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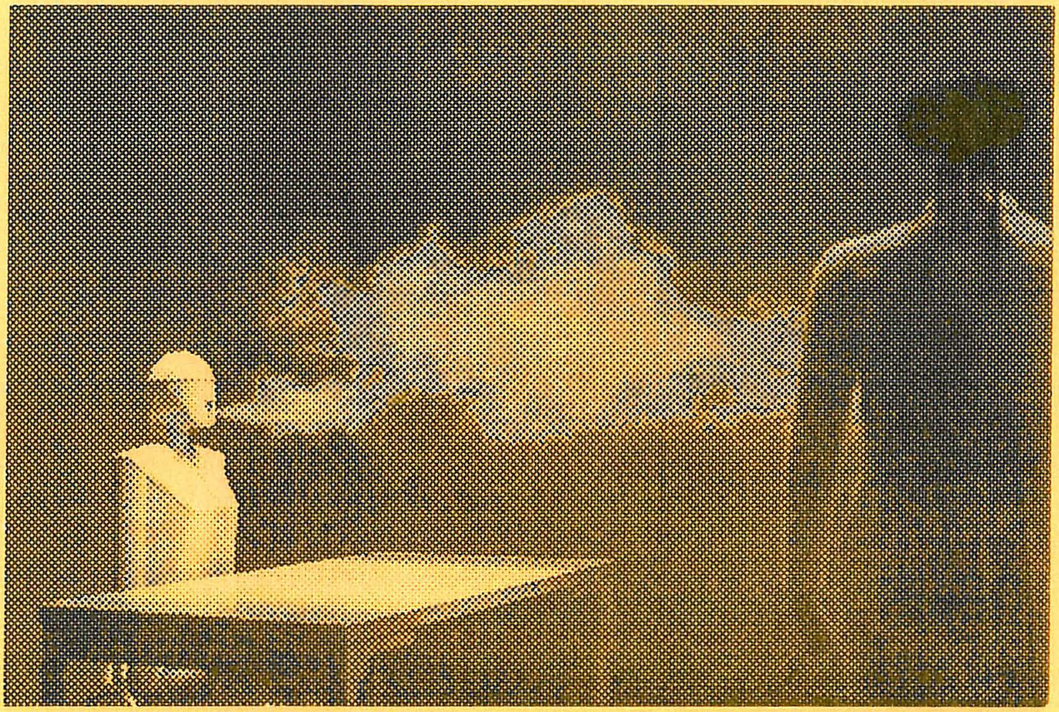

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PAPER NO. 69

Proceedings of Indoor Air '96, 7th International Conference on Air Quality and Climate, Nagoya, Japan

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PASSIVE SMOKING IN A DISPLACEMENT VENTILATED ROOM

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ABSTRACT

The aim of this research is to see if the displacement ventilation principle can protect a person from exposure to passive tobacco smoking. This is done by full-scale experiments with two breathing thermal manikins, smoke visualisations, and tracer gas measurements. In some situations, exhaled smoke will stratify in a certain height due to the vertical temperature gradient. This horizontal layer of exhaled tobacco smoke may lead to exposure. In other situations, the smoke is mixed into the upper zone, and the passive smoker is protected to some extent by the displacement principle and the convective boundary layer flow around the body.

INTRODUCTION

In a displacement ventilated room, the contaminant distribution is often assumed to be described by the two-zone model, ie. the room is divided into a lower, clean zone and an upper, polluted zone. Ideally, the air inhaled by occupants should come mainly from the lower, clean zone. The benefits of the system are high ventilation and temperature efficiencies. However, it is well known that the traditional two-zone model is only a rough approximation of the true concentration distribution. The inhaled concentration is lower than the ambient concentration in most cases, but not always. These subjects have been addressed by several workers, see eg. (Stymne et.al 1991), (Brohus et.al. 1996), (Mundt 1996). The aim of this research is to see if the displacement ventilation principle can protect a person from exposure to passive tobacco smoking. This means that the focus is on the human respiration. Exhaled air will rise due to its buoyancy. This is a very weak flow and may, similar to plumes, easily meet isothermal conditions in a displacement ventilated room, where a vertical temperature gradient is always present. According to (Hyldgaard 1994) exhaled air has been observed to stratify in a certain height due to the temperature gradient. It is not clear if this stratification will always occur, or if it will result in larger exposure to contaminants. These are the main questions of this investigation.

