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The Choice of Airtightness and Ventilation System for Single Family Houses

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Introduction

Since 1973 research and development work has been going on in Sweden concerning the airtightness and ventilation of buildings. The rules of the Swedish Building Code (SBN 1975 and SBN 1980) have been made stricter regarding heat losses and include a stipulation that the intentional ventilation rate in occupied buildings should be 0.5 air changes per hour (ach). Regulations have also been established which specify a maximum airleakage of 3 ach at 50 Pa pressure difference. This airtightness has been reached by an increased construction cost of between 500 and 2000 Sw Kr per single family house. These rules and the production of more airtight houses has lead to the almost universal use of mechanical ventilation systems, although natural ventilation systems are still permitted. Approximately half of the domestic mechanical ventilation installations are exhaust air systems, some of which incorporate heat pumps for hot water. The remainder are balanced ventilation systems with heat exchangers. The total cost for a mechanical exhaust air system is approximately the same as that for a natural ventilation system; nevertheless, discussions on natural ventilation continue. However, proposed revisions to the Building Code are to include:

- stricter regulations for airtightness (≤ 1.0 ach at 50 Pa pressure difference).
- regulations for heat recovery in new houses which will bring the use of natural ventilation into question.

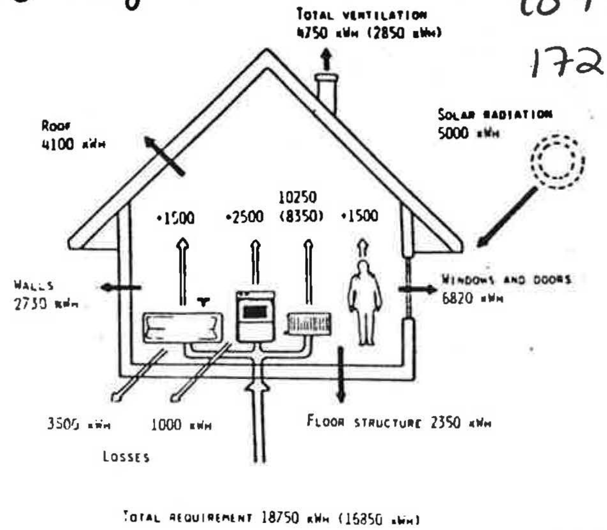

Figure 1. Heat balance at a total ventilation of 0.3 and 0.5 air changes per hour. The values within parentheses correspond to 0.3 ach

Basic knowledge seems to be insufficient in the field of building and ventilation technology. There is no total view of the balance of energy and no regard is paid to the interplay between different flows of energy.

Strongly varying information has been presented concerning airtightness, type of ventilation system, minimum air exchange rate and the technical as well as the economical consideration for heat recovery (Tables 1 and 2). Problems with moisture, mildew and rot are often reported for new houses and have therefore complicated the question.

This paper aims to present facts and ideas to improve cost effective design for airtightness and ventilation systems. Schematically alternative measures to save energy are presented. An investigation for determining the rate of ventilation in some occupied houses is described.

Table 1. Minimum air exchange rate

Depending on	m³/h per person	ach	Notations
Lack of oxygen	0,5		
Problems with CO and CO_2	10–15	0,1–0,2	4 persons, based upon the whole volume
		0.6–1,0	2 persons in a room with 12 m² floor area
Problems with moisture	4	0,2	5 persons in the house. Water vapour: 40 g/person/h and 150 g/h when cooking
Avoid condensation of water on window panes	7		
Unpleasant smell Laundry	5–40 ?	?	Room floor area 41–5 m²
Cooking (increased ventilation)		0,2–0,6	80–250 m³/h
Unacceptable content of poisonous gases			
–smoking	~20		Depending on room volume
–formaldehyde	?	?	
–radon		~0,3	Timber houses without basement
		~0,7	Timber houses with concrete-basement
		~1,0	Lightweight concrete houses

Measurements for determining the rate of ventilation/heat balance

The mean heat balance for a single family house situated in the south of Sweden is exemplified in Figure 1. Ventilation rate measurements were first made in 25 technically identical, timber framed, single family houses. Two of the houses incorporate balanced ventilation systems with air-to-air heat recovery and the remainder have mechanical exhaust ventilation. These houses were designed in accordance with the Swedish Building Code and have a volume of 320 m³ and a floor area of 155m².

The investigation included:

1. a) Airtightness measurements (pressurization test).

   b) Determination of the relationship between air change rate (tracer gas method) and airtightness at 50 Pa pressure difference.

2. Tracer gas measurements to determine:

   a) The unintentional ventilation

   b) The total ventilation for a mechanical ventilation rate of

      (i) ≈ 0.25 ach (SBN, recommended when houses are unoccupied)

      (ii) ≈ 0.50 ach (SBN, reccommended when houses are occupied)

      (iii) ≈ 1.00 ach (forced ventilation when cooking, etc.)

