PROGRESS AND TRENDS IN AIR INFILTRATION
AND VENTILATION RESEARCH

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Paper 17

THE PERFORMANCE OF RESIDENTIAL VENTILATION SYSTEMS

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1. SYNOPSIS

The indoor climate and ventilation were measured in 50 dwellings with various ventilation systems. The health and comfort of people living in the dwellings were studied with a simultaneous questionnaire. The ventilation rates measured with a tracer gas using the decay method varied from 0.1 to 1.2 m^3/hm^3, with an average of 0.5 m^3/hm^3. The ventilation rate in the bedroom was usually lower than the mean ventilation rate of the dwelling. The ventilation rates measured in a two-week period with the passive perfluorocarbon method varied from 0.2 to 1.9 m^3/hm^3, with an average of 0.8 m^3/hm^3.

There was a statistically significant correlation between the ventilation rate and the typical sick building symptoms expressed by people living in the dwellings. When the ventilation rate was low (below 0.3 m^3/hm^3), people had more symptoms than when the ventilation rate was high (above 0.6 m^3/hm^3). No such correlation was found between the various ventilation systems and health.

2. INTRODUCTION

People spend most of their time in residential buildings. Ventilation has an effect on the indoor air quality and people's health and satisfaction with the indoor climate. Residential buildings are often criticised for having poor ventilation, yet little information is available on the operation of various ventilation systems in practice. The aim of the study was to gather information on ventilation in residential buildings and compare ventilation systems in respect to health and satisfaction. 50 residential buildings were selected for the study, in which the operation of the ventilation system and the indoor climate parameters were measured.

3. METHODS

The sample consisted of 28 residences in detached or semi-detached houses and 22 apartments in the Helsinki area. The ventilation systems were: natural ventilation, mechanical exhaust and balanced ventilation. The measurements were carried out during the 1987-88 heating season and they covered the ventilation rates in each room, the carbondioxide concentration, the dust concentration, the level of noise from the ventilation system and the thermal climate. The ventilation rates were measured by the tracer gas technique using both the decay method and the passive perfluorocarbon method. The ventilation rate was estimated as the inverse value of the nominal time constant.

A questionnaire on health, comfort and satisfaction was carried out with the measurements. People living in the dwellings were asked whether they had had any of the following symptoms during the last two months: skin, eye, nasal or respiratory symptoms, fatigue or headache. A summation score was calculated from the perceived symptoms as in previous studies [1, 2, 3]. The scale of the summation score of symptoms was from 0 (no symptoms) to 6 (suffering from all six types of symptoms).

4. RESULTS OF THE MEASUREMENTS

4.1. Ventilation rates in dwellings

The ventilation rates measured with a tracer gas using the decay method varied from 0.1 to 1.2 m^3/hm^3 when the ventilation systems were in normal operation, i.e. as they were operated most of the day [4]. The average was 0.5 m^3/hm^3. In over half of the dwellings the ventilation rate was between 0.3 and 0.6 m^3/hm^3. The distribution of the mean ventilation rate is shown in Figure 1.

