INVESTIGATIONS ON AIR CHANGE AND AIR QUALITY IN DWELLINGS

Niels C. Bergsoe
Danish Building Research Institute
Indoor Climate Division
Postbox 119
DK 2970 Denmark

ABSTRACT

Using passive sampling techniques, including a passive sampling, multiple tracer gas technique (the PFT-technique), the Danish Building Research Institute has performed field measurements in about 130 dwellings. The dwellings comprised detached, naturally ventilated single family houses and single family houses and flats ventilated with exhaust ventilation systems. The object of the measurements was, in each of the types of dwellings, to determine the level of the outdoor air exchange rate, the level of the relative humidity and the level of the concentration of organic vapors in the indoor air. Also a simple questionnaire was elaborated in order to obtain information on the occupants and their airing habits.

The average outdoor air exchange rate in dwellings equipped with mechanical exhaust systems was found to be approximately 0.5 [h^{-1}]. Naturally ventilated dwellings had an average outdoor air exchange rate of about 0.35 [h^{-1}]. The relative humidity was in average just below 45 pct. both in mechanically and naturally ventilated dwellings. Neither the relative humidity nor the concentration of organic vapors showed any correlation with the outdoor air exchange rate.

1. INTRODUCTION

Quantification of the ventilation is important as both the energy consumption and the internal environment of a dwelling are being affected. Excessive ventilation may lead to energy wastage and insufficient ventilation may cause problems relating to the quality of the air within the dwelling or, in extreme cases, may be harmful to the occupants.

The ventilation in dwellings has till now primarily been evaluated on the basis of theoretical considerations and less on practical measurements. In addition, the practical measurements has been limited to short term measurements of outdoor air exchange rates and investigations on the performance of individual components, e.g. air inlets. Still, it is recognized that the ventilation, particularly in dwellings, is very much dependent on the behavior of the occupants and on individual structural details of the dwelling. Therefore, evaluation of different ventilation principles and assessment of appropriate ventilation, must be based not only on theoretical considerations, but rather on the results of practical measurements, preferably performed as long term field measurements.

One reason for the limited empirical knowledge from field measurements is, that with known techniques it has been practically and economically impossible to perform long term field measurements at a large scale.

Now, however, the Danish Building Research Institute has taken a passive sampling, multiple tracer gas technique in use. The technique, originally developed at Brookhaven National Laboratory in the USA (1), is named the PFT-technique. The Danish Building Research Institute has, on the basis of successful tests (2), purchased the equipment and used the technique for large scale field measurements.

Using passive sampling techniques, including the PFT-technique, 123 dwellings has been investigated. The investigations comprised measurements of whole-house outdoor air exchange rates, the relative humidity and the concentration of organic vapors in the indoor air. Room temperatures and room volumes were measured when the passive measurement devices were placed in the dwelling.

The object of the measurements was, in each of the types of dwellings, to determine the level of the outdoor air exchange rate, the level of the relative humidity and the level of the concentration of organic vapors in the indoor air.

2. MEASUREMENTS

The dwellings for this investigation were selected among dwellings built after 1982 as the latest Danish building code is dated 1982. The dwellings were divided into three groups, viz.
a) flats in multi-storey buildings ventilated with exhaust ventilation.
b) single family houses ventilated with exhaust ventilation
c) detached, naturally ventilated single family houses

Sample sizes were initially fixed statistically with respect to number of dwellings built in the period, and later slightly modified according to availability. In total 123 dwellings were investigated: 67 dwellings from group a), 36 dwellings from group b) and 20 dwellings from group c).

The dwellings were all located in and close to the Copenhagen area.

2.1 Passive Measurement Techniques

Whole-house outdoor air exchange rates were measured using the PFT-technique.

The technique is based on the principle of constant emission of tracer. Tracer is emitted passively at a constant rate from a small source. The average concentration of tracer over a period is measured using passive samplers. The outdoor air supply is then taken to be equal to the emission rate of the source, divided by the average tracer concentration.