3. Measurements of airflow through exhaust air terminal devices for alternatives (i), (ii) and (iii). These measurements gave information about the intentional ventilation through the devices and ducts.

Table 2. Increase of production cost and energy conservation for different measures

Measure	Energy conservation kWh/year	Increase of production cost Sw.Kr.
Stricter requirements for air tightness from 3 to 1 changes per hour at 50 Pa	≤ 1000	3000–5000*
Balanced ventilation with heat exchange instead of exhaust air-system	1000–2000	8000
Heat pump using the exhaust air for domestic hot water	1000–2500	5000

*According to some factories only 500 Sw.Kr.

Results

When the mechanical ventilation rate in each of the 25 'identical' houses was set at 0.25 ach (unoccupied condition), the measured total ventilation averaged 0.29 ach (Figures 2 and 3). The minimum value was 0.12 and the maximum 0.50 ach. This difference is approximately equal to 4000 kWh per year in the south of Sweden. The fans in these houses operate with a small total pressure and are therefore sensitive to climatic variations, especially wind fluctuations.

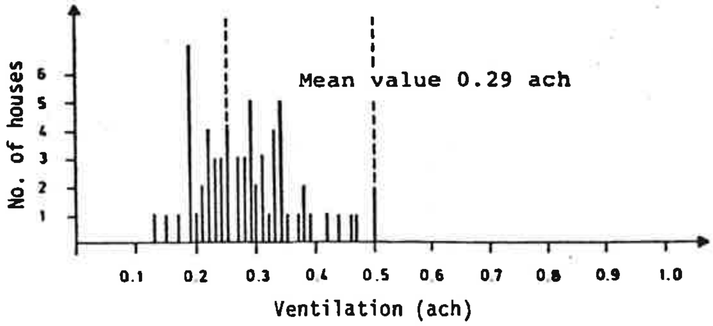

Figure 2A. Measured total ventilation (ach)

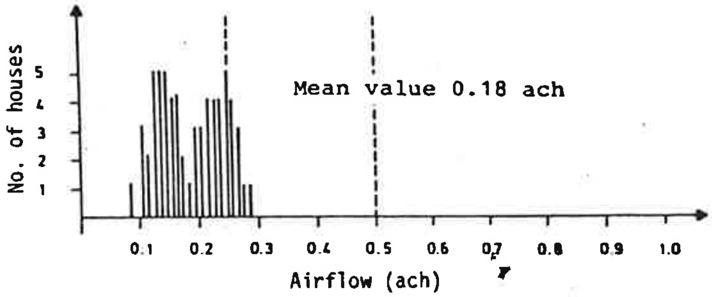

Figure 2B. Measured air-flow through the ventilation system (ach)

Similar measurements made in 5 more-recently constructed houses revealed a mean total ventilation rate of 0.22 ach with actual values ranging between 0.15 and 0.29 ach (Tables 3 to 5). This smaller difference corresponds to 1500 kWh per year in the south of Sweden and was mainly due to ducts with better airtightness and to more successful adjustment of the exhaust air terminal devices.

The measured air leakage at 50 Pa for the 25 'identical' houses varied between 2.6 and 7.4 ach, with a mean value of 4.7 ach. The unintentional natural ventilation averaged 0.14 ach, with measurements ranging between 0.05 and 0.42 ach.

For the five more-recently constructed houses, the corresponding air leakage at 50 Pa varied between 1.7 and 2.1 ach with a mean value of 1.8 ach. The unintentional natural ventilation averaged 0.05 ach with measurements varying between 0.04 and 0.07 ach.

The mean heat balance for the 30 houses is shown in Figure 1.

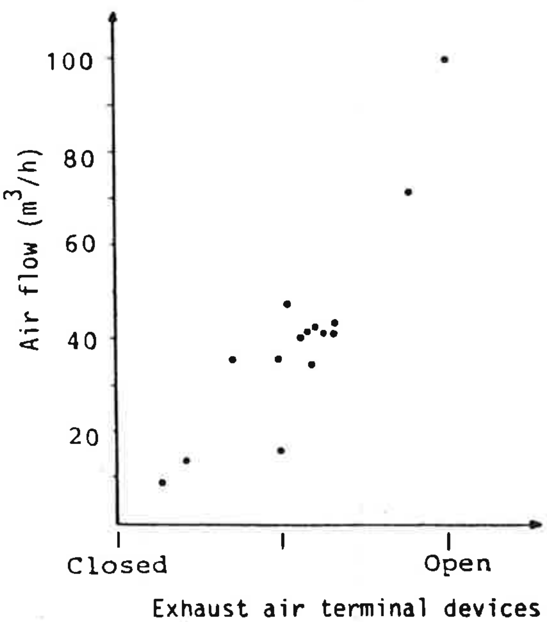

Figure 3. Recorded air-flow and adjustment of exhaust air terminal devices. The devices were presumed to have an air-flow of 50m³/h

Summary of observations

Differences in rate of ventilation between technically 'identical' houses mainly result from defective workmanship, which results in increased air leakage through the ducts, walls, roof and floor. Incorrect adjustment of the exhaust air terminal devices and insufficient job description and operating instructions to contractors and occupants will also contribute to the great differences.

