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HOME VENTILATION UNDER NORMAL LIVING CONDITIONS

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This paper presents the results of measurements of home ventilation which were part of a study on IAQ in The Netherlands. Kitchen ventilation was determined by tracer gas experiments, real-time in ten occupied homes, and weekly average ventilation rates in over 170 kitchens and living rooms. The concept of the Transfer Index is introduced as an alternative way to describe complex ventilation systems. In addition, questionnaire and diary information on occupant ventilation behavior is presented.

INTRODUCTION

In the Eighties, a study was carried out in the Netherlands, aimed at the characterization of typical indoor pollutant levels in Dutch homes, in relation to properties of the home and its occupants(1, 2, 3). The (for the purpose of this paper) relevant objectives of the study were:

- the characterization of the distribution of pollutant levels inside Dutch homes, and
- the identification of the factors which influence indoor pollutant levels.

To evaluate the role of ventilation on indoor air quality, the study involved tracer gas experiments, and registration of occupant's ventilation habits through questionnaires and diaries. The home ventilation characteristics were determined in two measurement programs:

- real-time monitoring of pollutant levels in different rooms of a limited number of homes,
- week-long integrated measurements in a large number of homes.

These two programs were carried out in the heating season (± October-March), when the ventilation of homes was expected to be at a minimum. This paper presents a summary of the results of the measurements of ventilation and ventilation behavior.

To evaluate the ventilation of the kitchen, and the transfer of kitchen air (with combustion products from cooking and water heating with unvented gas appliances) to the living room in occupied homes under normal living conditions in a large number of homes survey type of study, the tracer gas constant-flow method is most appropriate. With this method, average ventilation rates can be determined over time periods of several days, or longer, with relatively simple and cheap equipment which can be left unattended for over a week (4). The tracer gas is emitted with a constant and known flow P (mg/h) in a room of volume V (m^3) over the entire measurement period for which the average tracer gas concentration C (mg/m^3) is determined in the room. Under conditions of ideal mixing the average air change rate per hour (ACR) is: ACR = P / (V.C) (h^{-1}). Conditions of ideal mixing, however, are seldom met in occupied homes. Therefore, the effective volume of air that participates in the air exchange, differs from the physical volume and is difficult to assess. Furthermore, the air exchange between two rooms, i.e. between kitchen and living room, cannot be described easily in terms of ACR. The transfer index (TI) is a measure which does not suffer from the uncertainty about the effective ventilation volume. The TI describes the exposure to a tracer gas at a certain point, after release at an other point in the room (or in another room). In other words, it expresses the efficiency in protecting a given position from exposure to a airborne contaminant, released at another point in the ventilation system (5). With the constant flow method, the average TI can be calculated from: TI = C / P (h/m^3). Thus, the higher the ventilation and the larger the room, the lower the TI will be. Under conditions of ideal mixing and a known effective room volume, TI is the reciprocal of the product of ACR and the effective volume V.

MATERIALS & METHODS

The real-time measurement program was carried out in twelve homes in Wageningen. SF_6 tracer gas was emitted in the kitchen of the homes at a constant flow of about 1 ml/min from a 1-liter stainless steel cylinder with a Brooks flow controller (model 8844; needle size 2). Thus, a constant SF_6 emission could be maintained over a period of over 7 days. Between homes, the SF_6 emission varied from 165-300 mg/hour. A Wilks infrared spectrophotometer was used to determine SF_6 tracer gas concentrations in the kitchen. After a warming-up period of at least 12 hours, the instruments were calibrated and the measurements were started. The infrared spectrophotometer was calibrated according to the operation manual. Cell path length was set at a maximum of 25 meter and the wavelength at 11.6 μm. Periodically, checks were made by introducing calibration gases of various concentrations into the cell from cylinders prepared at the laboratory. Data acquisition was handled by a HP model 85 micro-computer.