METHODS

This is an experimental study, carried out in a full-scale test room, ventilated by the displacement principle. The room is 8 m long, 6 m wide and 4.7 m high. The walls are made of 22 mm uninsulated plywood. The floor is insulated with 50 mm mineral wool. The surrounding laboratory is kept at 20-22 °C. Fresh air is supplied through a wall mounted, low velocity inlet device, and extracted through two circular openings (diameter 250 mm) in the ceiling (see figure 1). Human beings are simulated by two breathing, thermal manikins, which are described in more detail below. Two types of additional heat sources are used: 1) a so-called "person simulator" consisting of a steel cylinder (diameter 0.4 m, height 1.0 m), painted in a dull black colour, and with four light bulbs inside as heat source. This is the same type of person simulator as described in eg. (Kofoed et.al.1991). 2) a point source consisting of four heating coils shielded by a small,

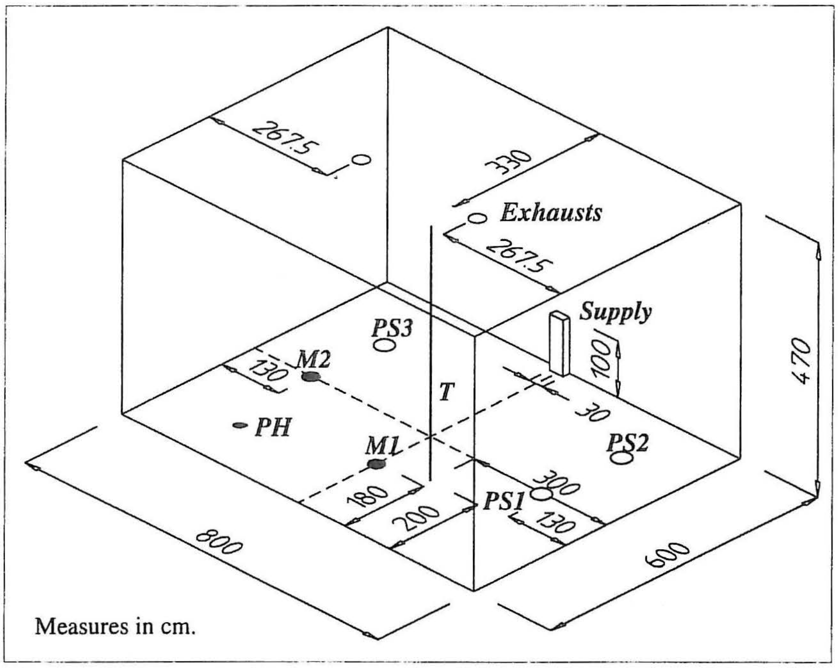


Figure 1 : Test room, situation of supply (S), exhausts (E), manikins (M), Person simulators (PS), Point heat source (PH).

blank steel cylinder (diameter 0.15 m, height 0.2 m, open in the top).

Two different fresh air supply rates are used, 160 m^3/h and 400 m^3/h, which corresponds to situations with respectively low and high stratification height. Different combinations of air supply rate and thermal load are chosen to produce different combinations of vertical temperature gradient and stratification height.

Four different setups of the room are investigated.
1) Air supply rate 400 m^3/h, thermal load: M1, M2, PS1, PH.
2) Air supply rate 160 m^3/h, thermal load: M1, M2, PS1, PH.
3) Air supply rate 400 m^3/h, thermal load: M1, M2.
4) Air supply rate 160 m^3/h, thermal load: M1, M2, PS1, PS2, PS3, PH.

Total heat effect of each heat source: M1: 75 W, M2: 100 W, PS: 100 W, PH: 500 W.

Breathing thermal manikins

Manikin no.1, "The Passive Smoker": This manikin is developed at the Danish Technical University. It is shaped as a 1.7 m high average sized woman. The surface area is 1.47 m^2. The tight fitting clothes have an insulation value of 0.8 clo. The manikin consists of a fibre armed polyester shell, wound with nickel wire used sequentially to measure the surface temperature and to heat the manikin to a specified skin temperature in 16 individual zones. The skin temperature and the heat output correspond to a person in thermal comfort.

