THE IMPLEMENTATION AND EFFECTIVENESS OF AIR INFILTRATION
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PAPER 13

THE INFLUENCE OF CLIMATE AND VENTILATION SYSTEM ON AIRTIGHTNESS REQUIREMENTS

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1. INTRODUCTION

Air infiltration typically accounts for a third of the energy loss in a heated building. The driving forces for natural air infiltration are wind and temperature differences. For a given combination of weather conditions the amount of air infiltration is determined by the character of the building envelope, mainly its airtightness. A useful technique in characterizing this housing quality is to measure air leakage. An air leakage standard for new construction has been in effect in Sweden since 1975. Pressurization, using a fan to measure air leakage, is performed routinely in checking new Swedish dwellings.

In addition to these shorter tests, long-term measurements of air infiltration have been made possible with the constant concentration tracer gas technique. An automated system working on that principle has been developed at the National Testing Institute. Results from constant concentration tracer gas measurements and fan pressurization measurements in three houses were used to study the influence of climate and ventilation system on airtightness requirements. A period of one year was examined using an air infiltration model developed at Lawrence Berkeley Laboratory.

2. TEST METHODS

In order to perform the measurements necessary for this paper, two methods were used: the pressurization technique and the tracer gas technique (1,2).

The pressurization technique was used to test envelope airtightness of the three houses. The procedure was the following:

A fan was mounted into the building envelope. The entire house was first pressurized and then depressurized (i.e. a differential pressure was established between the inside and the outside of the house). All vents that were part of the mechanical ventilation system were sealed off during the test and all other vents were measured separately. Using a flow meter, the air flow through the fan was determined. It can be assumed that this rate was equal to the air flow through the building envelope at the same time. A pressure flow rate profile was established for the house.

The tracer gas technique was used for measuring air infiltration for natural running conditions in the tested houses. Tracer gas, a gas normally not present in buildings, was injected into the house and the amount injected and the concentration were measured. A completely automated constant concentration tracer gas technique (3) was used.

The measurement system maintains a constant concentration of a tracer gas in nine rooms simultaneously. Tracer gas is injected into each room and the concentration is measured in each room. A target concentration is maintained. The system measures the supply of fresh air to each room, i.e. air that comes directly to the room from the outside without passing through another room. The result is given in m³/h directly without any estimation of the effective volume.

3. MODEL

The results were further examined using a mathematical model of air infiltration developed at Lawrence Berkeley Laboratory (1). The primary input to this model is the air leakage of the entire building envelope, which is given as an effective leakage area:

$$L = Q \sqrt{\frac{\rho}{2\Delta P}}$$

where Q is the airflow |m³/s|,
ΔP is the pressure drop across the building envelope |Pa|,
L is the effective leakage area |m²| and
ρ is the density of air |kg/m³|

Because the pressures driving infiltration are normally within a limited range (1 to 10 Pa), the effective leakage area is calculated for a pressure difference of 4 Pa.

The forces that drive infiltration are pressure differences across the building envelope caused by wind forces and by indoor-outdoor temperature differences. The stack-induced infiltration is calculated as follows:

$$Q_s = L\, f_s \sqrt{\Delta T}$$

where Q_s is the stack-induced infiltration |m³/s|,
f_s is the stack parameter $|m/(sK^{1/2})|$ and
ΔT is the inside-outside temperature difference |K|.

The stack parameter is given by the following expression:

$$f_s = \frac{(1+R/2)}{3} \left| 1 - \frac{X^2}{(2-R)^2} \right|^{3/2} \sqrt{\frac{gH}{T}}$$

where $R = \dfrac{L_{floor} + L_{ceiling}}{L_{tot}}$

$X = \dfrac{L_{ceiling} - L_{floor}}{L_{tot}}$

g is the acceleration of gravity $|m/s^2|$,
H is the inside height of the structure $|m|$ and
T is the inside temperature $|K|$.

The wind-induced infiltration is calculated as follows:

$$Q_W = L\, f_W\, v$$

where Q_W is the wind-induced infiltration $|m^3/s|$
f_W is the wind parameter |dimensionless| and
v is the wind speed $|m/s|$.

