Table 2. Analysis of variance of the ventilation rate in the livingroom and the bedroom.

	ventilation rate livingroom					ventilation rate bedroom				
source	DF	SS	MS	F	p	DF	SS	MS	F	p
model	9	2.22	0.24	2.47	0.037	9	24.00	2.67	7.98	<0.001
error	24	2.23	0.10			24	8.02	0.33		
period	1	0.14	0.14	1.43	0.242	1	0.06	0.06	0.18	0.678
type house	1	0.16	0.16	1.66	0.210	1	1.75	1.75	5.24	0.031
age of house	1	0.39	0.39	4.05	0.056	1	8.81	8.81	26.37	<0.001
number of occupants	3	0.22	0.08	0.77	0.520	3	6.42	2.14	6.41	0.002
smoking	1	0.42	0.42	4.42	0.046	1	5.52	5.52	16.52	<0.001
ventilation hood	1	0.18	0.18	1.92	0.179	1	1.66	1.66	4.96	0.036
draught precautions	1	0.07	0.07	0.72	0.404	1	0.83	0.83	2.49	0.128
Multiple R^2	0.481					0.750				

DF: degree of freedom; SS: sum of squares; MS: mean square; F: variance ratio; p: significance.
$N = 17$

These results are in agreement with the results presented by Van Dongen and Phaff [4]. They investigated the behaviour of the occupants of about 280 dwellings in the Netherlands in ventilating using a questionnaire. Non-smokers reported ventilating more in comparison to smokers, whereas with increasing moisture production (related to the number of occupants), people reported ventilating more.
In conclusion, the modified BNL/AIMS technique has been found feasible for measuring ventilation rates and airflows in dwellings and buildings. The field experiment, although performed in a limited number of houses, shows that relevant information can be obtained. This information describes the ventilation habits of occupants in combination with the ventilation due to the construction, and can be used to assess the exposure of occupants during normal occupancy conditions.

ACKNOWLEDGEMENTS

The study was supported by a grant of the Ministry of Welfare, Health and Cultural Affairs. The authors are grateful for the useful comments delivered by the members of the BIMI working group and for the assistance in the field experiment by the Building Establishment Agency of the city of Rotterdam.

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LIMITS OF NATURAL AND MECHANICAL VENTILATION FOR RESIDENTIAL REQUIREMENTS

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ABSTRACT

This paper reports on an investigation to determine the proper amount of air exchanges available through natural or mechanical ventilation. The "olf" and "decipol" methodology is used to check the quality level of the air. A computer code, developed by some of the authors, makes it possible to compute the ventilation rates for a building utilizing natural ventilation. Thus it is possible to verify the conditions suitable for satisfactory amount of air exchanges available through window and door openings to satisfy an acceptable indoor air quality (IAQ) to the occupants before the need to resort to mechanical ventilation. Two examples, of different geometrical situations, are depicted using a graphic simulation that synthesizes building conditions related to the level of comfort provided by the ventilation.

INTRODUCTION

A recent methodology, proposed by P.O. Fangers and coauthors (1), allows the determination of both the quantity (ventilation rates) and quality of the air to be provided inside a building, in order to bring comfortable conditions to the occupants.
This represents a remarkable enhancement in the analysis of the indoor air quality. The current standards, in fact, only take into account the ventilation rate (l/s, m^3/hour or A.C./hour), with no regards to the quality of the air introduced in the confined environment, implicitly assuming that a high frequency of the exchanges guarantees the needed air cleanliness.

With this new approach, the quality of the air and the pollution produced by a given source, are checked by means of computing the "olf" and "decipol" quantities.
The method, is particularly recommended for commercial buildings and for dwellings operated by mechanical ventilation, when the value of the ventilation rate is known.
But a large amount of residential dwellings (as well many commercial), are currently served by natural ventilation. In these buildings, the comfort conditions are achieved by the occupants properly operating the windows or door openings. For these buildings, there is an urgent need for methods to determine if the natural ventilation rates are satisfactory.

NATURAL VENTILATION THROUGH THE OPENINGS

An easy computer code for evaluating the air flow rates in a cross-ventilated room has been recently proposed (2). NATVE model provides the ventilation rates (in m^3/s) under some simplified conditions, but it avoids the cumbersome operations related to the solution of a set of non-linear algebraic equations. It is based on the most consolidated developments in the field and has been checked by means of experimental data provided by some authors (3) and validated by ISPRA Joint Research Centre (4, 5). As the structure of the NATVE model is very simple, it doesn't take into account the temperature difference between indoor and outdoor environments. However the procedure here introduced is independent by the method employed to determine the ventilation rates; thus more sophisticated methods can only improve the accuracy of the results.
The air flow rate Q_v is computed by means of the following equation:

$$Q_v = A v \prod_{i=1}^{6} K_i \qquad (1)$$

where **A**= the inlet free opening area, **v**= the wind speed, $\mathbf{K_1}$= the discharge coefficient, $\mathbf{K_2}$= the wind pressure coefficient, $\mathbf{K_3}$= the inlet-outlet area ratio coefficient, $\mathbf{K_4}$= the inlet-outlet distance coefficient, $\mathbf{K_5}$= the internal partition coefficient, and $\mathbf{K_6}$= the fly screen coefficient. Typical values of the coefficients can be found in reference (3).
The method is sensitive to the most significant climatic and architectural parameters, such as the wind speed and direction, the linear dimensions of the building, the presence of internal partitions, the opening area of the windows, the fly-screen equipments, and the surrounding buildings.