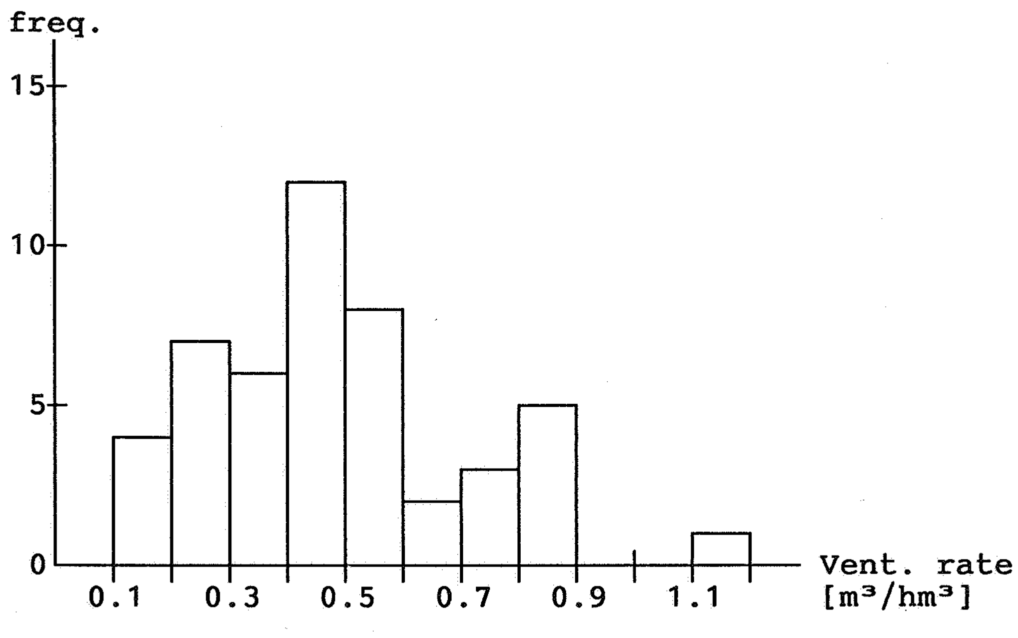

Figure 1. Measured mean ventilation rates in the dwellings.

The difference in the mean ventilation rates was not great between the various ventilation systems. The dwellings with natural ventilation had on average lower ventilation rates than the dwellings with mechanical ventilation. In these 15 dwellings the average ventilation rate was 0.40 m^3/hm^3. In the dwellings with mechanical exhaust (18 dwellings) the average ventilation rate was 0.55 m^3/hm^3. The lowest ventilation rates were usually in the dwellings where a mechanical ventilation system was installed but operated only during cooking and bathing, i.e. it was most of the time out of operation. In dwellings with balanced ventilation (17 dwellings) the average ventilation rate was 0.50 m^3/hm^3. The mean ventilation rates of the dwellings with various ventilation systems are shown in Figure 2.

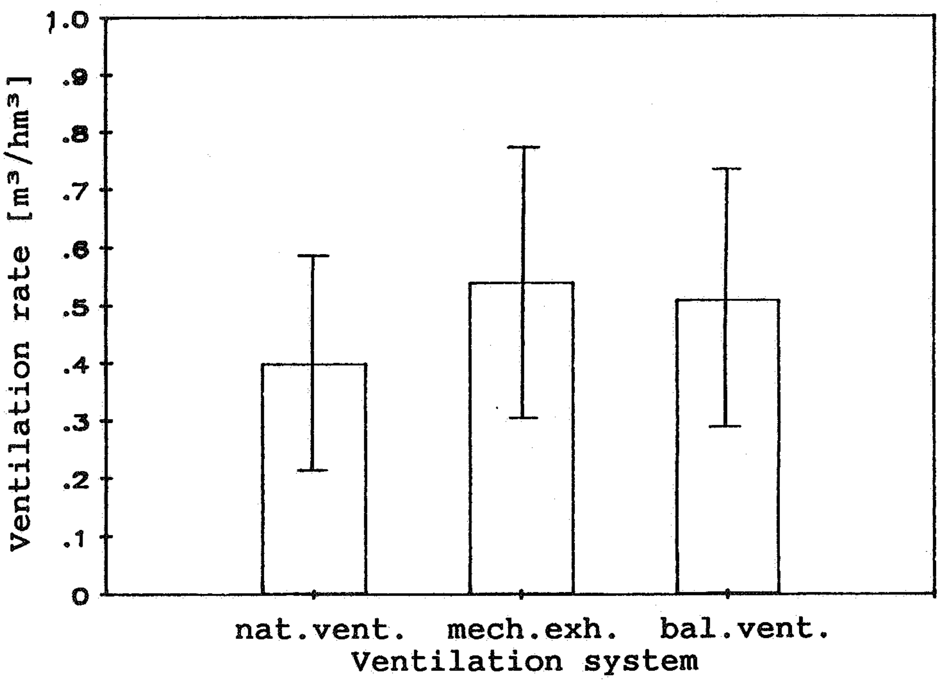

Figure 2. Measured mean ventilation rates and standard deviations in the dwellings.