The wind parameter is given by the following expression:

$$f_W = C' \left| (1-R)^{1/3} \right| \left(\frac{\alpha \left(\frac{H}{10}\right)^{\gamma}}{\alpha' \left(\frac{H'}{10}\right)^{\gamma'}} \right)$$

where		
	C'	is the generalized shielding coefficient,
	α, γ	are terrain parameters at the structure,
	α', γ'	are terrain parameters at the site of the wind measurements,
	H	is the inside height of the structure $|m|$ and
	H'	is the height of the wind measurement $|m|$.

The air flow resulting from the two driving forces must be combined to arrive at the total infiltration. If the expressions for wind- and stack-induced infiltration are interpreted as effective pressure differences across the leakage area of the structure, the total infiltration can be determined by adding these pressures. If the flow is proportional to the square-root of the pressure, then two flows acting independently must add as follows:

$$Q_{tot} = \sqrt{Q_w^2 + Q_s^2}$$

This equation is useful for a structure without any specially designed ventilation system. Most Swedish one-family houses do however have unpowered vents or a mechanical ventilation system. Unpowered vents protrude beyond the envelope and should therefore not be included into the total leakage area. Their ventilation should be calculated separately (4).

The ventilation through the vents should be combined with the other flows using superposition:

$$Q_{tot} = \sqrt{Q_w^2 + Q_s^2 + Q_{vent}^2}$$

where Q_{vent} is the ventilation through the unpowered vents $|m^3/s|$.

If the house is equipped with an exhaust fan the same discussion as for an unpowered vent applies, i.e.

$$Q_{vent} = Q_{exhaust\ fan}$$

where $Q_{exhaust\ fan}$ is the rating of the fan $|m^3/s|$.

A balanced ventilation system should not affect the pressure drop across the envelope caused by natural driving forces. The fan flow can therefore simply be added to the natural ventilation:

$$Q_{tot} = Q_{fan} + \sqrt{Q_w^2 + Q_s^2}$$

where Q_{fan} is the rating of the fan $|m^3/s|$.

4. BUILDINGS

Three houses were tested. Each represents common residential constructions and ventilation systems.

Svaneholm: a one-family house built during the early sixties. It is a one-storey, 135 m² building with full basement. The external walls are made of pre-fabricated elements (0.3 m 1.2 m wide, 2.4 m high) each of which is a wood frame filled with cellulose filament. This kind of structure has a large number of vertical joints. The facade is brick with a vapour barrier consisting of tar-impregnated board. Heating is a hydronic system with an oil fired boiler. The furnace room was sealed off from the rest of the house during the tests. The house is ventilated without fans: air is exhausted through simple vertical ducts.

Borås: a 1 1/2-storey, 140 m² one family house with crawlspace. Built in 1977. It has a well insulated timber frame and a plastic air/vapour barrier. Heat is supplied by electric baseboard heaters. The ventilation system has an exhaust fan and air inlets in the exterior walls.

Skultorp: a one-storey house, 108 m² built in 1982. It has no basement but a crawl-space. It has a heavily insulated timber frame structure with a plastic air/vapour barrier. The ventilation system has both supply and exhaust fans. The house is heated by a warm air system.

5. RESULTS

The airtightness of the three houses are shown in table 1.

Table 1. Comparison of airtightness, number of air changes, with all vents sealed.

	Swedish Building Code	Built 1972 Svaneholm	Built 1977 Borås	Built 1982 Skultorp
Pressurization at 50 Pa, hr^{-1}:	3.0	5.0	4.8	1.1

For all three houses the ventilation rate of each individual room was monitored. There is quite a variation between different rooms for the Svaneholm house (5) i.e. fresh air coming directly into the room without passing through another room. This is a function of the ventilation system and the distribution of the envelope airtightness.

In the Borås house most rooms are adequately ventilated. The kitchen seem to be very poorly ventilated, i.e. hardly any fresh air comes directly into the kitchen. One of the bedrooms also has a very low ventilation rate, probably caused by too tight an exterior wall.

The Skultorp house has a ventilation rate which is almost constant with time (5). This is due to the fact that the ventilation system is coupled with a very tight building envelope. The ventilation rates of individual rooms depend on how well the ventilation system is adjusted.

In order to further examine these three houses during a complete year they were modelled using the LBL-model, as the measurements were taken only for a few days. The model was first applied to the houses for the same weather conditions as during the tracer gas measurements.