THE PERCEIVED AIR POLLUTION

In order to quantify the air pollution sources and the way they are perceived by people indoors and outdoors, the "olf" and "decipol" quantities have been respectively introduced (1).
The olf measures the emission rate of bioeffluents from a standard person, while any other source is referred to a number of standard persons that would cause the same effects of the involved pollutant source. The decipol is the pollution produced by one olf under a ventilation rate of 10 l/s of clean air.
By relating the olfs subjected to different levels of ventilation with the dissatisfaction of judges that find the air quality unacceptaple (6), it was possible to establish a link between the percentage of dissatisfied judges and the ventilation rate. Thus, the flow rate Q_r required for obtaining the desired quality of the perceived indoor air, is the following (7):

$$Q_r = 10 \frac{G}{C_i - C_o} \frac{1}{\epsilon_v} \qquad (2)$$

where **G**= the pollutant sources (olf), $\mathbf{C_i}$= the perceived indoor air quality (decipol), $\mathbf{C_o}$= the perceived outdoor air quality (decipol), $\boldsymbol{\epsilon_v}$= the efficiency of the ventilation system. The parameter $\mathbf{C_i}$ is related to the percentage of dissatisfied **PD**, by means of the equation:

$$C_i = 112\,[\ln(PD) - 5.98]^{-4} \qquad (3)$$

METHOD OF ANALYSIS

The method presented here, is based on the comparison of the flow rates in the actual conditions, calculated by means of equation (1), with those required to achieve a given indoor air quality, computed by means of equations (2) and (3).
For assigned climatic conditions and for given architectural features, when $\mathbf{Q_v}$ is equal or greater than $\mathbf{Q_r}$, the natural ventilation regime should guarantee the desired indoor air quality to the occupants. On the contrary, when the actual flow rate is less than Q_r, forced mechanical ventilation should be provided. Obviously, the actual ventilation rates are strongly affected by the layout of the windows and their opening surfaces, as well as by the angle of incidence of the external wind and its velocity. All these parameters can be easily changed and analyzed by means of the model mentioned in the previous sections.
Two cross-ventilated rooms have been selected with the aim of showing the suitability of the method in determining the limits of the natural ventilation. Table 1 reports the main features of the buidings, while the layout of the windows can be seen in Figures 1a and 1b.

Table 1. Characteristics of the example buildings.

	Case 1	Case 2
Building type	office	residential
Floor area (m^2)	8m·4m	8m·4m
Volume (m^3)	96	96
No. of windows (all with fly-screen)	2	4
No. of occupants	6	5
Percentage of smokers	50	20
C_o (decipol)	0.2	0.5
Pollutant sources (olf/m^2 of floor)	0.15	0.10
Ventilation efficiency	1	1
Perc. of dissatisfied	20	20

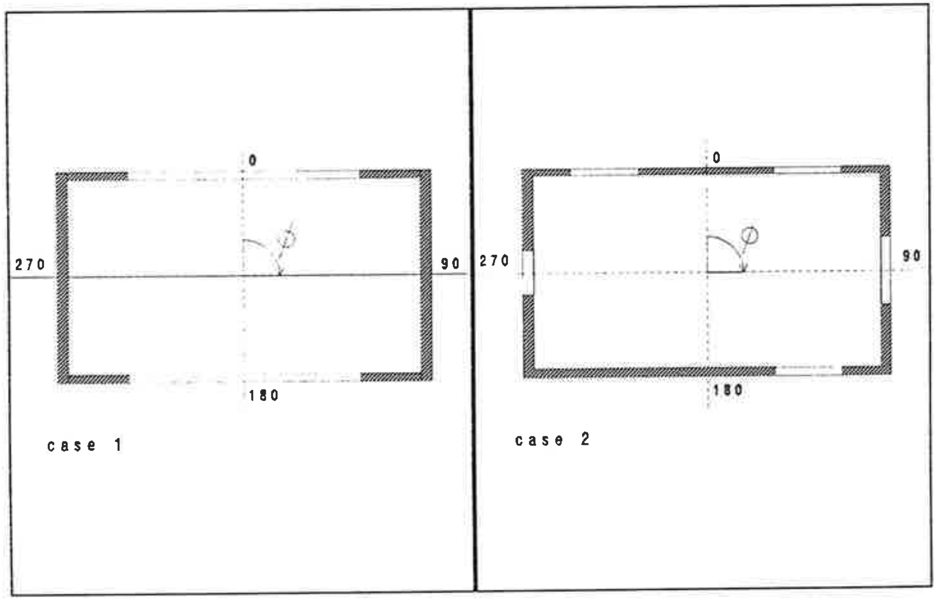

Fig. 1. Sketch of the examined rooms with the layout of the windows.