The microclimate will also influence the rate of ventilation but to a lesser extent than the earlier mentioned factors. From the measurements it can be seen that all occupants are satisfied with a ventilation rate of ≈ 0.3 ach. However, a higher ventilation rate is needed when cooking or when several smokers are present in the house.

The indoor climate seems to be satisfactory if the ventilation system is working and there is sufficient air distribution between different rooms of the house.

Planning and production of new buildings, products and installations must be carried out carefully. Good design, appropriate building materials, suitable production conditions, conducive working environment and a satisfactory quality control are of great importance.

Airtightness and type of ventilation system

As previously mentioned, stricter regulations for airtightness are being discussed in Sweden. Such a decision must, however, be based upon technical and economic realities. The interplay between microclimate, unintentional and intentional ventilation, and type of ventilation system must be considered. Measurements and calculations made by Larm[6,9] (see also Figure 4), show that the total ventilation will be approximately 0.1 ach lower if the airtightness is 1 ach instead of 3 ach at 50 Pa. Our own investigation has given this result too.

Table 3. Airtightness at 50 Pa

House No.	Air leakage at 50 Pa			
	Positive pressure difference (m³/h)	Negative pressure difference (m³/h)	Mean value (m³/h)	Mean value (ach)
2	894	830	862	2.1
4	772	685	729	1.8
6	758	710	734	1.8
8	704	713	709	1.7
10	768	753	761	1.8

Table 4. Measured airchanges per hour (ach)

House No.	Unintentional ventilation 2a	Basic rate ~0,25 ach 2b(i)	Basic rate ~0,50 ach 2b(ii)	Forced ventilation 2b(iii)	Temperature °C Indoors	Temperature °C Outdoors
2	0.06	0.29	0.55	0.81	21.4	12.4
4	0.07	0.24	0.44*	0.90	17.4	10.0
6	0.04	0.15	0.43	0.92	19.5	12.3
8	0.05	0.21	0.52	1.08	19.0	16.4
10	0.04	0.24	0.51	0.89	20.8	7.4
					Wind velocity 0–2 m/s	

*The slot valves were closed during the measurement.

Table 5. Measured total ventilation (tracer gas method) and air flows through the exhaust air terminal devices (m³/h)

House No.	Unintentional ventilation	Basic rate ~0,25 ach		Basic rate ~0,50 ach		Forced ventilation	
		Total ventilation	Through the exhaust air terminal devices	Total ventilation	Through the exhaust air terminal devices	Total ventilation	Through the exhaust air terminal devices
2	25	120	67	227	185	335	301
4	29	99	74	182*	184	372	319
6	17	62	60	178	171	380	312
8	21	87	60	215	181	447	348
10	17	99	78	211	185	368	313

*The slot valves have been closed during the measurement.

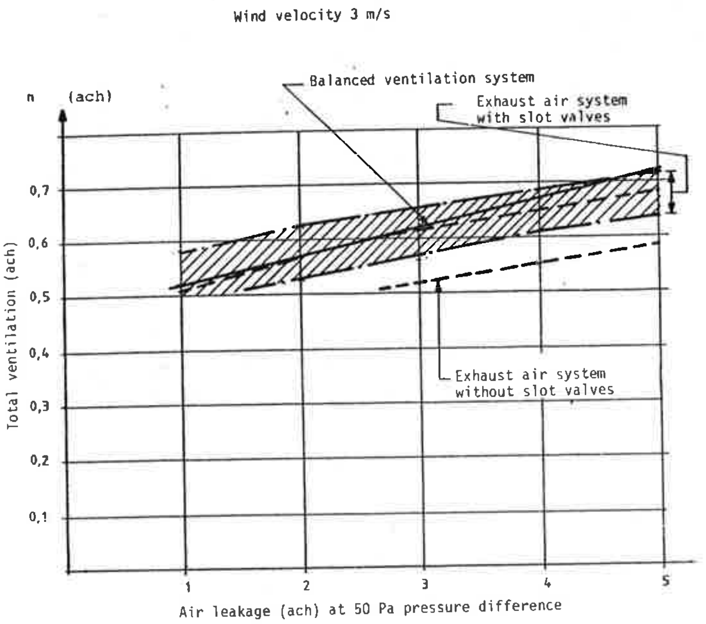

Figure 4. Total ventilation at different airtightnesses for balanced ventilation system and exhaust air system with or without slots

To achieve an airtightness of less than 1 ach at 50 Pa pressure difference, joints should, as a rule, incorporate sealants and adhesive tapes, possibly in combination with plastic sheeting. Sometimes, faults resulting in increased air leakage have been discovered after a few years. The durability and ageing properties have not been considered sufficiently. Movements in foundations and wood-based materials have also resulted in an increased air leakage.