Manikin no.2, "The Smoker": This manikin is developed by the first author of this paper. The external geometry of the manikin is designed to be as similar as possible to that of manikin no.1. The surface area is 1.44 m^2. The manikin consists of a hollow aluminium shell. Inside it is equipped with two fans, forcing the air to circulate rapidly, and with 15 m of heating wire distributed evenly throughout the interior of the manikin, thus ensuring an even temperature distribution. The total heat effect supplied to the manikin can be controlled between 0 - 400 W.

The mouth, which is used for exhalation in these experiments (since this is typical of active smokers), consists of a circular opening (diameter 12 mm).

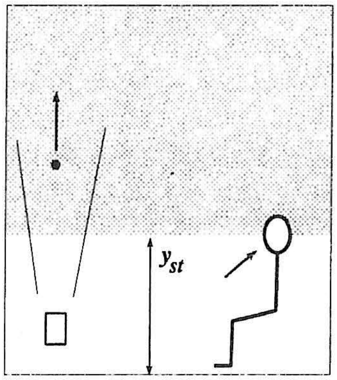
Artificial lungs: Both manikins are connected to artificial "lungs" that provide respiration through mouth and/or nose. An artificial "lung" consists simply of cylinder with a piston driven by an electric motor. This produces a pulsating, sinusoidal breathing, quite similar to reality. The chosen pulmonary ventilation is 6.0 liter/min, respiration frequency is 10 min $^{-1}$, corresponding to a person at rest.

The air flow pattern is visualised with smoke. Temperatures are measured with thermocouples (type K, accuracy ±0.15°C) and a data logger (type Fluke Helios 2287 A) connected to a PC. The contaminant distribution is studied by tracer gas measurements using Dinitrogenoxide (N_2O) as tracer gas, and a gas analyser (type Brüel & Kjær 1302). N_2O is 44/29 times heavier than atmospheric air, but is considered appropriate as tracer gas for the following reasons: 1) N_2O is added to the air exhaled by a manikin to simulate exhaled tobacco smoke. At equal temperatures, exhaled air is heavier than air due to the content of CO_2 and water vapour. The concentrations of N_2O in the exhalation (ca.4%) are close to the natural concentration of CO_2 in exhalation air. 2) The excess temperature is of greater importance to the flow of the exhaled air than the above-mentioned differences in molecular weight. The exhaled air is heated to 32°C, which is the temperature of exhaled air from human beings (Cole 1982). The room air is 20-22 °C.

RESULTS

Stratification heights

In all four experimental setups, the stratification height y_{st} that would result from the pollution source being simultaneously a heat source (as often assumed when dealing with displacement ventilation) is found by adding tracer gas above a heat source (preferably the point source) at a height of 2 m (see figure 2). The measured concentration c is made dimensionless by the return concentration c_R.The dimensionless concentration profile (see figure 2) does not necessarily show all the typical two-zone-model characteristics. There can be both vertical and horizontal concentration gradients inside the two zones due to eg. downdraft at the walls.



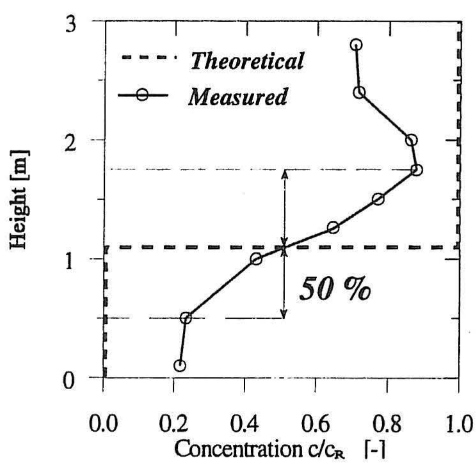


Figure 2 + 3: Estimation of y_{st}

Temperatures

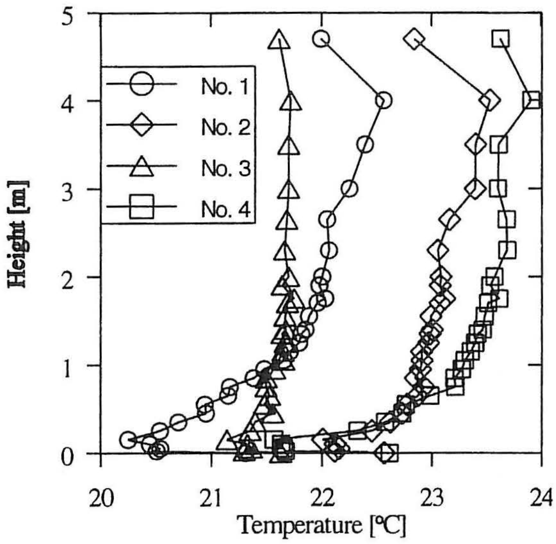


Figure 4 : Vertical temperatur profile for exp. 1-4.