4.2. Ventilation rates in bedrooms

The ventilation rate in the bedroom was usually lower than the mean ventilation rate of the whole dwelling. Closing the bedroom door especially decreased the ventilation rate if air was not supplied to the bedroom. On average the highest ventilation rate was in the bedrooms with balanced ventilation. On average the lowest ventilation rate was in the bedrooms with natural ventilation. The ventilation rate was most evenly distributed in the dwellings with mechanical air supply to each room. The mean ventilation rates of the bedrooms with various ventilation systems are shown in Figure 3 and the correlation between the ventilation rate of the bedroom and the mean ventilation rate of the dwelling is shown in Figure 4.

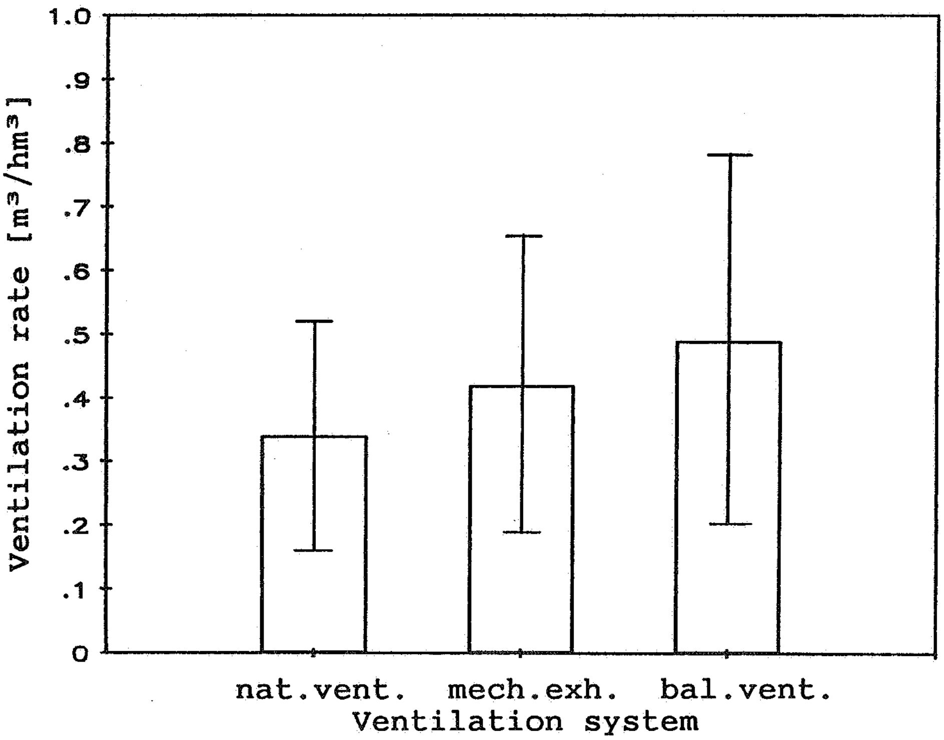

Figure 3. Measured mean ventilation rates and standard deviations in the bedrooms.

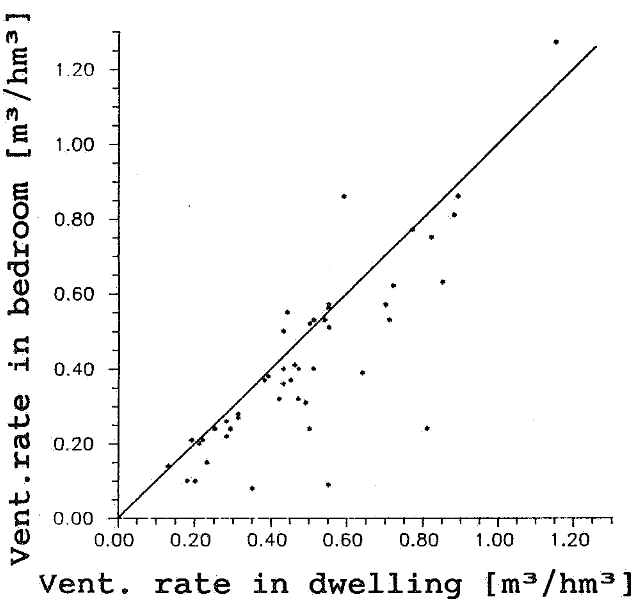

Figure 4. The correlation between the mean ventilation rates of the dwellings and the ventilation rates in the bedrooms.