The results for the Svaneholm house showed a very close correlation between measurements and predictions (see fig. 1). The average measured value was 70.7 m^3/h and the predicted value 71.5 m^3/h. For the test period the model tracks the measured ventilation rate very well.

The results for the Borås house showed a discrepancy between model and real life. The model overpredicted by about 20 % (see table 2).

Table 2. Ventilation rates for the Borås house (air infiltration + exhaust fan ventilation) in m^3/h.

Measured	153	145
Predicted	176	181

For the Skultorp house the LBL-model overpredicts with 15 % (see fig. 2).

The size of the discrepancy between model and measurement is to be expected, when considering that the model is rather simple and that there are inaccuracies in the measurements as well.

Table 3. Parameter values used in the LBL-model.

House	Svaneholm	Borås	Skultorp
$L_{ceiling}$ (cm^2)	125	69	30
L_{floor} (cm^2)	0	72	30
L_{tot} (cm^2)	250	360	89
L_V (cm^2)	300/2	0	0
α	0.85	0.67	1.0
γ	0.20	0.25	0.15
C'	0.185	0.185	0.24
C_V	0.2	0	0
H (m)	3.0	5.0	2.4
H_V (m) is the height of the vent	4.0	0	0
T (°C) is the indoor temperature	22	20	20
$Q_{exhaust\ fan}$ (m^3/h)	0	159	20
Q_{fan} (m^3/h)	0	0	126

The model was used to predict the ventilation rates for each of the houses during one sample/year in the same city. Hourly weather data for Stockholm was used. With all windows closed, the Svaneholm house (unpowered vents) never reached the required minimum ventilation rate of 0.5 ach (155 m^3/h). Its monthly average ventilation rate varies very much (see fig. 3). The lowest values were for July and August (0.14 ach); the highest were for November and January (0.26 ach).

The Borås house (exhaust fan) had an almost constant ventilation rate of 0.52 ach (see fig. 4). Its lowest monthly average value was 0.48 ach and; highest was 0.56 ach.

The Skultorp house (balanced ventilation) had a constant ventilation rate of 0.60 ach (see fig. 5). The lowest monthly average value was 0.59 ach; the highest was 0.62 ach.

6. DISCUSSION

To evaluate the performance of the tested houses the ventilation rates were analyzed and the energy losses caused by air infiltration calculated using weather data from Stockholm. All changes in air tightness were proposed, based on calculations using the LBL-model.

The Swedish building code specifies a required minimum ventilation rate of 0.5 ach. The Svaneholm house with unpowered vents, never reaches this level unless windows are opened. The energy loss caused by ventilation is 2550 kWh for one heating season. If the house is to reach the minimum required ventilation rate during the heating season the effective leakage area must be increased from 250 cm² to 650 cm² (from 5.0 ach to 13.0 ach at 50 Pa). This would increase the energy loss to 5350 kWh, an energy loss which is hard to recover.

The Borås house meets the required minimum ventilation rate during most of the year. The energy loss caused by ventilation is 6350 kWh for one heating season. An exhaust air heat pump could be installed which would reduce the heat loss to only the loss due to the natural air infiltration, i.e. 1050 kWh. If we assume that this number should be below 500 kWh, the effective leakage area should be reduced from 360 cm² to 200 cm² (4.8 ach to 2.7 ach at 50 Pa).

The Skultorp house exceeds the minimum required ventilation. The natural air infiltration is very small. With no heat recovery the energy loss from ventilation is 5250 kWh. If "all" heat from the exhaust air could be recovered the heat loss from ventilation i.e. from natural air infiltration would be 400 kWh. The ventilation system should be optimized and adjusted to 0.5 ach.

7. CONCLUSIONS

Three typical Swedish one-family houses were examined, each with a different type of ventilation. If doors and windows were closed the one-family house with unpowered vents (airtightness of 5.0 ach at 50 Pa) would be inadequately ventilated all year around, although the house was not as tight as required by the Swedish Building Code. The ventilation rate for the summer was also very low. Airing during most of the year is hard to control, and means additional energy consumption. In summer it presents less of a problem, for people can easily be expected to open their windows to get fresh air.

The one-family house with an exhaust fan ventilation system (airtightness of 4.8 ach at 50 Pa) was adequately ventilated during most of the year. The heat loss caused by air infiltration could be reduced by making the house tighter, i.e. bringing it below the required level of 3.0 ach at 50 Pa.