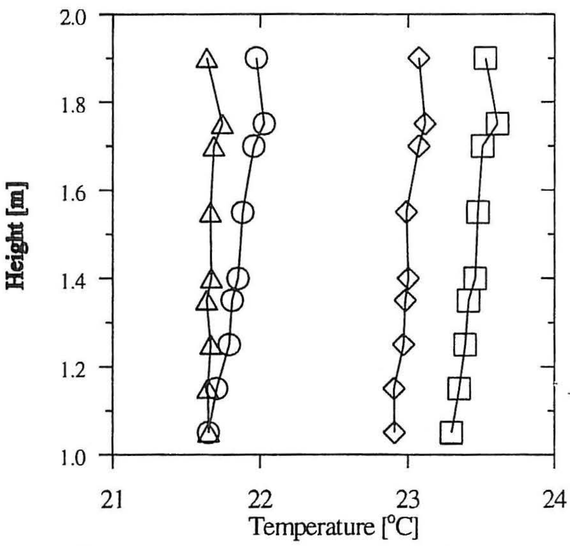


Figure 5 : Vertical temperature profiles, height 1- 2m.

Due to the uninsulated walls of the test room, it was difficult to produce vertical temperature gradients with much difference. The gradients in the area of most interest (1-2 m) vary between 0.0 - 0.5 °C/m. (Exp. No.1: 0.5 °C/m, No.2: 0.3 °C/m, No.3: 0.0 °C/m, No.4: 0.4 °C/m) In real life, vertical temperature gradients will often be larger (Up to ca. 1.0 °C/m).

Smoke visualizations

In all experiments, the flow pattern is visualised with smoke. This is illustrated with a photo for experiment no.1. The other visualisations are shown as shematic drawings in the following.

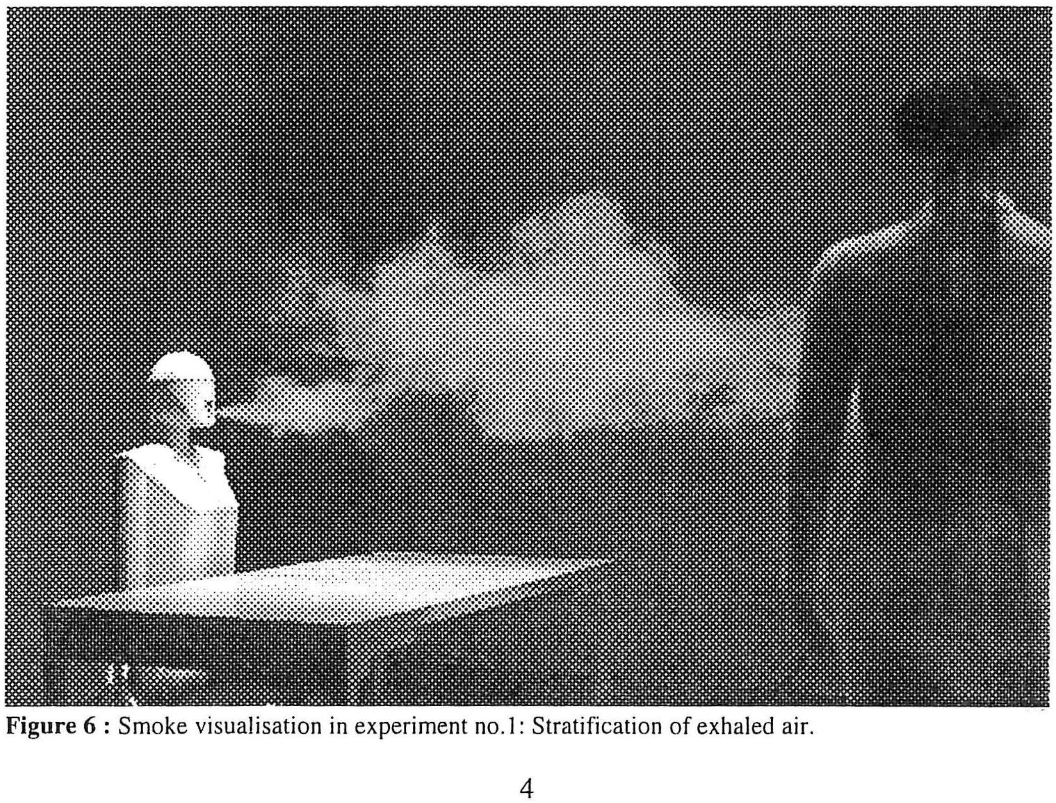
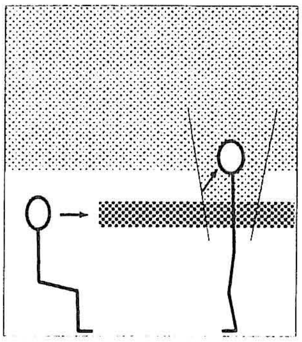
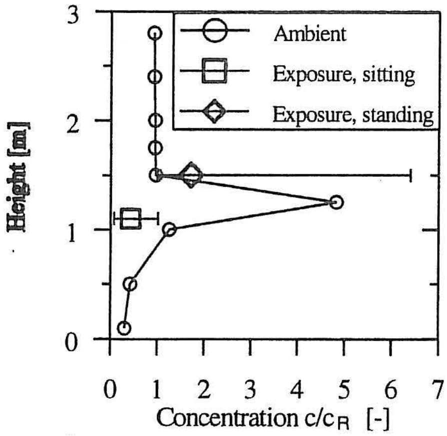