4.3. Long term ventilation rates

The ventilation rates measured with the passive perfluorocarbon method varied from 0.2 to 1.9 m^3/hm^3, with an average of 0.8 m^3/hm^3 [5]. During the two-week period people lived normally and used the ventilation system and windows as usual. In these measurements the differences in the mean ventilation rates were not great between the various ventilation systems, being less than 0.2 m^3/hm^3. The distribution of the mean ventilation rate measured by the PFT-method is shown in Figure 5.

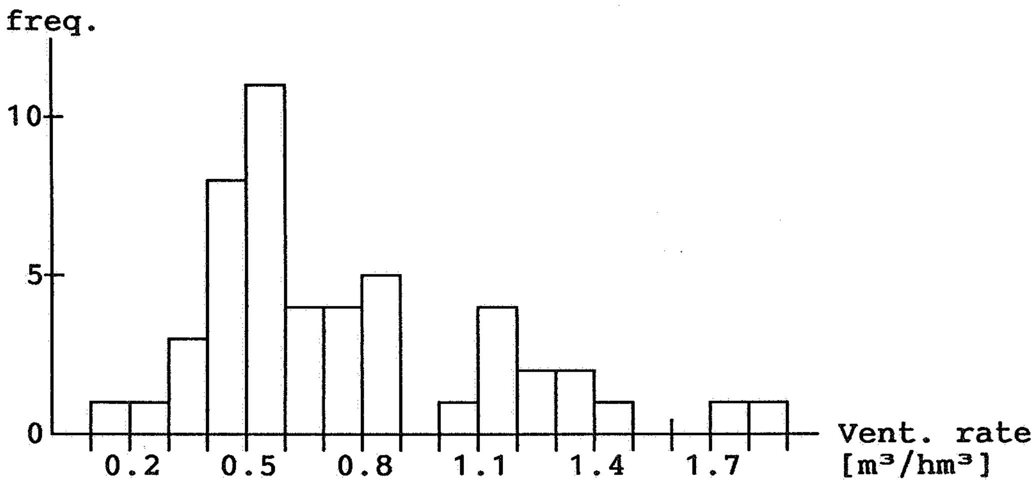

Figure 5. The mean ventilation rates in the dwellings measured by the PFT-method in a 2-week period.

The ventilation rate measurements using the passive perfluorocarbon technique were carried out twice in spring 1988. The mean ventilation rates in the second period (in April) were on average lower than in the first period (in January). The averages were 0.78 m^3/hm^3 (first period) and 0.61 m^3/hm^3 (second period). Airing and outdoor temperature may explain the difference between these two periods. The outdoor temperature was 7 °C higher in the second period (-3 ° and +4 °C). The differences between these two periods are shown in Figure 6.

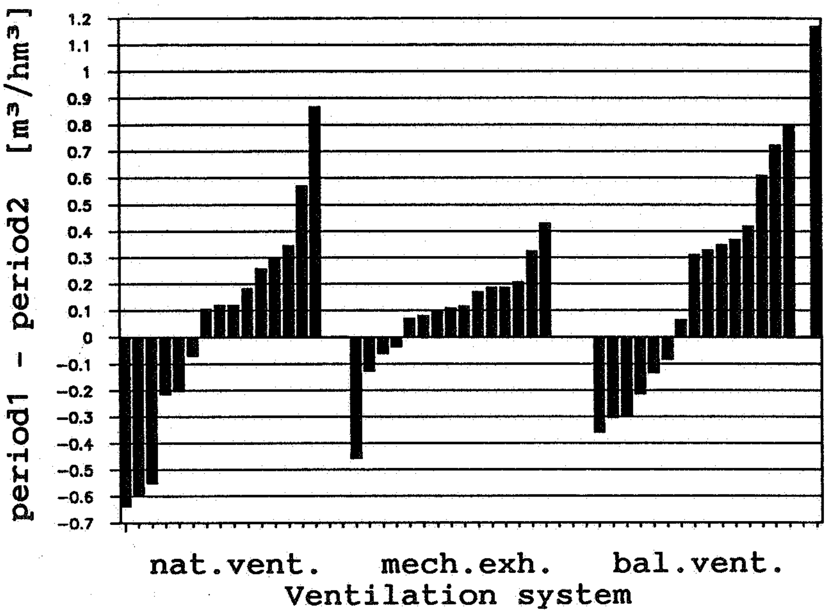

Figure 6. The differences in the mean ventilation rates between two measuring periods.