Figure 2 shows the ventilation rates (m^3/s or A.C./hour) obtained by changing both velocity and angle of incidence of the wind for the case 1. According to the current standards (8), a maximum percentage of dissatisfied (20%) has been assumed. This value defines the limits of natural and mechanical ventilation.
As it is possible to note, the direction of the wind flow is extremely important for the indoor comfort conditions. The proper ventilation rate can be achieved with an external wind velocity of approximatively 0.25 m/s, when the wind blows normally on the south window; but if the wind direction is supposed to rotate toward 75° from the south, the suitable wind velocity should reach 0.45 m/s. It's also important to note in Figure 2 that, if a percentage of dissatisfied of 30% is accepted, the useful range of the natural ventilation is significantly enlarged, being sufficient with an external wind velocity of only 0.12 m/s, with normal incidence.
Figure 3 depicts the situation for the commercial building of case 2. The presence of windows on the side walls, modifies remarkably the suitability range of the natural ventilation. The air changes, indeed, are very sensitive in this case even to small rotations of the wind direction. In fact, if the angle of incidence will vary from 0° to 30°, Figure 3 shows that the natural ventilation becomes insufficient to guarantee comfortable conditions to the occupants and the forced ventilation must be employed. It's evident that the results can't be generalized, as they largely depend on architectural and climatic situations (see Table 1 and Figure 2 and 3). Accordingly, the limit of the natural ventilation should be established for each different case.

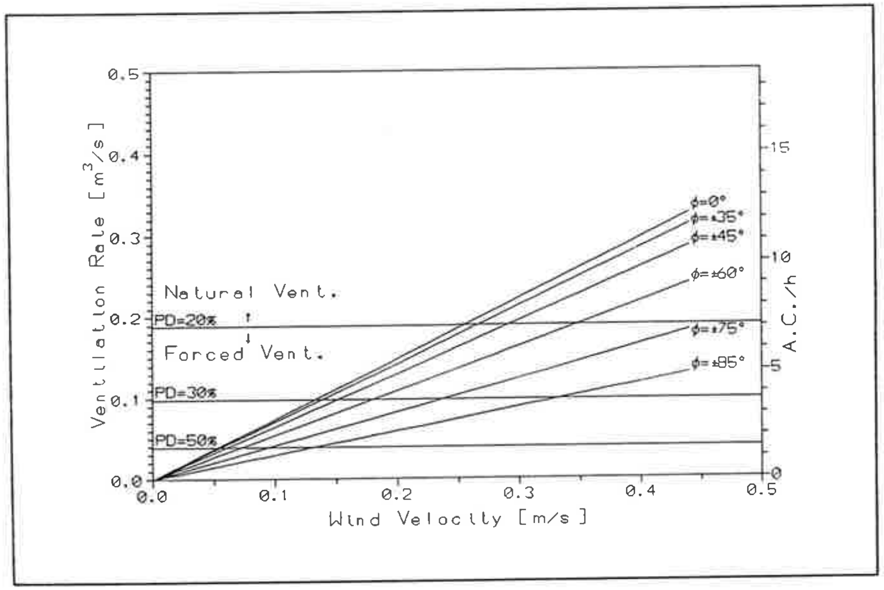

Fig. 2. Limits of natural ventilation for the room of case 1

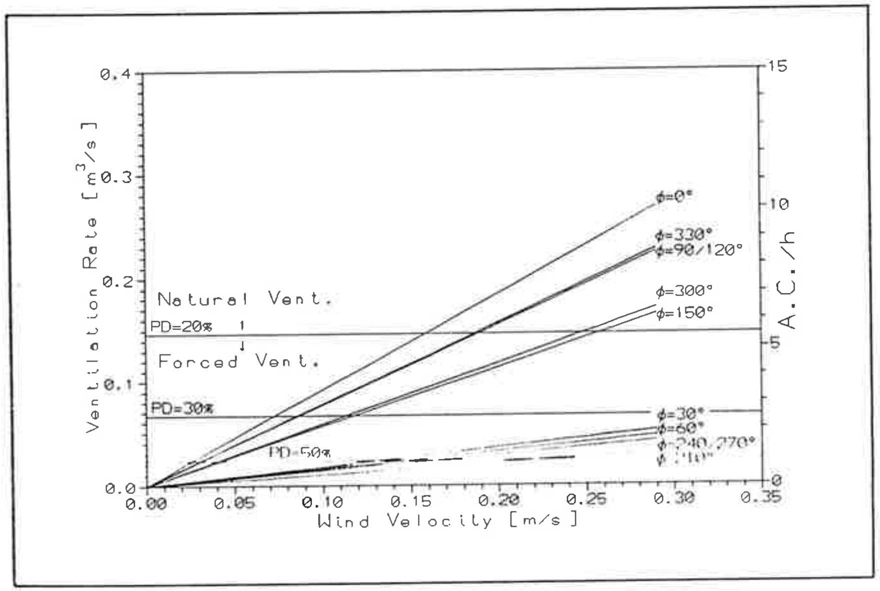

Fig. 3. Limits of natural ventilation for the room of case 2

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