CONCLUSIONS

A simple methodology for the evaluation of the usefulness of the natural ventilation in order to ensure an acceptable IAQ has been presented. It is based on the comparison of the actual flow rates with those required for achieving an assigned percentage of dissatisfied. The evaluation of this percentage is carried out by means of the "olf" and "decipol" approach.
Two examples have been reported, respectively, for a residential and a commercial buiding. They are supported with comprehensive graphs, where it's possible to single out the shifting point from natural to mechanical ventilation.
Although the method certainly requires further refining, it promotes itself as a good tool for architectural analyses, particularly when reliable data on the wind are available for the site.
It could be also employed in the so-called "intelligent buildings", for defining proper stategies for dwellings equipped with automatic control systems, in order to optimize the ventilation equipment.

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THE PERFORMANCE OF VENTILATION SYSTEMS IN DETACHED HOUSES

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ABSTRACT

The paper discusses the results of case studies on indoor air quality and on the performance of natural ventilation system in some detached houses. The studies were made during autumn 1992.

25 % of new detached houses have a natural ventilation system. The studied single-family houses were built in the 1980's and the ventilation systems were in accordance with the prevailing building practise. Two of the houses were equipped with a natural ventilation system, while the reference house had a balanced ventilation system.

The air-exchange rate in the houses with natural ventilation was approximately 0.3 1/h. In the test house with balanced ventilation system the air-exchange rate was 0.4 1/h. This was measured at the lowest and most frequently used capacity. The value recommended by the Finnish Building Code is 0.5 1/h (4 L/s,person).

The CO_2-concentrations in the bedrooms of the houses with natural ventilation varied between 600 - 4000 ppm. In the mechanically ventilated house the variation range was 600-1800 ppm. The recommended maximum concentration of CO_2 is 1500 ppm.

The recommended rates of exhaust air flow in kitchen, WC and bathroom were not achieved in any of the houses equipped with natural ventilation. In the house with mechanical ventilation the recommended values were reached at the maximum capacity. The natural ventilation system is very depended on weather conditions. During the test period (October 1992), the outdoor temperature was close to the annual average temperature in Oulu. The measurements proved that the natural ventilation system typical of today's detached houses does not produce the required air-exchange rate.

INTRODUCTION

The aim of the study was to measure the performance of natural ventilation system in each room and to study the quality of indoor air (impurities and related factors) in typical modern detached houses. The length of the test period was several days and the measurements were continuous.

25 % of new detached houses have a natural ventilation system. A little more than 50 % have a balanced ventilation system. The rest of the houses have a mechanical exhaust system. While the share of balanced ventilation system with heat recovery increases

continuously, single-family houses are still being built with a natural ventilation system. Most of the older houses have a natural ventilation system.

The air tightness of detached houses has improved during the last 15 years. According to the data collected by the VTT Building Laboratory, the air tightness in the single-family houses is nowadays approximately 3 - 4 1/h at a 50 Pa pressure difference. At the turn of 70's and 80's it could be 6 - 8 1/h at 50 Pa. The increase of the air tightness has been caused by the improvements in window tightness and the installation of vapor barriers. At the same time, the air flow paths in chimneys have disappeared when the construction methods have changed. These changes have deteriorated the function conditions for buoyancy driven natural ventilation. As there are no controlled intakes for supply air, the air flow rates have reduced. In mechanical exhaust system the improvement of tightness has caused an increase in the feeling of draught, when the intake of fresh air has not been arranged. The renovations made to save energy combined with the introduction new building and furnishing materials have created a situation in which the indoor air quality deteriorates unless the operational conditions of the system should be improved or the system itself should be developed.

Three single-family houses at different sides of Oulu were chosen for the study. Two of them were equipped with a natural ventilation system with a kitchen range hood. The ventilation system in house 2 had even long horizontal ducts, which is unfortunately rather common in practise (although against the Building Code). In house 1 the ducts were mainly vertical. There were no special air inlets in either of the houses. All the houses had an electrical heating system, installed in the ceiling in house 1. House 3 had a mechanical ventilation system with a three-stage capacity adjustment. The measurements were carried out in October 1992 during three consecutive weeks. The monitoring period lasted 3 days in each house.

THE METHODS AND MEASUREMENTS

The indoor air contaminants were measured using a photo-acoustic gas monitoring system including a multi-channel sampling and injection device for tracer gas measurements. In each room (max 6 rooms) CO_2, CO, VOC, formaldehyde and H_2O concentrations were measured. The air-exchange rate of each room was measured using the decay method. Nitrous oxide (N_2O) was used as tracer gas. The air-exchange rate in the parents' bedroom in each house was measured using the constant concentration method. In the houses with natural ventilation the exhaust air flow of each outlet was measured continuously for one week using thermoanemometers, hoods and portable data loggers. The air flow rates of each unit in the house equipped with mechanical ventilation system were measured at the maximum and minimum capacities by single measurements. In this house the system was usually running at the minimum capacity. The people living in each house recorded the daily routines affecting ventilation: opening of windows, the use of kitchen range hood and closing of doors.