The ventilation rates measured with the PFT-method were higher than those measured with the decay method. The averages were 0.78 m^3/hm^3 (PFT-method) and 0.49 m^3/hm^3 (decay method). In the decay measurements the ventilation fans ran at normal capacity and the windows were closed. The differences between these two methods are shown in Figure 7.

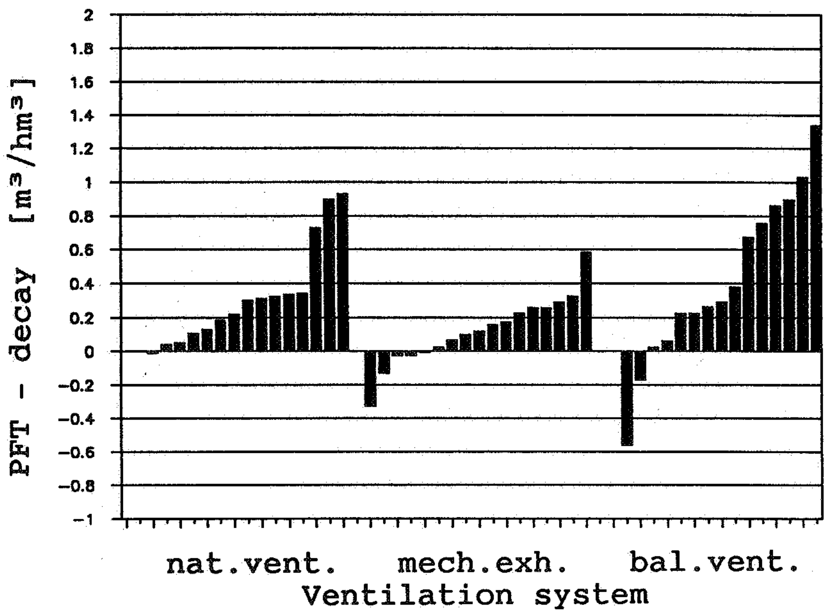

Figure 7. The differences in the ventilation rates between the PFT and decay methods.

4.4. Carbondioxide concentration

The steady-state carbondioxide concentrations measured at night in master bedrooms varied from 500 to 3700 ppm with an average of 1300 ppm. Typically two adults slept in the bedrooms. The difference in the CO_2-concentration was not great between the various ventilation systems. The distribution of the CO_2-concentration is shown in Figure 8.

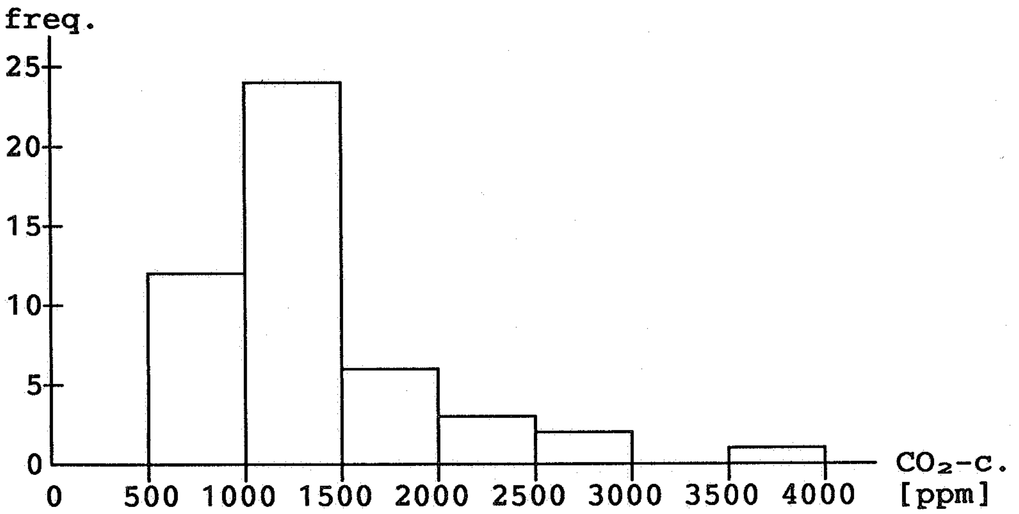

Figure 8. Measured steady-state carbondioxide concentrations during the night in master bedrooms.