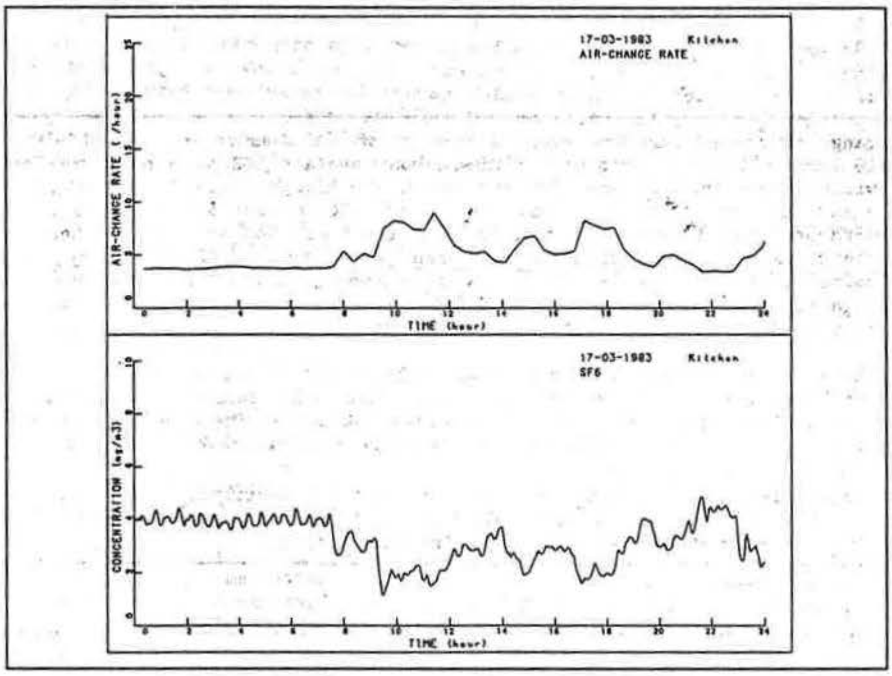
For the SF_6 determination in the week-long measurement program, a device was developed which sampled air in 10 liter aluminum-polyethylene foil bags (Linde Plastigas). The sampling bag was connected with a 1/16 inch stainless steel tube to a Charles Austen model L12 pump with a 1/16 inch polyethylene inlet line. The pump was switched on and off by a timer to run for one out of every ten minutes over the week-long sampling period. A Hoke 1335 G 4 B metering valve was used to adjust the sampling flow at about 10 ml/min. Laboratory experiments showed virtually no loss of SF_6 after storing the sampling bags for 7 to 8 days; consequently no desorption of SF_6 was observed after evacuation of the sample and flushing of the bag with zero air. The bags content was analyzed gaschromatographically on SF_6 with electron capture detection. Detection limits for SF_6 was 0.1 $\mu g/m^3$. Initial tests at the laboratory indicated a coefficient of variation for duplicate samples of about 10%, but 15 duplicate field samples had a coefficient of variation of about 15%. The SF_6 emission (in the kitchen) was similar to that in the real-time monitoring program. Instead of pure SF_6, the cylinders contained air with 15,000 mg/m^3 SF_6, because compared to the infrared analyzer, the gaschromatographic method has a lower detection limit.

Additional information about the homes contained, a.o. items on: type of home, number of floors and rooms, volume of kitchen, living room and one bedroom, open/closed kitchen, presence of doors, windows and ventilation provisions. Questionnaire and diary information was gathered on frequency and duration of use of ventilation provisions and of interior doors between kitchen, living room and bedroom.

RESULTS

In ten of the twelve homes of the real-time measurement program, successful measurements of the SF_6 concentration in the kitchen were obtained over periods of several days. For these homes, the SF_6 concentration in the kitchen was plotted versus time of day; kitchen air change rates (ACR) were calculated from the SF_6 emission rate, the 30-minutes average SF_6 concentration and the volume of the kitchen. These ventilation rates were plotted versus time of day in combination with the SF_6 concentrations. In several cases, these plots revealed cyclic patterns and rapid changes in the SF_6 concentrations (cf. Figure 1). The rapid changes in SF_6

Figure 1 ACR (h^{-1}) and SF_6 level (mg/m^3) in the kitchen of home 4



concentration often coincided with the use of gas appliances. From interviews with occupants it appeared that the rapid changes in SF_6 concentrations also occurred at times when the use of ventilation provisions was not changed. This indicates that the changes in SF_6 concentration reflect mixing of stratified kitchen air by human activity and by the use of gas appliances, as well as changes in ventilation of the kitchen. The cyclic pattern of the SF_6 concentration, which was observed in several homes paricularly during the night, was probably the result of convection of the kitchen air caused by the heat of the refrigerator motor. The operation of the refrigerator motor was monitored in several homes by placing an additional thermo couple on the shield of the refrigerator motor. It appeared that the cyclic fluctuations of the SF_6 concentrations had the same frequency as the repeated operation of the refrigerator motor.