The one-family house with a balanced ventilation system (airtightness of 1.1 ach at 50 Pa) was adequately ventilated all year although it is tighter than required. The heat loss from natural air infiltration was sufficiently low. The ventilation rate could be lowered to 0.5 ach by adjusting the fans.

In different climates,the above total ventilation rates and heat loss rates caused by air infiltration would be different, requiring different air tightness levels.

The best way of both supplying adequate ventilation and conserving energy is to insure that the building envelope is sufficiently tight and then install a mechanical ventilation system. To control the year round conditions the system should either be a balanced type or the exhaust air type with special vents to the outside for supplying fresh air.

8. REFERENCES

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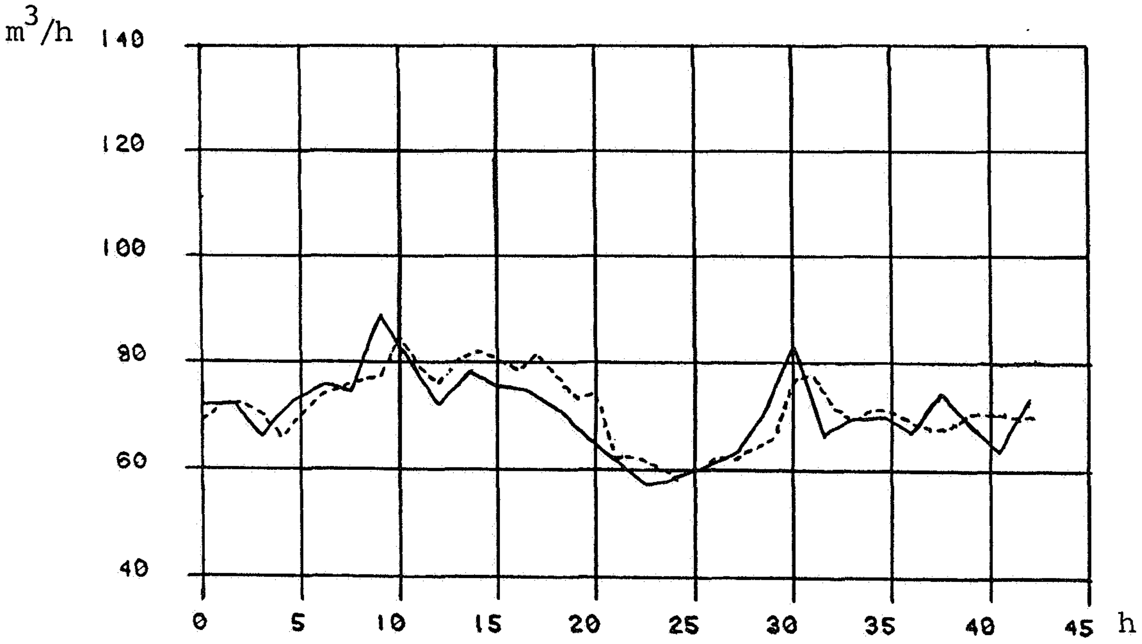

Fig. 1 Measured ventilation rate vs. predicted ventilation rates for the Svaneholm house (air infiltration + unpowered vent ventilation)