4.5. Dust concentration

Dust concentrations in the dwellings were measured using the deposition method: a dust sample passively collected settling dust on a greasy surface. Measured dust concentrations were collected in bedrooms on a horizontal plane at a height of approximately 1.4 m for 100 hours. The dust concentrations varied from 7 to 70 µg with an average of 20 µg. In the dwellings with natural ventilation the dust concentrations were on average lowest. In the dwellings with balanced ventilation the dust concentrations were on an average highest. But the differences were small. The highest separate dust concentrations were also in the dwellings with mechanical ventilation. The people living in the dwellings and their activities influence the dust concentration more than the ventilation system and the ventilation rate. The dust concentrations in the bedrooms with various ventilation systems are shown in Figure 9.

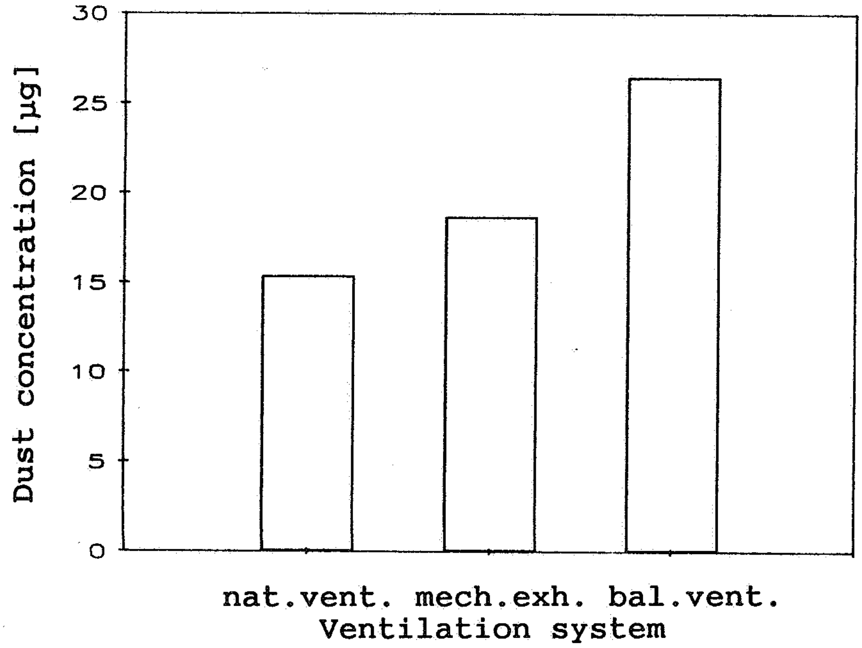

Figure 9. Measured dust concentrations in the bedrooms.

5. RESULTS OF THE QUESTIONNAIRE

5.1. Ventilation

The people living in the dwellings felt that the most common defects of the ventilation in the heating season were the non-uniform air-exchange in the dwelling, and the fact that they were not able to control the ventilation system. Some people also felt that the ventilation system caused noise and draught.

Almost one third were dissatisfied with the ventilation system during the heating season. Most dissatisfied were the people living in the dwellings with natural ventilation (half). The people living in the dwellings with mechanical ventilation were generally more satisfied with the ventilation.

There were differences in airing habits between the ventilation systems. In the dwellings with natural ventilation people aired more often than in the dwellings with mechanical ventilation. The proportion of people who seldom aired was biggest in the dwellings with balanced ventilation.