The tracer gas emitter is a small aluminium shell, about 32 mm long and 7 mm in diameter, which, at a known temperature, emits tracer at a constant rate through a silicone rubber plug. Several different types of tracers, all different types of perfluorocarbon, are available. At present the Danish Building Research Institute is using three different types.

The passive sampler is a glass tube, approximately 64 mm long and 7 mm in diameter, containing a charcoal-like adsorbent in the middle. The tube collects the tracer gas by the principle of passive diffusion. If several different types of tracers are used simultaneously, one tube will collect all types in use. Subsequent thermal desorption and gas-chromatographic analysis is required to obtain the concentration results. The analysis is performed in the laboratory. When the samplers are being desorbed they are simultaneously cleaned out and ready to be used again.

The relative humidity were measured by means of calibrated, small wooden blocks. The blocks, made from beechwood, measure approximately 50 mm x 48 mm x 15 mm and weighs approximately 25 g. The method is based on the fact that wood exposed to room air will attain a moisture content almost in equilibrium with the relative humidity of the room air. The moisture content is determined by weighing out the wooden blocks on an electronic, precision balance to a hundredth of a gram. On the basis of numerous tests the technique is expected to have an uncertainty of ± 5 pct.

The concentration of organic vapors in the indoor air were measured using passive organic vapor monitors manufactured by 3M. The samplers were analyzed to [mg/m^3] TVOC (Total Volatile Organic Components).

2.2 Measurement Procedures

The inhabitants were called only once. During the call the passive samplers for measurements of relative humidity and organic vapors were placed in the livingroom and passive tracer gas emitters and passive adsorption tubes were deployed through out the dwelling. The temperature in the livingroom was measured as well as the volume of the dwelling. The inhabitants were interviewed primarily concerning specific airing habits. The duration of the call was 15-20 minutes.

About one week later stamped and addressed envelopes, plastic bags and a simple questionnaire were sent out. The inhabitants were asked to put the samplers in separate plastic bags, fill in the questionnaire and return the matter. The questionnaire dealt with questions as when interviewed and a space to fill in when the measurement had ceased. The duration of the passive measurements were 1-2 weeks.

The measurements were performed during winter 1988/89 and early spring 1989. The climatic conditions in the period were fairly mild and the outdoor temperature ranged from just below zero to about 10 °C.

3. RESULTS

The results of the measurements of the average outdoor air exchange rate are presented in table 1 and figure 1. On average, a higher outdoor air exchange rate is seen in dwellings equipped with mechanical exhaust ventilation compared to naturally ventilated single family houses.

TABEL 1. Summary statistics of PFT-measurements of the average outdoor air exchange rates, ACH [h^{-1}].

	Flats mech. exhaust	Single family mech. exhaust	Single family naturally vent.
Average ACH [h^{-1}]	0.59	0.55	0.33
Standard dev.	0.27	0.26	0.08
Minimum	0.20	0.22	0.20
Maximum	1.53	1.16	0.50

