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MEAN VENTILATION EFFECTIVENESS – A SENSITIVE PARAMETER: AN EXPERIMENTAL STUDY

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ABSTRACT

In order to improve the indoor air quality a change in the ventilation system is often one of the actions. The mean ventilation effectiveness or contaminant removal effectiveness is then often presented as a measure. Great care should however be taken when evaluating a system using these parameters.

Measurements have shown that in displacement ventilation the mean ventilation effectiveness can fluctuate very much for the same air flow, the same cooling load, the same inlet – outlet devices and the same height of the tracer gas supply. The vertical position of the tracer gas supply as well as the distance from heat sources in form of people, lamps, PCs etc. is of major influence. The density of the tracer gas used in the measurements is in some cases also an influencing factor.

The paper presents some results concerning these facts obtained under laboratory conditions which give an idea of the spread that can be obtained when measuring the mean ventilation effectiveness in office buildings. The paper also shows that an increased ventilation air flow rate does not always improve the mean ventilation effectiveness in displacement ventilation; in fact the effect can be the opposite. The ventilation effectiveness was found to have a maximum at a certain ventilation flow rate.

KEYWORDS

Mean ventilation effectiveness, contaminant removal effectiveness, displacement ventilation

INTRODUCTION

A mechanical ventilation system is often used to get an acceptable indoor air quality in the zone of occupancy. The ventilation design principle is then of great importance. There are mainly two design principles available, mixing ventilation which is the most common one and displacement ventilation (Nielsen, 1993) which has become more popular in the last decades, especially in Scandinavia.

Tracer gas measurements are often used to evaluate the performance of a ventilation system. Many times the results of such measurements are presented without giving the full information of how the measurements were conducted and the term ventilation effectiveness is often used when the appropriate term should be the mean value of some local ventilation indexes measured in the occupied zone. This paper illustrates how difficult it is to interpret the results of tracer gas measurements and the uncertainty in the results depending on different parameters. In a paper published earlier this year (Mundt, 1994) some results concerning the local ventilation effectiveness were presented and in this paper the variation in the mean ventilation effectiveness is investigated. Both these indices are measures of the movement and dilution of contaminants. The mixing of ventilation air is characterised by the air change efficiency.

The mean ventilation effectiveness or the contaminant removal effectiveness, ε^c, is a measure of how a contaminant is removed from a room. It is dependent on both the characteristics of the air flow and on the characteristics of the pollutant.

$$\varepsilon^c = \frac{C_e(\infty)}{\langle C(\infty) \rangle} \cdot 100 = \frac{\tau_n}{\tau_n^c} \cdot 100 \tag{1}$$

where $C_e(\infty)$ = steady state concentration at the exhaust duct

$\langle C(\infty) \rangle$ = steady state mean concentration of the room

τ_n = nominal time constant for the ventilation air = room volume / supply air flow rate

τ_n^c = nominal time constant for the contaminant = $\int_0^\infty \left[1 - C_e(t)/C_e(\infty)\right] dt$

By measuring in the exhaust duct in a step-up procedure the nominal time constant for the contaminant can be evaluated (Sandberg and Sjöberg, 1983). The nominal time constant for the ventilation air can either be calculated directly with known values or measured from a step down procedure with a uniform contamination distribution.

MEASUREMENTS

Measurements were conducted in a room 3.6x3.6x2.4 m (LxWxH) with displacement ventilation. The heat load in the room was varied, the heat sources consisting of a person simulator (100 W), a fluorescent light (36 W) and a radiator with a variable effect placed on the wall, 1 m above the floor, opposite the supply device. The ventilation air flow and supply air temperature were varied. In all cases the supply air temperature was set so that the heat load in the room was taken away by the ventilation air. The different measure situations and the positions of the tracer gas source is shown in Fig. 1. The height of the tracer gas source is 1.0 m in case A-E, 1.4 m in case F and G and 1.2 m in case H. Nitrous oxide, N_2O, or a mixture of N_2O and helium, He, were used as tracer gas. The density of N_2O is 1.8 kg/m^3 and the density of the mixture is the same as for air. The tracer gas source was made of a perforated table-tennis ball or in case of an extended source, a perforated plastic tube. The concentrations were measured with infrared analysers (Miran) and recorded together with the temperatures, measured by thermocouples, in a data acquisition system.

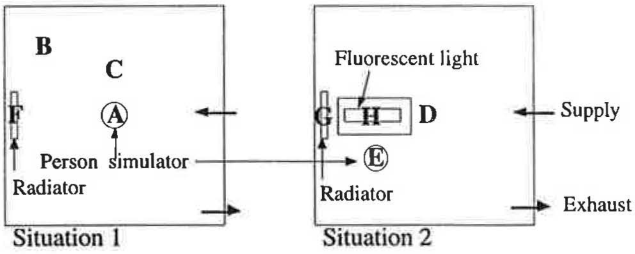

Fig. 1. Plan of the room with the different measurement situations.

RESULTS

Tables 1 and 2 show the conditions for the measurements with the heat sources present in each case as well as the ventilation air flow. The column "tracer gas source" tells whether a mixture of N_2O and He or only N_2O has been used as well as the position of the source with reference to Fig. 1. Two series of measurements are reported, the first one showing the influence of different positions of the tracer gas source and the distribution of the heat sources. The second one showing the influence of an increased air flow at a constant temperature gradient.

From Table 1, case 1-6, the influence of the position of the tracer gas source is clear. If the tracer gas is released above a heat source the mean ventilation effectiveness is of course much higher than when it is released outside a convective plume. However the power of the heat source also influences the result as well as the position of the heat source relative to other heat sources (cases 1, 4 and 6). When the gradient in the room is 2.1 °C/m, the convective plume from the person simulator does not penetrate all the way up to the ceiling (Mundt, 1992) but spreads at a lower level. The vertical transport in the remaining part of the room height is done by the plume from the radiator, so the closer the person simulator is to the radiator the faster is the transport of the contaminant to the exhaust.