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——— measurement

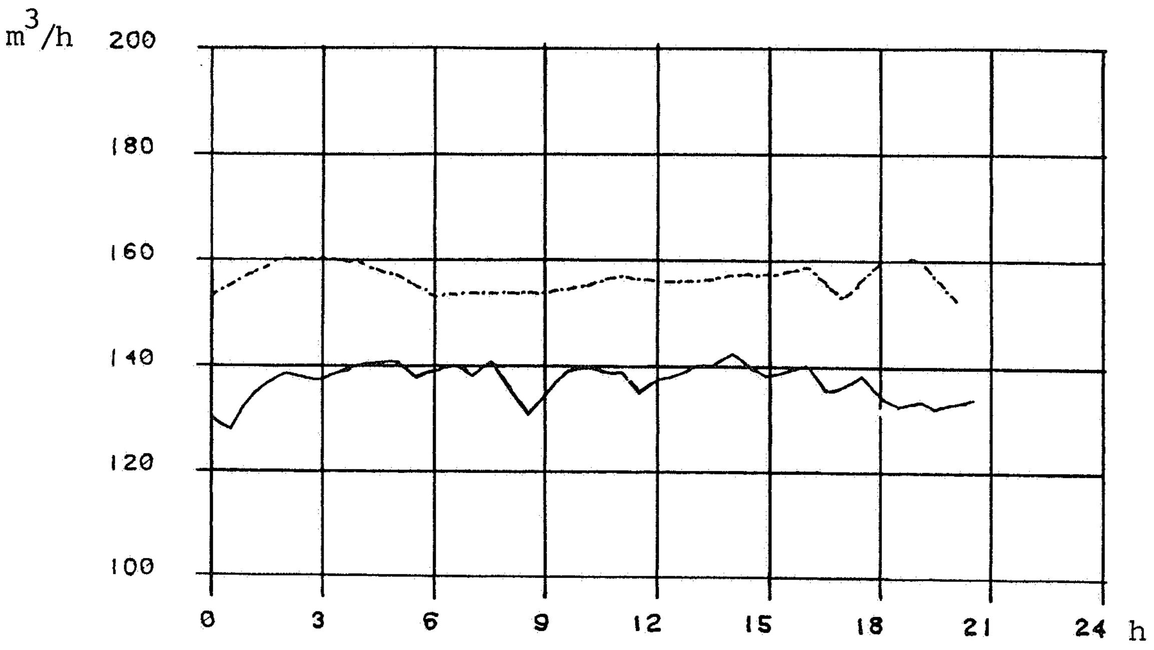

Fig. 2 Measured ventilation rate vs. predicted ventilation rate for the Skultorp house (air infiltration + balanced ventilation)

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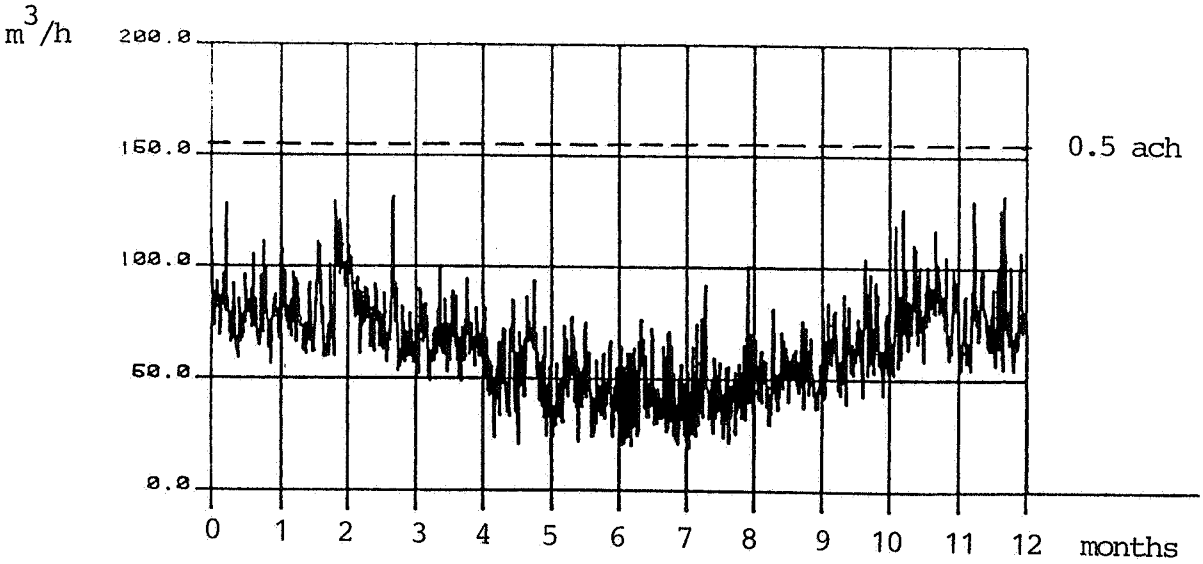

Fig. 3 Predicted ventilation rates for the Svaneholm house (air infiltration + unpowered vent ventilation)