To smoothen the effect of short-term fluctuations in SF_6 concentrations on the ACR, 4-hour average ACR and transfer indices (TI) were calculated from 4-hour average SF_6 concentrations. Table 1 presents the overall mean and

Table 1 Overall mean and range of the 4-hour average ACR (h^{-1}) and the overall mean transfer index (min/m^3) of 10 homes of the real-time monitoring program

home nr.	4-hour average ventilation rate (h^{-1}) overall mean	range	overall mean transfer index (min/m^3)
3	8	3-14	0.26
4	7	4-19	0.34
5	0.8	0.4-3	0.73
6	2	1-6	2.10
7	0.5	0.4-0.8	0.96
8	4	2-8	1.00
9	0.7	0.4-1	0.80
10	3	2-6	0.22
11	9	4-24	0.55
12	5	2-9	0.89

range of the ACR and the overall mean TI of the measurement period in the 10 homes. Large differences in the 4-hour average ACR were observed both within homes and between different homes. The highest 4-hour average ACR in a kitchen was about 2-6 times the lowest ACR in that kitchen. The homes with an overall mean ACR, smaller than 1 h^{-1} all had an open kitchen and therefore a large kitchen volume. When judged by the TI from a hygienic point of view, home 10 had the best (=lowest) value. This home had the highest capacity to dilute and disperse pollutants generated in the kitchen. Judged on the ACR however, home 10 is only the sixth best in rank.

The week-long measurement program was carried out in a large number of pre-war homes (Rotterdam) and post-war homes (Ede). In Ede, eight homes had no ventilation provisions or appliances in the kitchen. These homes were part of a flat for elderly people and had a small electric cooking facility. The

Table 2 Percentage of homes in which none of the ventilation provisions in kitchen, living room and bedroom were actively used for ventilation during the winter; questionnaire-information

location	Ede post-war homes (n=174)	Rotterdam pre-war homes (n=102)
kitchen	5%	6%
living room	17%	20%
bedroom	3%	15%

living rooms and bedrooms in Ede all had one or more ventilation provisions. In Rotterdam, one kitchen, five living rooms and nine bedrooms had no ventilation provisions. All these rooms had an open connection to other rooms which did have one or more ventilation provisions. According to the questionnaire information, a substantial proportion of the occupants never used their ventilation provisions during the winter season (cf. Table 2). The kitchen window fan was only used regularly in about 50% of the homes in which this appliance was present. The range hood, when present, was used regularly in 80-90% of the homes. Two reasons for not using provisions in a room were often heard during the field work, especially in Rotterdam. The first reason was that the room had an open connection with other parts of the home where the occupants did use ventilation provisions. The second reason was draught. In Ede 29% of the respondents often experienced draught, against 44% of the respondents in Rotterdam. The median of the total use of ventilation provisions during the measurement week, according to the diaries, is presented in Table 3. The geometric mean of use of interior doors in the 3 locations in Ede and Rotterdam is given in Table 4. The range in the use of interior doors was from 0% tot 100% in all the locations in both towns. Particularly interior

Table 3 Median of the percentage of time that ventilation provisions were used in different rooms; diary-information

	median of time that ventilation provisions were used	
	Ede (n=128)	Rotterdam (n=82)
kitchen	8	5
living room	2	0.1
bedroom	42	7

doors of the kitchen were open during a considerable fraction of the time; the geometric mean was 29% of the time in both towns. The interior doors of the other locations were, on average, open during a few percent of the time. In Rotterdam, the interior doors of the bedroom were on average open twice as long as in Ede. This is mainly because in Rotterdam the bedroom door was removed in 10% of the homes, while in Ede this was only the case in 1% of the homes.

