the mean throughout the building, though some larger differences did occur. While additional study is required to determine if 10% is an appropriate limit for concentration uniformity, it is encouraging that this degree of uniformity was achievable under such difficult circumstances. Attaining uniformity required almost an entire day and involved adjusting the HVAC system controls to keep the outdoor air intake rate as constant as possible. Unexpected modulations in the outdoor air intake rate or inabilities to attain equilibrium for other reasons caused some tests to be aborted. The impact of modifying the HVAC controls on the rest results are not known. In a given building, the system operation characteristics under which reliable measurements can be conducted may severely limited.

The issue of what value should serve as a reference when computing ventilation effectiveness from the age of air in the occupied space has been addressed before (5). The use of the nominal time constant of the building τ_n is inappropriate because its use combines the effects of nonuniform outdoor air delivery throughout the building with the effects of nonuniform ventilation air mixing within the occupied space. It is more appropriate to use a value of the age of air in the return air for the space in question. The ventilation system layout and zoning will affect exactly where the return age of air can be measured. Additional research is needed to determine the most appropriate reference value for local age of air measurements.

Even with the measurement difficulties and uncertainties, the values of air change effectiveness in the occupied space were generally near 1.0. Some deviations from one did exist, but based on the limited experience with these measurement procedures it is not clear whether these deviations are significant. Nonetheless, the results are consistent with good mixing of the ventilation air within the occupied space, as has been the case the limited testing to date (5,6).

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CONTAMINATION DISTRIBUTION IN DISPLACEMENT VENTILATION - INFLUENCE OF DISTURBANCES

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ABSTRACT

Tracer gas measurements have shown that in a room with displacement ventilation pollutants can be locked in at different levels depending on how they are produced, temperature gradients and ventilation air flows versus convective air flows. The upper zone is not a well mixed zone, sometimes well defined layers of pollutants can be found. The concentrations can be very fluctuating in the layer between the upper and lower zones. The distribution is very sensitive to disturbances, opening and closing of a door can cause a great decrease in the local ventilation effectiveness at a point. In spite of this or perhaps because of this a person can get a good air quality in the breathing zone, even if this zone is in a polluted layer. The convective plume around a body breaks through the polluted layers and very rapidly increases the local ventilation effectiveness. The displacement ventilation acts as a demand controlled system for clean air from the lower parts of the room. If however the lower parts are polluted the reverse effect, a decrease in the local ventilation effectiveness, is obtained.

INTRODUCTION

Displacement ventilation provides a well defined air transport within the convection plumes from the lower part of the room to the upper part. The temperature gradient is stable and not very sensitive to disturbances by people or door openings (1). However the contamination distribution is not as stable and behave in another way than the temperature distribution (2, 3, 4). The objective of this work is to study the behaviour of contamination distribution under different conditions.

Different tracer gases are used to study the contamination distribution from different sources (heated and not heated) under laboratory conditions. The measurements are conducted under the same conditions that have been previously used to study convection flows and temperature gradients (1, 5, 6).

The ventilation effectiveness and the air exchange efficiency are measured as well as the ventilation indices and the local air exchange indices for some points. The influence of disturbances caused by opening and closing a door is studied. The change in the local air exchange indices for some points are measured when a person enters the room. The spread of tracer gas released outside a convection plume is depending on the type of gas used. The concentration profiles in the room indicate a very strong stratification. Low local air exchange indices are found outside the plume and a connection between the local ages (which can be higher than the age of the air in the exhaust duct) and the sensitivity to disturbances is presented.

MEASUREMENTS

The measurements are conducted in a room with L= 3.6 m, W=3.6 m and H=2.4 m. The room is equipped with displacement ventilation and a heat source representing a person simulator (100 W) placed in the centre of the room. A higher gradient is obtained by using a radiator (200 W) placed 1 m above the floor on one of the walls. The temperatures measured by 56 thermocouples and the concentrations measured by 2 infrared analyzers (Miran) are recorded at variable time steps and collected for further analysis. Two tracer gases are used, N_2O with a density of 1.8 kg/m^3 and a mixture of N_2O and He with a density equal to air. The tracer gas is supplied either as a point source in the room, placed in the convective plume from the person simulator or outside it, or in the supply air. Fig 1 shows the room and the placing of the different measuring points. Altogether 12 tubes is used to measure the concentrations, only two at the time though.