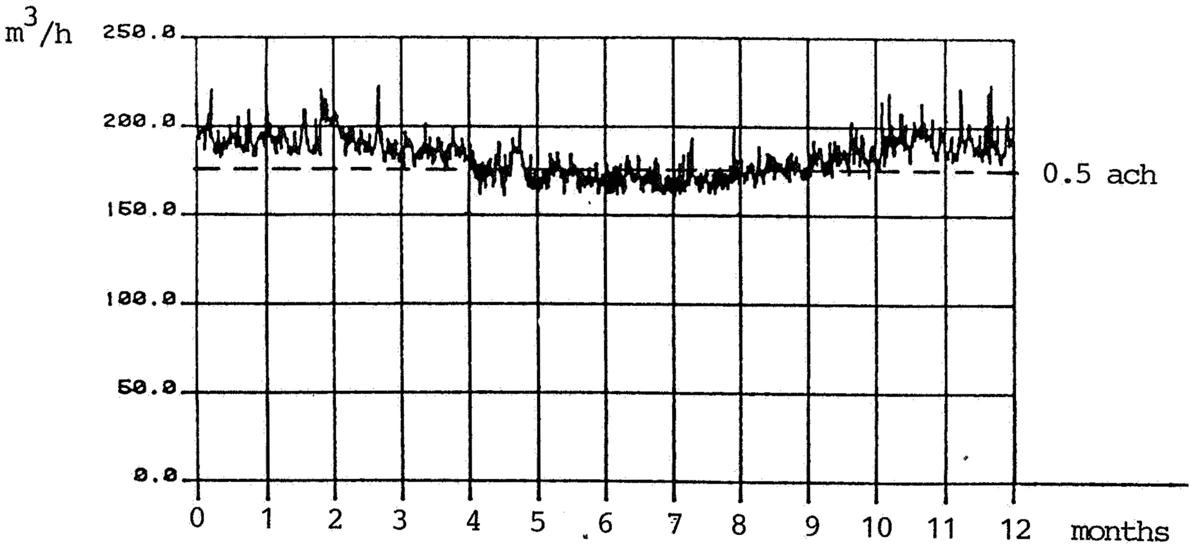

Fig. 4 Predicted ventilation rates for the Borås house (air infiltration + exhaust fan ventilation)

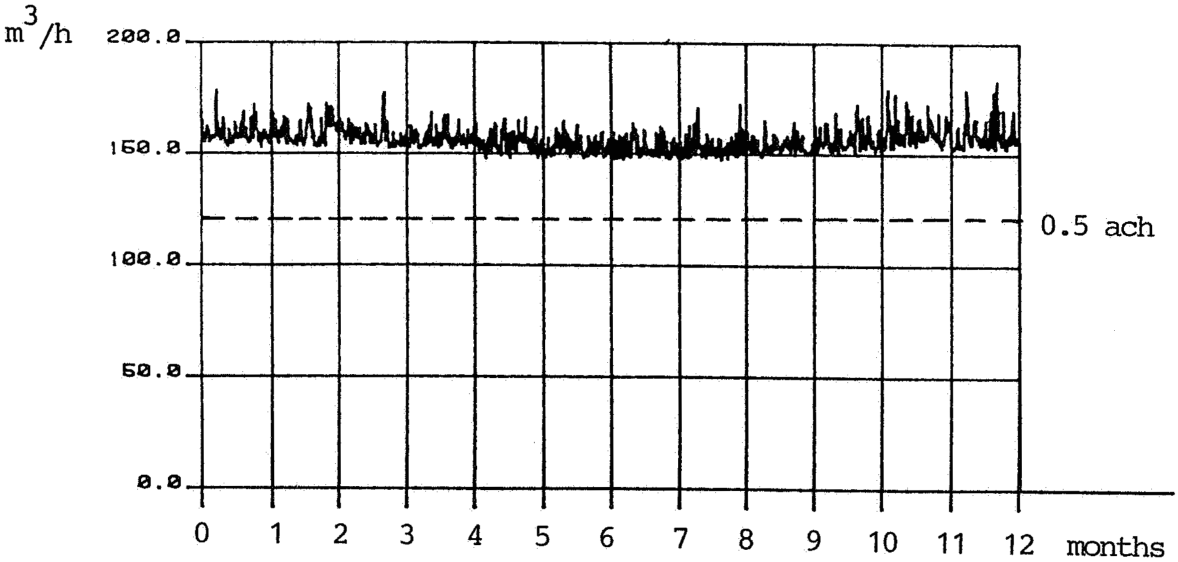

Fig. 5 Predicted ventilation rates for the Skultorp house (air infiltration + balanced ventilation)