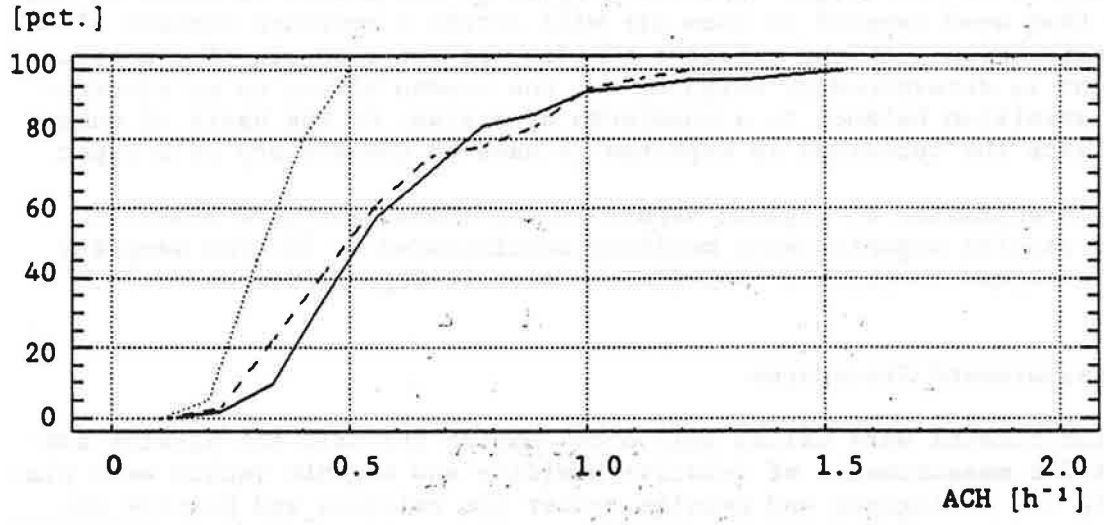

FIGURE 1. Cumulative, relative frequency plot of the average outdoor air exchange rate, ACH [h^{-1}].
Solid line : Flats, mechanical exhaust ventilation.
Broken line: Single family houses, mechanical exhaust ventilation.
Dotted line: Single family houses, naturally ventilated.

TABEL 2. Summary statistics of measurements of the average relative humidity, RH [pct.].

	Flats mech. exhaust	Single family mech. exhaust	Single family naturally vent.
Average RH [pct]	42.9	42.9	42.7
Standard dev.	4.8	3.9	4.4
Minimum	29.4	34.6	32.5
Maximum	61.5	49.4	49.3

In defiance of the differencies in the average air exchange rates, the average relative humidity is approximately 43 pct. in all three categories of dwellings (tabel 2 and figure 2). Also shown, in figure 3, is the difference between the absolute water content in the indoor air and in the outdoor air.

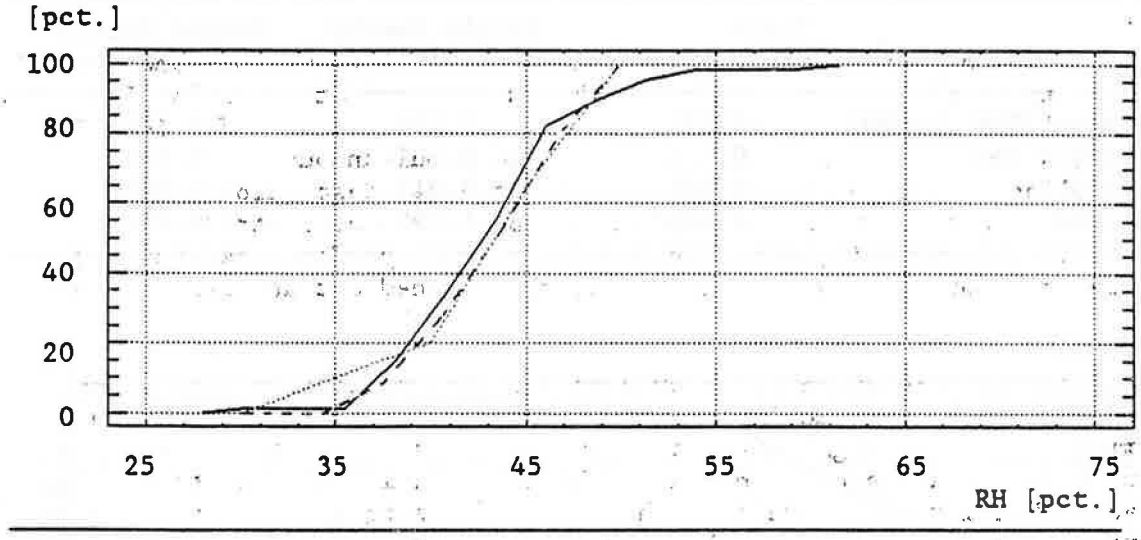

FIGURE 2. Cumulative, relative frequency plot of the average relative humidity, RH [pct.].
Solid line : Flats, mechanical exhaust ventilation.
Broken line: Single family houses, mechanical exhaust ventilation.
Dotted line: Single family houses, naturally ventilated.

