the air flow lowers that critical temperature. It would therefore make sense to raise the fan speed to arrive at the stipulated 0.5 air changes per hour.

The mechanical ventilation rate in the Lättbygg 85 houses is controlled by the occupants (0.1 ach, 0.3 ach or 0.5 ach) and is therefore often below 0.5 ach. This increases the air exfiltration and makes the ventilation more sensitive to the influence of wind and temperature.

A reasonable level of outdoor air, upstairs in an airtight two-storey house, can be ensured by locating the supply vents upstairs close to the floor and the supply vents downstairs close to the ceiling. The outdoor air flow through the vents will then also be only marginally affected by the outdoor temperature. If the relocation of the supply vents is not possible, then in order to get at least transferred air to the rooms upstairs from the rooms downstairs exhaust air terminals can be installed in each room upstairs.

If more than 3/4 of the outdoor air is to enter through the the supply vents, then the airtightness of the building envelope must be better than 1.0 air changes per hour at 50 Pa. The adjustment of the supply vents should be done at a pressure difference of 4 Pa.

If the average air exfiltration during the heating season is to be lower than 5 % of the overall outdoor air ventilation, then the airtightness (incl. open supply vents) should be better than appr. 3.0 air changes per hour at 50 Pa.

The performance of an exhaust fan system is very much dependant upon the overall airtighness and the distribution of the airtightness of the building. Many existing modern houses are less airtight than the two houses tested i.e. only a small part of the outdoor enters through the supply vents and the direct supply of outdoor air to individual rooms is strongly affected by the natural driving forces. Most of the time there will probably be some air exchange in the individual rooms, but it will be a varying combination of outdoor and transferred air.

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