5.2. Ventilation and symptoms

A statistically significant correlation was found between the measured ventilation rate and the summation score of symptoms (chi-square test: $p < 0.01$). When the average ventilation rate in a dwelling was below 0.3 m^3/hm^3, people expressed several symptoms. When the ventilation rate was above 0.6 m^3/hm^3, people expressed only few or no symptoms. The connection between the ventilation rate and the summation score of symptoms is shown in Figure 10.

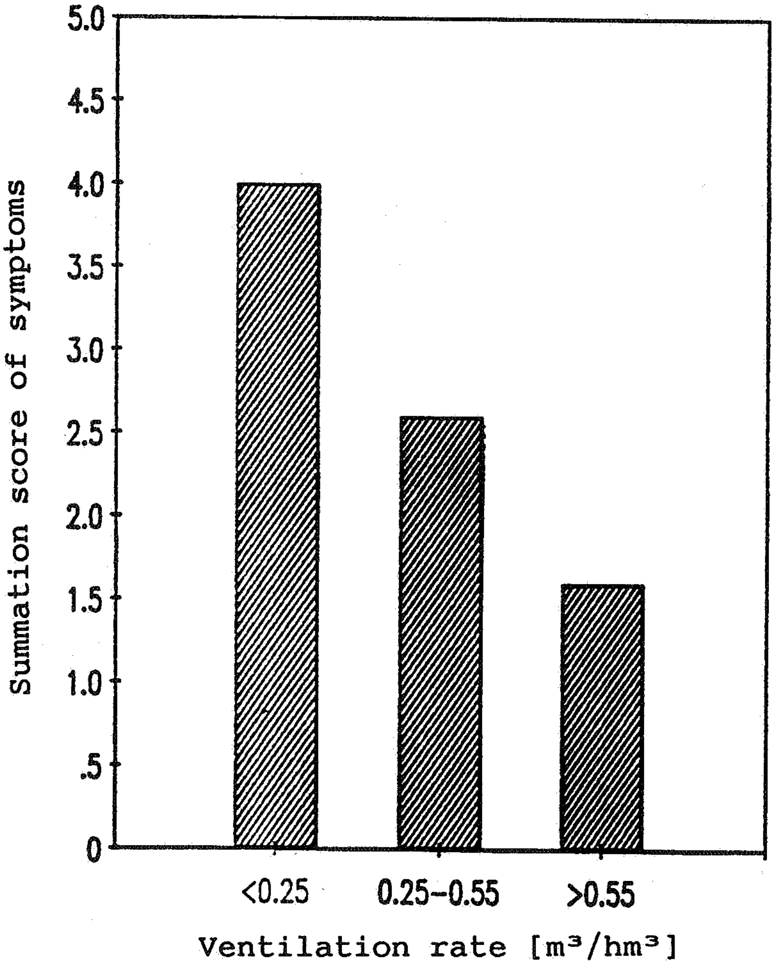

Figure 10. The connection between the ventilation rate and the average of the summation score of symptoms (n = 98).

A correlation was also found between common colds and the measured ventilation rate. When the ventilation rate was above 0.5 m^3/hm^3, 25 % of the people living in the dwellings had flu more often than once a year; when the ventilation rate was below 0.3 m^3/hm^3, the percentage was 60.

A correlation was also found between the sensation of sufficient ventilation and the ventilation rate ($p < 0.05$). When the ventilation rate was low (below 0.3 m^3/hm^3), the majority of the people often felt the ventilation in the bedroom insufficient. When the ventilation rate was high (above 0.6 m^3/hm^3), the majority of the people felt the ventilation in the bedroom was usually acceptable.

A statistically significant correlation was found between the steady-state carbondioxide concentration during the night and the sensation of the freshness of the air ($p < 0.01$). When the CO_2-concentration was below 1000 ppm, the majority of the people did not feel the air was stuffy. When the CO_2-concentration was above 1500 ppm, the majority of the people felt the air was stuffy sometimes or often.

The summation score of symptoms did not correlate with the ventilation system, i.e. the values of the summation score were distributed randomly within three ventilation systems.

6. DISCUSSION

The ventilation rates of dwellings vary a lot. The ventilation rates in the bedrooms are often too low, although people spend much of their time in the bedroom.

The ventilation rate of a dwelling has an effect on health. A low ventilation rate increases the number of the symptoms expressed by people; and the number of symptoms decreases as the ventilation rate increases. No statistically significant correlation was found between various ventilation systems and the number of symptoms expressed by people.