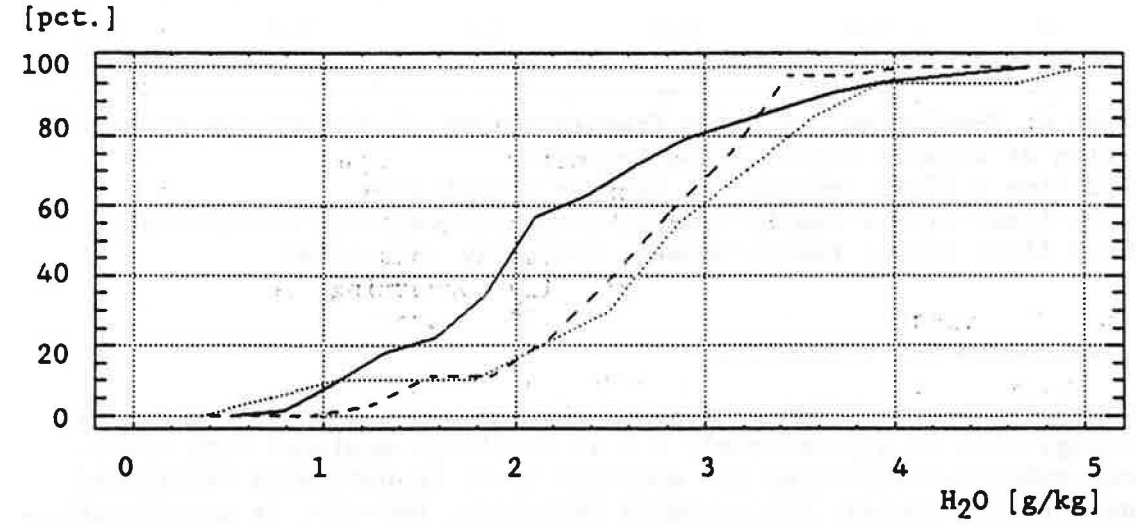

FIGURE 3. Cumulative, relative frequency plot of the difference between the absolute water content in the indoor air and in the outdoor air, [g/kg].
Solid line : Flats, mechanical exhaust ventilation.
Broken line: Single family houses, mechanical exhaust ventilation.
Dotted line: Single family houses, naturally ventilated.

The results of the measurements of the average concentration of organic vapors are presented in tabel 3 and figure 4.

TABEL 3. Summary statistics of measurements of the average concentration of organic vapors, TVOC [mg/m³].

	Flats mech. exhaust	Single family mech. exhaust	Single family naturally vent.
Average TVOC [mg/m³]	0.332	0.286	0.325
Standard dev.	0.364	0.350	0.225
Minimum	0.031	0.017	0.069
Maximum	2.523	1.795	0.902