Table 4 Geometric mean of the percentage of time during which interior doors were open in Ede and Rotterdam; diary-information

	geometric mean (% of time)	
location	Ede (n=128) post-war homes	Rotterdam (n=82) pre-war homes
interior kitchen door	29	29
interior living room door	3	4
interior bedroom door	3	7

Successful tracer gas experiments were carried out in 72 kitchens and 73 living rooms in Ede. In Rotterdam these measurements were successful in 69 kitchens and 73 living rooms. Table 5 shows the geometric mean and range of the TI and ACR in the kitchen and the TI in the living rooms in the two towns; for homes with an open kitchen/living room the ACR of the living room was also calculated. The geometric mean TI had comparable values in Ede and Rotterdam in the kitchen as well as in the living room. As could be expected, the TI of the living room was lower than that of the kitchens. High kitchen ACR were observed more frequently in Rotterdam than in Ede. Kitchen ACR of 15 (h^{-1}) were observed in 3 homes in Ede and 11 homes in Rotterdam. In all these homes the interior door of the kitchen was either removed or left open during the entire measurement period. The kitchen with the highest ACR of 24 (h^{-1}), observed in Ede had an TI of 0.5 (min/m^3), the same value as the geometric mean of all kitchens in Ede. The kitchen with the highest ACR in Rotterdam had a TI of 0.2 (min/m^3). In this kitchen the vent light as well as the interior door were open all the time during the measurements. These comparisons of the ACR and corresponding TI in the kitchen clearly illustrate the difficulties which occur in determining ACR in occupied homes, when the effective ventilation volume cannot be determined accurately and deviates from the physical volume of the room.
Multiple regression analysis with the logarithm of the TI in the living room as dependent variable and as independent variables the logarithm of the TI in the kitchen, the number of doors between kitchen and living room and location (Ede/Rotterdam) showed that the independent variables explained 38% of the variance in the dependent variable. After adjustment

Table 5 Geometric mean (and range) ACR (h^{-1}) and TI (min/m^3) in kitchens and living rooms in Ede and Rotterdam

location	geometric mean (and range) of TI and ACR in Ede post-war homes	Rotterdam pre-war homes
kitchen TI	0.5 (0.1-2.3) n=72	0.6 (0.1-4.6) n=69
living room TI	0.2 (0.02-1.1) n=73	0.2 (0.1-2.4) n=73
kitchen ACR	4 (0.5-24) n=72	6 (0.9-47) n=69
living room ACR*	2 (0.5-7) n=26	1 (0.3-3) n=6

* only for homes with an open kitchen/living room

for the logarithm of the TI in the kitchen and the number of doors between kitchen and living room, the logarithm of the TI in the living room was significantly higher in Rotterdam than in Ede, indicating a higher exchange of air from kitchens to living rooms in Rotterdam.

DISCUSSION

The results of the tracer gas experiments in the week-long measurement program revealed a large range in ACR and TI in kitchens and living rooms in both towns. It is obvious form both measurement programs that the effective ventilation volume of a room may seriously deviate from the physical volume. This affects the value of the ACR in an unknown manner. The TI is a parameter, the value of which does not involve the room volume. It directly describes the efficiency in protecting the sampling point from exposure to the tracer gas, no matter how complex the ventilation system is. The usefulness of the TI to evaluate ventilation, however, depends heavily on the location of the tracer gas emission and sampling points. Careful selection of these points, made possible by flexible emission and sampling tubing, is therefore required. Duplicate SF_6 samples with a coefficient of variation of 15 % taken in five kitchens, ten living rooms and fourteen open kitchens/living rooms in the week-long measurement program, showed that differences in the location of the sampling points had only a minor effect on the outcome of the TI. The differences in the TI in kitchens and living rooms signify that in the Netherlands, most homes cannot be considered as one single compartments, as can be judged from the data on the use of interior doors in the week-long measurement program.

REFERENCES

1. Lebret E (1985) Air pollution in Dutch homes: An exploratory study in environmental epidemiology. Agricultural University, Wageningen; Doctorate Thesis
2. Lebret E, Wiel HJ van de, Bos HP, Noij D & Boleij JSM (1984) Volatile hydrocarbons in dutch homes. Proceedings Third International Conference on Indoor Air Quality and Climate, Stockholm, Vol. 4:169-174
3. Lebret E, Wiel HJ van der, Bos HP, Noij D & Boleij JSM (1986) Volatile organic compounds in Dutch homes. Environ Int 12:323-326
4. Sherman MN, Grimsrud DT, London PE & Smith BV (1981) Air infiltration measurement techniques. Proceedings First Air Infiltration Centre Conference on Air Infiltration, Instrumentation and Measurement techniques, Berkshire
5. Lidwell OM (1960) The evaluation of ventilation. J Hyg 58:297-305