RESULTS

Contaminants

The people living in the houses did not complain any symptoms that could be caused by high concentration of formaldehyde. In Finland the maximum allowable concentration of formaldehyde is 0.15 mg/m^3 in new buildings and 0.30 mg/m^3 in old ones. The lowest formaldehyde concentrations were found in house 1 (built 1983) and the highest in house 3 (built in 1989).

The average concentrations of VOCs were as follows:

House 1: 3.0 - 4.2 mg/m^3
House 2: 2.6 - 3.3 mg/m^3
House 3: 3.0 - 3.1 mg/m^3

The concentration of VOCs can be considered harmless. The concentration increased in the kitchen during cooking, otherwise concentrations were equal.

The average CO_2-concentrations were as follows:

House 1: 409 - 1495 ppm
House 2: 826 - 1127 ppm
House 3: 870 - 1217 ppm

The CO_2-concentration varied according to the number of people. The highest concentration, 4000 ppm, was measured in the closed bedroom of house 1 when there were one adult and one child sleeping. When there were two adults and one child sleeping in the same room but the door was open, the concentration rose up to about 1600 ppm. In house 2 there was only one adult sleeping in the bedroom and the doors were open. The CO_2-concentrations remained reasonable, approximately 1100 ppm. In the bedroom with mechanical ventilation system (house 3), the CO_2-concentration rose to 1800 ppm when one adult and four children slept in the room and the ventilation system was operating in minimum capacity. When 1 - 2 people slept in the room, the CO_2-concentration remained between 1200-1400 ppm. In the daytime, when the load varied, the CO_2-concentration did not exceed 1000 ppm in any of the houses. The variation in CO_2-concentrations in different houses (house 1 and 3) is presented in figures 1 and 2. The number of people in the room and the position of windows and doors is marked in the figures.

▢ = ovi kiinni, door closed; ▱ = ovi auki, door open; ❷ = 1-2 henkilöä, 1-2 persons; ❸ = useampi henkilö, >2

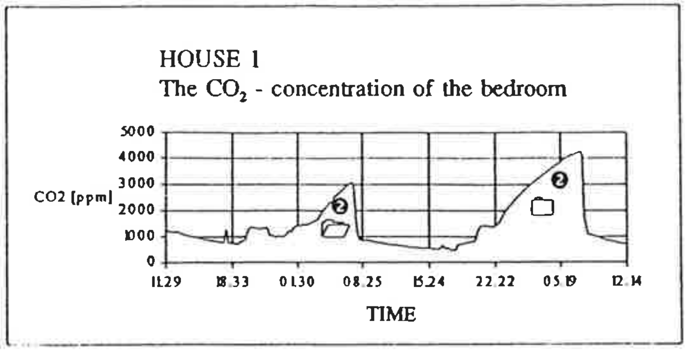

Fig. 1. The CO_2 - concentration in the bedroom (house 1, natural ventilation)

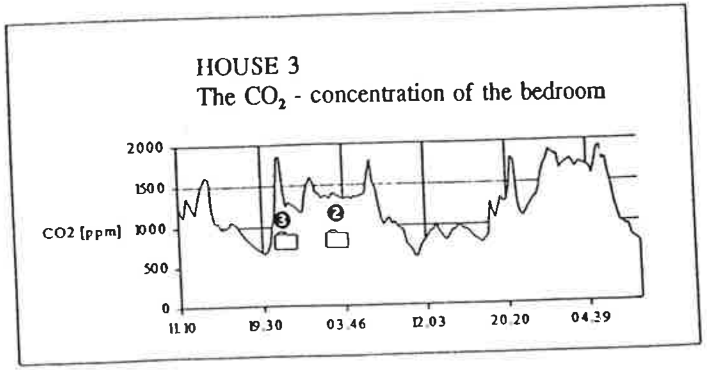

Fig. 2. The CO_2 - concentration in the bedroom (house 3, balanced ventilation)

The air-exchange rates

The air-exchange was measured in all rooms using the concentration decay method. The air-exchange rates in the parents' bedrooms were measured using the constant concentration method. The length of the measurement was two days. Table 1 presents the rate of air-exchange in different houses measured using the concentration decay method. The air-exchange rates measured using the constant concentration method are presented in table 2. The constant concentration measurements include the air transfer between the rooms.

The recommended values were achieved only in the house with balanced ventilation. The air-exchange rates measured using the concentration decay method were compared with the air flows measured at the air outlets (table 3). The results are approximately equal. These results imply that the tightness of the houses is reasonablely good. Tightness was not measured separately.