Two different ventilation air flows is used (150 m^3/h and 93 m^3/h) and two different heat loads (100 W and 300 W). With the above mentioned variation for the tracer gas this gives altogether 16 measuring situations, only some of these are however reported in this paper.

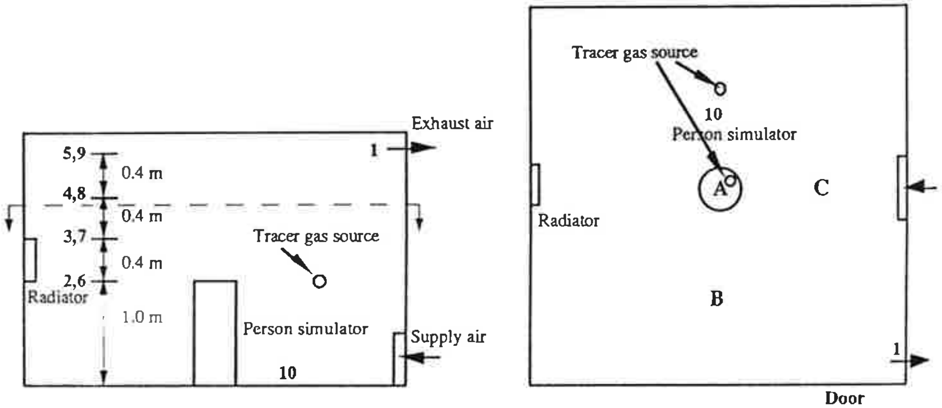

Fig 1 Plan of the room used for the measurements, tracer gas concentrations (1-10) were measured at the levels shown in the left figure and the position of the tubes in the room is shown in the right figure.

The measurements are conducted in the following way:

1. step up procedure to measure the *mean ventilation effectiveness*

$$<\varepsilon> = \frac{\tau_n}{\tau_t} \cdot 100 = \frac{C_e(\infty)}{<C(\infty)>} \cdot 100 \qquad (1)$$

where $C_e(\infty)$ = concentration in the exhaust duct, $<C(\infty)>$ = mean concentration in the room

2. measuring of the *local ventilation effectiveness*

$$\varepsilon_p = \frac{C_e(\infty)}{C_p(\infty)} \cdot 100 \qquad (2)$$

where $C_p(\infty)$ = concentration at a point in the room

3. mixing of the air in the room and changing the tracer gas supply to the supply air duct
4. the mixing is stopped and the temperature gradient allowed to develop
5 stopping the tracer gas supply and measuring *the air exchange efficiency*

$$<\varepsilon_a> = \frac{\tau_n}{2<\tau>} \cdot 100 \qquad (3)$$

where $\tau_n = \frac{V}{q}$ = nominal time constant and $<\tau>$ = room mean age of air
and the *local air exchange effectiveness*

$$\varepsilon_{ap} = \frac{\tau_n}{\tau_p} \cdot 100 \qquad (4)$$

where τ_p = local age of air at a point
During step 2 different influences of disturbances are studied.

The temperature gradients, the volume flows in the convective plumes and the heights to which the convective plumes rise as well as the the level at which they start to disintegrate can be calculated by methods presented earlier (1, 5, 6).

RESULTS

The air exchange efficiency $<\varepsilon_a>$ and the local air exchange effectiveness ε_{ap} for some points in the room are given in table 1 for different situations. The parameters were in one case measured without letting the gradient develop after the mixing of the room air. The gas supply and the fans were stopped at the same time and the measurements started. These values are also presented in table 1. Table 2 presents the mean ventilation effectiveness $<\varepsilon>$ for the different cases.

Table 1 Air exchange efficiency $<\varepsilon_a>$ and local air exchange effectiveness ε_{ap} for different situations with point 2-5 in the plume, position A and point 6-9 in position B.

Ventilation flow rate	150 m^3/h			93 m^3/h	
Heat load, gradient	100 W, 0.6 °C/m		300 W, 1.5 °C/m	100 W, 0.6 °C/m	300 W, 2 °C/m
	without gradient	with gradient			
$<\varepsilon_a>$	80	77	72	74	72
ε_{ap2}	242	242		264	
ε_{ap3}	207	168		182	
ε_{ap4}	181	162		150	
ε_{ap5}	128	125		132	
ε_{ap6}	219	182	150	120	148
ε_{ap7}	140	113	103	88	103
ε_{ap8}	116	117	104	83	109
ε_{ap9}	127	121	115	122	115
ε_{ap10}	589	407		372	

Table 2 Mean ventilation effectiveness $<\varepsilon>$ with different tracer gases and gas release position.