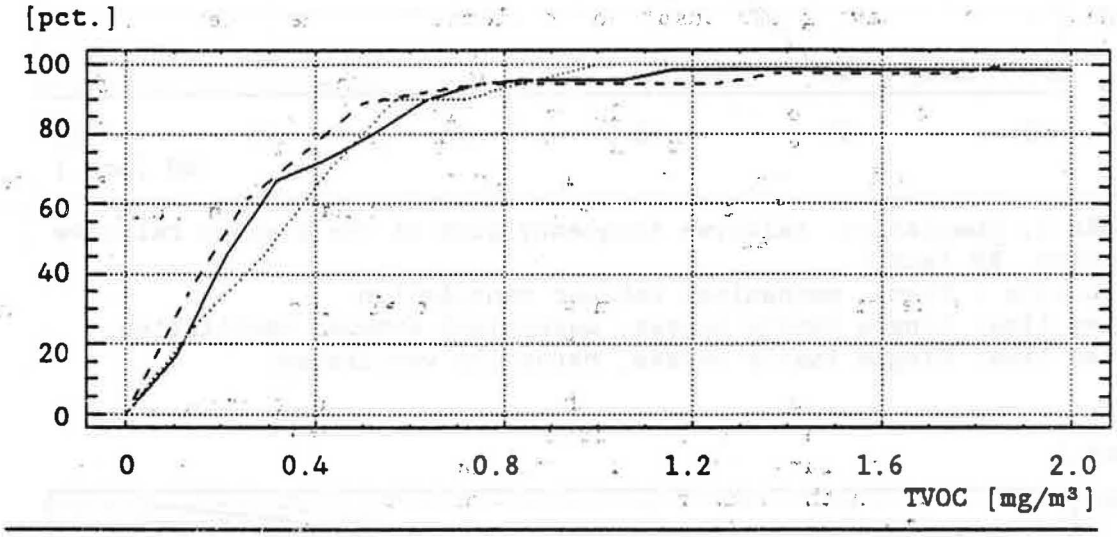

FIGURE 4. Cumulative, relative frequency plot of the average concentration of organic vapors, TVOC [mg/m³].
Solid line : Flats, mechanical exhaust ventilation.
Broken line: Single family houses, mechanical exhaust ventilation.
Dotted line: Single family houses, naturally ventilated.

4. DISCUSSION AND CONCLUSION

The results of the PFT-measurements show that the average outdoor air exchange rate is approximately 0.5 in dwellings equipped with mechanical exhaust ventilation and somewhat lower in naturally ventilated single family houses. The standard deviation, however, is considerably different in the two categories. Expressed in percentages is the standard deviation in mechanically ventilated dwellings about 47 pct. while it in naturally ventilated single family houses is 24 pct. This might indicate significant differencies in the performance of the mechanical ventilation systems, but the object of these measurements has not been to investigate the performance of the individual systems.

The Danish building code provides that it must be possible to ventilate a dwelling corresponding to 0.5 air changes per hour.

The code also provides that it in flats in multi-storey buildings has to be effected by mechanical exhaust ventilation in bathrooms, lavatories and kitchens. These measurements show that on average the provision is met in dwellings equipped with mechanical exhaust ventilation.

The results of the measurements of the relative humidity show approximately the same humidity, namely 43 pct., and the same standard deviation, about 10 pct. expressed in percentages, in all types of dwellings.

Recommendations for maximum acceptable humidity in the indoor air can be given on two different viewpoints. One is that in wintertime condensation on windows must be prevented. Normally, a difference in absolute water content in the indoor air and the outdoor air of 2.5 [g/kg] should be sufficient. Differencies of 3.3 [g/kg] - 4.2 [g/kg] may cause problems in dwellings with double glazing when room temperature is lowered and curtains are drawn. If 3.5 [g/kg] is taken as the limit it can be seen from figure 3 that 10-20 percent of the dwellings investigated may be suspected of having condensation problems. The other viewpoint is that the number of house dust mites per gram house dust must be kept low. This means a maximum acceptable humidity in the indoor air of 7.0 [g/kg] corresponding to about 45 RH [pct.] at 20-22 °C, in typical climatic winter conditions in Denmark. Even if the climatic conditions in the measuring period were not typical, figure 2 might indicate that some of the dwellings investigated may be suspected of having an increased number of house dust mites.

The mild climate might also explain why no correlation was found between the outdoor air exchange rate and the relative humidity.

The results of the measurements of the concentration of organic vapors show approximately the same concentration in all three categories of dwellings, but with large standard deviations. Also, a test proved no correlation between the measured TVOC-concentration and the outdoor air exchange rate. The reason is presumably the wide range of pollutant sources and pollutant strengths found in dwellings.

Only unofficial recommandations to the concentration of TVOC in the indoor air exists, but compared to previous field measurements no indication is given that the results here obtained are high.

5. REFERENCES

(1) Russell N. Dietz, R. W. Goodridge, E. A. Cote, R. F. Wieser
Brookhaven National Laboratory.
Detailed description and performance of a Passive Perfluorocarbon Tracer System for Building Ventilation and Air Exchange Measurements.
BNL 36327, February 1985.

(2) Niels C. Bergsoe
Danish Building Research Institute.
Evaluation through field measurements of BNL/AIMS, a multiple tracer gas technique for determining air infiltration rates.
Paper presented at the 8th AIVC Conference, Federal Republic of Germany, 21 - 24 September 1987.