A sample of 50 dwellings is relatively small, so in order to increase the statistical reliability the study is to be expanded to cover a larger group of dwellings. People's satisfaction with the ventilation and the effect of the ventilation and heating systems on their health and comfort is being studied with a questionnaire mailed to over 2000 dwellings with ventilation systems similar to those in this study. 300 of these dwellings have been selected for detailed analysis during the 1988-89 heating season. The analyses of these measurements will be complete by the end of 1989.

7. REFERENCES

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4. Ruotsalainen, R., Majanen, A. The performance of ventilation in some experimental residential buildings (in Finnish). Espoo 1987. Univ. of Tech., HVAC-lab. 103 p.

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Discussion
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Peter Jackman (Building Services Research & Information Association, UK)

If the lowest ventilation rates occurred in those houses where the mechanical ventilation was switched off, how do you explain the fact that people were prepared to put up with unpleasant symptoms when they could have been alleviated simply by turning on the ventilation system?

R. Ruotsalainen (University of Technology, Helsinki)

People do not realize that the ventilation rate really has an effect on symptoms and comfort. Also they do not always know how the ventilation systems are designed to be operated.

Mike Holmes (Ove Arup, London, UK)

You said that you measured noise. Is there any evidence that people prefer to switch the system off and suffer the consequences of a low air exchange rate rather than live in a noisy environment?

R. Ruotsalainen (University of Technology, Helsinki)

The noise of the ventilation was not a major reason to turn off the mechanical ventilation system. Approximately 10% of people expressed that ventilation causes noise.

Willigert Raatschen (Dornier GmbH, Germany)

You showed the comparison between PFT results and tracer gas decay results. There was a very poor agreement. Are PFT's not reliable or did you compare average values with point measurements?

R. Ruotsalainen (University of Technology, Helsinki)

The measurements with the decay method are point measurements and the measurements with the PFT-method are average values during a 2-week period. The ventilation rates measured with the PFT-method were in average 0.3 ach higher than measured with the decay method. The main reasons for this were that during the decay measurements the ventilation systems were in normal operation and windows were closed. So the agreement was not so poor.

Jorma Heikkinen (Technical Research Centre, Finland)

What do you mean by ventilation rate in a bedroom? Is it the air coming from outside or does it include the air flow from other rooms?

R. Ruotsalainen (Technical University of Helsinki)

The ventilation rate in the bedroom includes both the air flow from outside and the air flow from other rooms.

N. Bergsoe (Danish Building Research Inst.)

What were the criteria for selecting houses and apartments?

R. Ruotsalainen (University of Technology, Helsinki)

We selected some dwellings from blocks of flats and from small houses; and from these two groups we selected the same amount of dwellings with three different ventilation systems.

David Hill (Eneready Products Ltd, Canada)

Health and air change correlated.

Health and ventilation technology independent.

Can you correlate occupancy and ventilation in M^3/hr (not ach)

R. Ruotsalainen (University of Technology, Helsinki)

When the outdoor air flow rate per person was below 7 l/s person, 66% of people expressed several symptoms. When the outdoor air flow rate per person was above 11 l/s person, only 22% of people expressed several symptoms.

Martin Liddament (AIVC, UK)

I am very interested in your presentation on the performance of residential ventilation systems. I would be pleased if you could supply the following additional information.

Average CO_2 concentration	?	?	?
Average dust concentration	?	?	?
Cold symptoms	60%	?	25%
Ventilation rate	<	>	
	.3m²/hm³ .6m³/hm³		

Also how many tracer decay measurements were made in each dwelling?

Risto Ruotsalainen (University of Technology, Helsinki, Finland)

Here are the average values you asked, shared by the ventilation rates. In each of the 50 dwellings was made one measurement using the decay method.

VENTILATION RATE (ach)	<0.3	0.3-0.5	>0.5
Several sick building symptoms (3-6) (%)	65	55	20
Common cold more often than once a year (%)	60	40	25
Dust concentration (μg)	14	24	21
Steady-state CO_2-concentration (ppm)	1800	1200	1300