The relationship between the rate of air flow and pressure difference is somewhat different for the building, its ventilation system (including devices and fans) and the supply air devices (slots) (Figure 5). For example, the capacity of the fan in an exhaust air system is sometimes so low that it is not capable of obtaining 0.5 ach if the occupants close the supply air slots. The positioning of ducts, devices and slots can result in a ventilation rate which is too low for the whole house or for individual rooms, in a vertical as well as horizontal direction.

The economical and technical arguments for a higher quality of airtightness than that corresponding to 3 ach at 50 Pa pressure difference are doubtful. However, a house with greater airtightness will result in a more effective mechanical ventilation system. Different airtightness rates will perhaps be necessary, depending on the type of ventilation system. Balanced ventilation systems with heat exchangers will probably require an airtightness of no more than 1 ach at 50 Pa pressure difference.

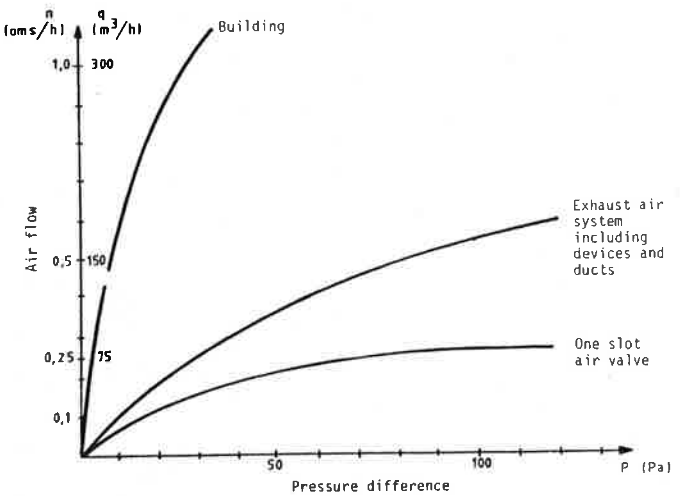

Figure 5. The relationship between air flow and pressure difference for the building, one slot, exhaust devices and ducts

From experience, mechanical exhaust air systems seem to be the most efficient type of ventilation system, from a total point of view. Natural ventilation systems seem to be dangerous in airtight houses. A combined ventilation and warm air heating system might be interesting but requires further research work.

Modified exhaust air systems

By adding an exhaust air terminal device in every room the cost will rise by about 500 Sw.Kr. Through this change of design the exhaust air system will be improved and the influence of slot air valves will be mainly eliminated. It will also be possible to save energy through a 'demand adjustment' of the ventilation system in different rooms and on different occasions. The ventilation efficiency will increase and the air change rate can probably be reduced for the whole house, Lögdberg[12].

Alternatively the exhaust air system can be complemented with a heat-pump for hot water. This seems to be an interesting technical and economical measure. Owing to the large possibilities of saving energy with this type of heat-pump, the design ought to also include space heating. This could be realized by a large radiator or water tube circuit around the external walls.

A new design for supply of fresh air through thin plastic tubes has been tested. This will make it possible to exclude slot air valves in windows and walls.

Conclusions

Research and development work concerning airtightness and ventilation should include projects which, in a few years, will be able to answer the following questions:

1. Different building materials, foundation and type of houses have varying ventilation requirements. Is it possible to reduce the air change rate from 0.5 to 0.3 ach in
   - prefabricated timber houses?
   - with or without basements?
   - houses built with light weight concrete?
2. How much energy can be saved by quality control, and by providing better job descriptions and operating instructions to contractors and occupants?
3. From technical and economic points of view, which measures are appropriate for higher airtightness and different types of ventilation systems? For example, modified exhaust air systems,
   - incorporation provision for space heating?
   - with exhaust air terminal devices in every room?
4. How much energy can be saved through a 'demand adjustment' of the ventilation system in such a way that good ventilation is obtained in those rooms where people spend longer periods?

Different measures and combinations of measures to save energy ought to be introduced in order to obtain the lowest total costs.

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All in Swedish except 11 and 12.

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Reminder

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