Ventilation flow rate	150 m^3/h					93 m^3/h			
Heat load, gradient	100 W, 0.6 °C/m				300 W, 1.5 °C/m	100 W, 0.6 °C/m		300 W, 2 °C/m	
Tracer gas	N_2O		N_2O+He		N_2O+He	N_2O+He		N_2O+He	
Tracer gas outlet	plume	room	plume	room	room	plume	room	plume	room
$<\varepsilon>$	183	89	192	116	115	161	92	164	94

The local ventilation effectiveness at different levels are presented in fig 2 and 3 for tracer gas N_2O+He. In the figures is also shown the levels at which the convection flows from the personal simulator equals the ventilation flows. This is said to be the border between two zones in the room. The rising area of the plume is shown as well, the top of this is the maximum height to which the plume rises for a certain gradient in the room and the lower level is the height at which the density difference in the plume has disappeared.

From table 1 can be seen that the air exchange efficiency $<\varepsilon_a>$ is only slightly influenced by the temperature gradient being formed before the measurements. This can be explained by the fact that the gradient is formed very quickly after the fans are turned off, measurements have shown that the gradient is redeveloped after 5 minutes. The table also shows that the air exchange efficiency doesn't change much with the ventilation air flow or the temperature gradient in the room.

The local air exchange effectiveness ε_{ap} however is influenced by both the formation of the gradient and the ventilation air flow as well as the resulting gradient in the room. Especially point 6 and 7 get a lower air exchange effectiveness when the gradient is formed before the measurements starts. This is explained by the fact that the temperatures in these points after the mixing are higher than after the gradient is formed so the air exchange in these points is very high in the beginning of the formation of the gradient.

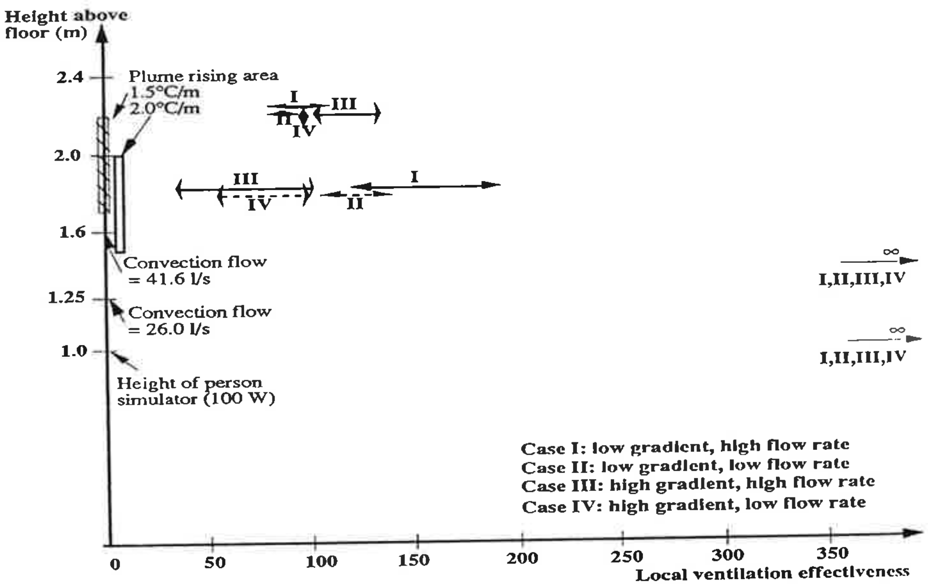

Fig 2 Local ventilation effectiveness at different levels at position B when the tracer gas source is in the plume.