Table 1. The air-exchange rates measured using the concentration decay method.

	room 1 (1/h)	room 2 (1/h)	room 3 (1/h)	room 4 (1/h)	room 5 (1/h)	room 6 (1/h)	kitchen (1/h)
house 1	0.26	0.29	-	-	0.29	0.27	0.27
house 2	0.26	0.26	-	-	-	0.30	0.26
house 3	0.38	0.42	0.36	0.40	0.40	0.40	0.41

Table 2. The air-exchange rates measured in the parents' bedroom using the constant concentration method.

	bedroom door closed (1/h)	bedroom door open (1/h)
house 1	0.10 - 0.27	0.57 - 0.85
house 2	-	1.3 - 2.0
house 3	-	2.6 - 2.9

Table 3. The comparison of the tracer decay and air flow measurements.

	concentration decay (1/h)	exhaust air flow (1/h)
house 1	0.27	0.28
house 2	0.27	0.29
house 3	0.40	0.43

Air flows in each room

The exhaust air flows were measured at the outlets. In house 3 also the supply air flow was measured. The average air flow of each room is presented in table 4.

Table 4. The average exhaust air flows in each room.

	toilet 1 (L/s)	toilet 2 (L/s)	room 1 (L/s)	bathrm (1/h)	room 2 (L/s)	room 3 (L/s)	sauna (L/s)
Building Code	10	10	15	15	15	3	min. 6
house 1	2	1	2	4	8	-	-
house 2	2	-	5	4	-	3	-
house 3*	5	-	4	4	4	4	6
house 3'	10	-	8	9	10	10	13

* minimum (1/3) capacity
' maximum (3/3) capacity

Indoor air temperature and relative humidity

The indoor air temperature in the houses did not vary significantly from each other. The average relative humidity varied from 42 % (house 1) to 31 % (house 3).

DISCUSSION

According to results the air exchange rate and the exhaust air flow in sanitary rooms in the houses with natural ventilation system were only about a half the values recommended by the Building Code. The recommendations were achieved in the reference house, which had a mechanical ventilation system. The CO_2-concentration, VOC-concentration and relative humidity are clearly correlated with the performance of the ventilation system and the human load. The air-exchange rate in the houses with natural ventilation (0.3 1/h) was sufficient to maintain the CO_2-concentration below the recommended value of 1500 ppm if only one person slept in the room and the door was open. The air exchange rate in the house equipped with the balanced ventilation system (0.4 1/h) was able to maintain reasonable CO_2-concentration in the bedroom with two persons. In the case when four persons slept in the bedroom, the system should have been run with a higher capacity. The results are in accordance with those reported e.g. in /1/ and /2/. The sample was limited because this kind of *in situ* measurements need huge resources. There is still a considerably large amount of houses, in which the families have bedrooms with high contaminant concentrations. We should pay special attention on the intake of fresh air, especially in bedrooms and on the operational conditions of ventilation systems.

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AIR EXCHANGE RATES IN RESIDENTIAL HOUSES

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ABSTRACT

The relationships between house characteristics and air exchange rate were examined. A representative sample of houses in the Boston Standard Metropolitan Statistical Area were selected. The sample was divided into terciles groups according to cumulative distribution of air exchange rate; the lower third and the upper third were used in the analysis. Air exchange rates were higher in dwelling units without an exterior storm door, with a small number of rooms (1-5), and in buildings with 5 or more units. These three characteristics may be related to the size and tightness of the dwelling unit.

INTRODUCTION

Air exchange rate (ACH) is a measure of ventilation. Ventilation rate is usually measured using tracer gases. Based on the mass balance assumption, air flow rate is determined as loss or removed air volume per unit period (1). ACH is obtained by dividing air flow rate by house volume. Reducting ventilation (i.e. lower ACH) will reduce energy consumption for residential space heating. Unfortunately, lower ventilation rates may lead to increased indoor air pollution. When considering energy consumption and the impact of indoor air pollution on human health, the mean air exchange rate over a period of weeks to months is relevant.

The objective of the Boston residential NO_2 characterization study was to quantify the fraction of total NO_2 exposure which may be attributable to unvented gas-fired appliances and other indoor sources (2). In this study, NO_2 concentrations and air exchange rates in over 500 households in Boston, Massachusetts were measured (3). In our previous paper, group means of ACH were compared to examined the effects of house characteristics on ACH (4). House characteristics related to ACH were building type, height of dwelling unit, energy conservation measures (such as double pane window and window caulking), and number of adult occupants (4). In this paper, the relationships between house characteristics and ACH are examined and a few attributable house characteristics to explain ACH distribution in residential houses are extracted, using categorical data.

MATERIAL & METHODS

Subject houses were selected to represent the total population of the Boston Standard Metropolitan Statistical Area (SMSA). A two-stage sampling scheme incorporating stratification by the kind of cooking fuel, was used for sampling and logistical efficiency. Detailed description of the sampling method has been reported elsewhere (3). A total of 973 eligible dwelling units were identified, with residents in 581 units agreeing to participate in