Cases 2, 3 and 5 with the tracer gas source outside the convective plumes and a ventilation flow rate of 90 m^3/h show rather high mean ventilation effectiveness compared to case 13, which has the same heat load but a larger ventilation flow rate. The reason for this might be the height of a "border" where the ventilation air flow is equal to the convective air flows. For the person simulator the convective air flow at 1 m is ≈90 m^3/h (Mundt 1992), this means that the ventilation air is not penetrating the room outside the plume above the height where the tracer gas source is situated, and the tracer gas is directly trapped by the plume from the layer where it is spread and transported upwards in the central region of the plume. When the ventilation air is increased, the "border" is moved upwards and the ventilation air is passing the tracer gas source and spreading the tracer gas in a thicker layer before it is trapped by the plume. The central region of the plume is then filled with the less contaminated air from the lower region and the outer part of the plume is more contaminated. As the central part is warmer than the outer part of the plume, the central part is reaching higher up in the room and the recirculation in the upper region of the room is dominated by the outer part.

Case 7 and 9 illustrates the influence of the position of the heat sources. In case 7, where the tracer gas is released above the lamp and the radiator is the only other heat source present in the room, the contaminated air is transported rather effectively to the exhaust, although the plume from the lamp does not reach the ceiling. Because of the high positions of the heat sources with low convective air flows, the recirculation in the upper part is very small. In case 9 however, the person simulator increases the recirculation and the nominal time constant for the contaminant is increased. Cases 11-14 demonstrate the influence of the density of the tracer gas.

Table 1. Conditions for the measurements, Series I

Case	Heat source (W)			Vent. flow	Tracer gas source		Gradient	ε^c
	Person	Lamp	Radiator	m^3/h	gas	Fig 1	°C/m	
1	100	-	200	90	mix	1A	2.1	291
2	100	-	200	90	mix	1B	2.1	130
3	100	-	200	90	mix	1C	2.1	143
4	100	-	200	90	mix	1F	2.1	486
5	100	-	200	90	mix	2D	2.1	174
6	100	-	200	90	mix	2E	2.1	395
7	-	36	200	90	mix	2H	1.7	245
8	-	36	200	90	mix	2G	1.7	345
9	100	36	100	90	mix	2H	1.7	184
10	100	36	100	90	mix	2E	1.7	367
11	100	-	-	150	mix	1C	0.5	116
12	100	-	-	150	N_2O	1C	0.5	89
13	100	-	200	150	mix	1C	1.5	115
14	100	-	200	150	N_2O	1C	1.5	72

In Table 2 the influence of an increased ventilation flow rate is shown in the case where the tracer gas is released outside a plume. As can be seen from Fig. 2 an increased air flow seems to increase the mean ventilation effectiveness up to a certain value, after which an increased air flow decreases the mean ventilation effectiveness. Although the factors mentioned above about the spread of the heat sources might explain some of the values, the decrease in the effectiveness with higher flow rates is quite obvious in this experimental set-up. The gradient in the room seems to be of minor influence, but more experiments are needed. The combined air flow pattern from the convective air flows with different plume rise heights in a room with displacement ventilation is of a complex nature.

Table 2. Conditions for the measurements, Series II

Case	Heat source (W)			Vent. flow	Tracer gas source		Gradient	ε^c
	Person	Lamp	Radiator	m^3/h	gas	Fig 1	°C/m	
15	-	36	50	90	mix	2D	0.5	185
16	100	-	-	150	mix	2D	0.5	98
17	100	-	-	200	mix	2D	0.5	109
18	100	36	-	250	mix	2D	0.5	90
19	100	-	-	60	mix	2D	1	181
20	100	36	-	90	mix	2D	1	257
21	100	36	50	150	mix	2D	1	117
22	100	-	150	250	mix	2D	1	66
23	100	-	100	60	mix	2D	1.7	107
24	-	36	200	90	mix	2D	1.7	163
25	100	-	200	150	mix	2D	1.7	90

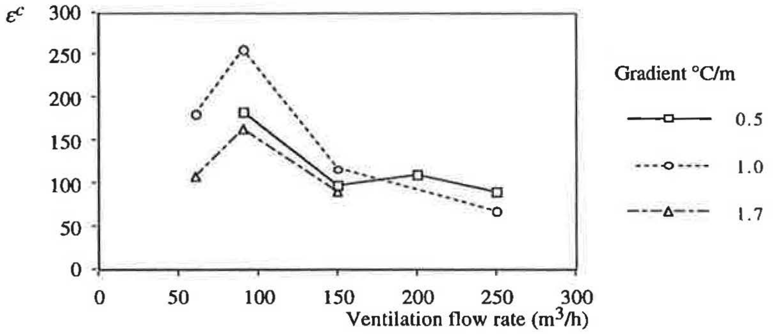

Fig. 2. Mean ventilation effectiveness in Series II.

CONCLUSIONS

The mean ventilation effectiveness in displacement ventilation is very much dependent on the position of the heat sources and the position of the contaminant source during the measurements. The interaction between the convective plumes in the room depending on the temperature gradient and the layout of the heat sources is of a complex nature. Great care should be taken when evaluating tracer gas measurements and the influence of a person might change the situation completely.

Measurements also showed that an increased ventilation rate does not always increase the mean ventilation effectiveness, but the effect can be the opposite in displacement ventilation.

ACKNOWLEDGEMENT

The Swedish Council for Building Research supported this work.

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