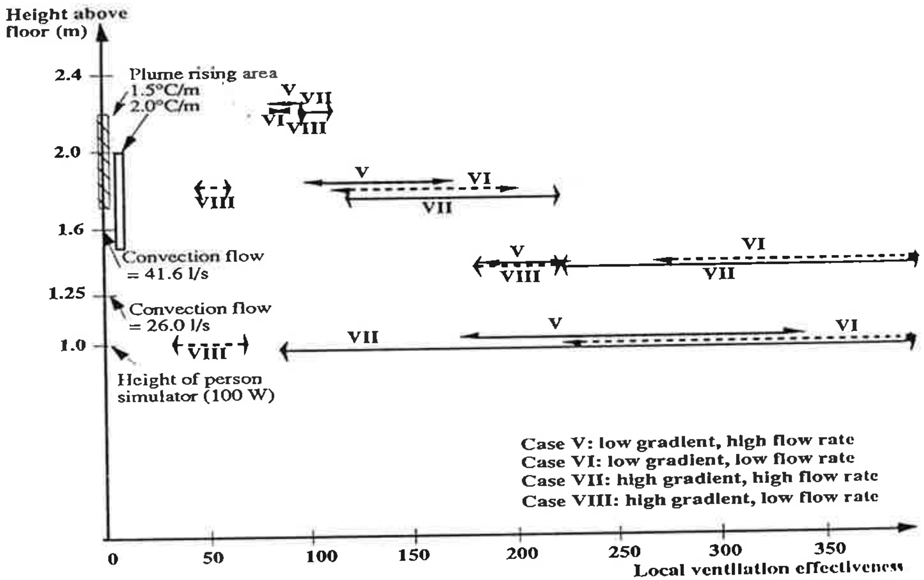

Fig 3 Local ventilation effectiveness at different levels at position C when the tracer gas source is outside the plume.

It can also be seen that points 6 and 7 have a very low air exchange effectiveness when the ventilation flow rate is decreased with the lower gradient, the age of the air is then higher in theses points than the age of the air in the exhaust.

The mean ventilation effectiveness $<\varepsilon>$, table 2, is naturally increasing when the tracer gas is released in the plume than when it is released outside the plume, also a heavy tracer gas gives a lower mean ventilation effectiveness.

Fig 2 shows that if the pollutant is released in the plume the lower part of the room is free from tracer gas even if the ventilation air flow is less than the convective air flow from the heat source. In case of a high temperature gradient the concentration has a maximum at the level at which the plume is spreading out horizontally. When the tracer gas is released outside the plume, fig 3, the concentration profile gives two maxima (minima of the local ventilation effectiveness) for a low air flow and a high temperature gradient. The concentrations are very fluctuating as can be seen from fig 2 and 3.

Two types of experiments were made concerning the stability of the concentration in the room. First the influence of opening the door and closing it again and second the influence on the local ventilation effectiveness in some points of a person entering the room.

In case VI in fig 3 (low gradient, low air flow rate and tracer gas released outside the plume) the door was opened and closed and the concentration in point 7 (1.4 m above the floor at pos C), was studied. Fig 4 shows the local ventilation effectiveness during the measurement. As can be seen the local ventilation effectiveness decreases very much for about 5 minutes and then slowly returns to the initial value. From table 1 the local air exchange effectiveness at this level is 88, the nominal time constant for the low flow rate is 0.33, this gives the mean age of the air at the point to be 22 min. The time for the concentration to return to the initial value after the maximum is also about 20 minutes.

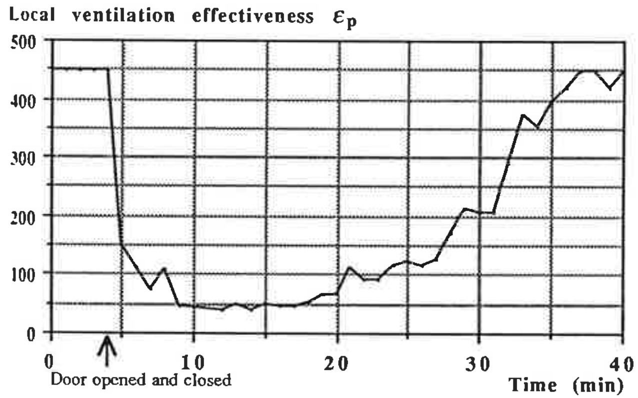

Fig 4 Local ventilation effectiveness in point 7 when the door is opened and closed

In case IV in fig 2 (high gradient, low air flow rate and tracer gas released in the plume) the concentrations in point 4, pos C and 8, pos B (1.8 m above the floor) were studied when a person entered the room and stood at the positions B and C for 5 minutes at each place. Fig 5 shows the local ventilation effectiveness in these points. As can be seen the air is immediately cleaner in the points because of the convection plumes around the body. After the persons left the room the concentrations returned to the original ones, and the same time dependence as mentioned above was noticed.

Other experiments showed the same effect, each person creates its own convective plume taking the air from the lower parts of the room. The same experiments were done with case VIII in fig 3, when the concentration at the level 1.0 m is high. For this case the concentration at level 1,4 m and above increased and gave a decrease in the local ventilation effectiveness when a person entered the room. The temperature gradients were not influenced by the persons entering the room, only a slight move to a higher temperature was noticed because of the increased heat load in the room.

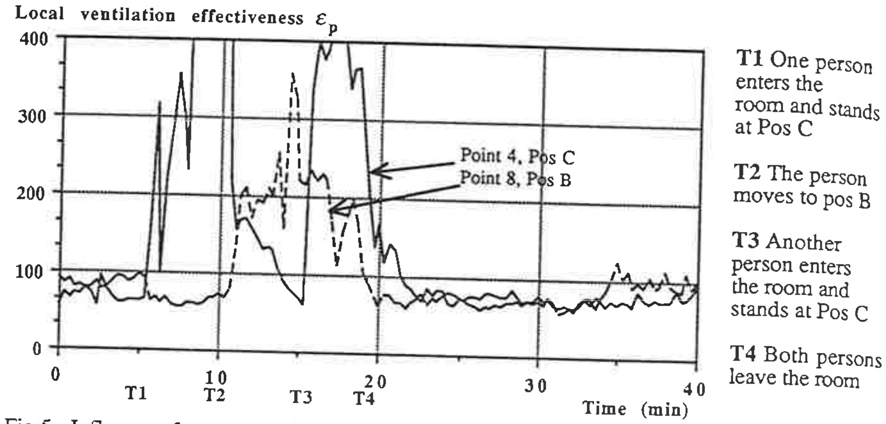

Fig 5 Influence of persons on the local ventilation effectiveness at the level 1.8 m.

CONCLUSIONS

In a room with displacement ventilation pollutants can be locked in at different levels depending on how they are produced, temperature gradients and ventilation air flows versus convective air flows. The upper zone is not a well mixed zone, sometimes well defined layers of pollutants can be found. The concentrations can be very fluctuating in the layer between the upper and lower zones. The distribution is very sensitive to disturbances, opening and closing of a door can cause a great decrease in the local ventilation effectiveness at a point. In spite of this or perhaps because of this a person can get a good air quality in the breathing zone, even if this zone is in a polluted layer. The convective plume around a body breaks through the polluted layers and very rapidly increases the local ventilation effectiveness. The displacement ventilation acts as a demand controlled system for clean air from the lower parts of the room. If however the lower parts are polluted the reverse effect, a decrease in the local ventilation effectiveness, is obtained.

ACKNOWLEDGEMENTS

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LOCAL EXHAUST VENTILATION - A NUMERICAL AND EXPERIMENTAL STUDY OF CAPTURE EFFICIENCY

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ABSTRACT

Capture efficiency of a local exhaust system, e.g. a kitchen hood, should include only contaminants being direct captured. In this study basic concepts of local exhaust capture efficiency are given, based on the idea of a control box. A validated numerical model is used for estimation of the capture efficiency. An experimental technique is introduced for field studies taking into account knowledge of flow patterns of air and contaminants obtained from smoke testing and contaminant concentrations. Holding together numerical and experimental data a fair agreement is observed.

INTRODUCTION

The main function of a kitchen hood is to extract pollution from cooking in order to keep the pollution level in the occupied space as low as possible. Basically a kitchen hood is intended to provide an air movement that will carry pollutants from the domain of release into the exhaust opening. It is common practice to characterize pollutant removal performance of kitchen hoods in terms of capture efficiency defined as the ratio between the flow rate of captured pollutants and the total emission rate of pollutants from the source. Although fairly simple in principle it is far from obvious how to estimate capture efficiency of a local exhaust system, e.g. a kitchen hood. As discussed elsewhere (1) standards for testing of kitchen hood capture efficiency are available. The purpose of this study is to introduce some fundamental concepts of local exhaust capture efficiency, and to derive general recommendations for testing of local exhaust systems. The study is not aimed at kitchen hoods but at local exhaust ventilation in general.

METHODS

Concepts of local exhaust capture efficiency

Consider a local exhaust opening (flow rate q_{le}) at a source of constant emission rate, S. At steady state the capture rate of the exhaust is S_{le} and concentration at the exhaust duct is C_{le}. Then the total capture efficiency is

$$\eta_{le}^{tot} = \frac{S_{le}}{S} = \frac{q_{le} \times c_{le}}{S} \qquad (1)$$

As pointed out by Jansson (2) S_{le} should include only contaminants being direct captured. Let this "direct" efficiency be denoted η^d_{le}. An estimate of η^d_{le} can be obtained from a mass