Figure 6 : Smoke visualisation in experiment no.1: Stratification of exhaled air.

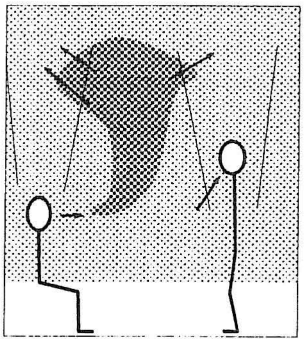
Tracer gas measurements and smoke observations

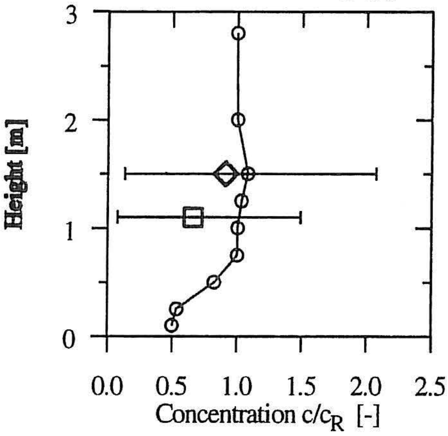




Experiment no. 1

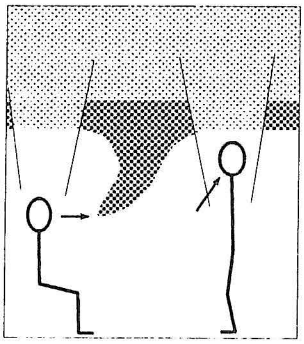
Pictures to the left:
Light gray area shows y_{st} estimated by the method described in the above.
Dark gray area shows smoke observation.

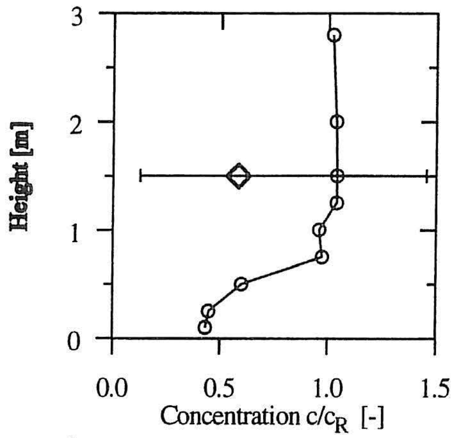




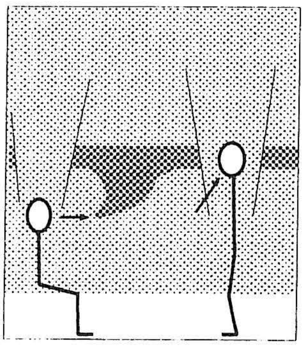
Experiment no. 2

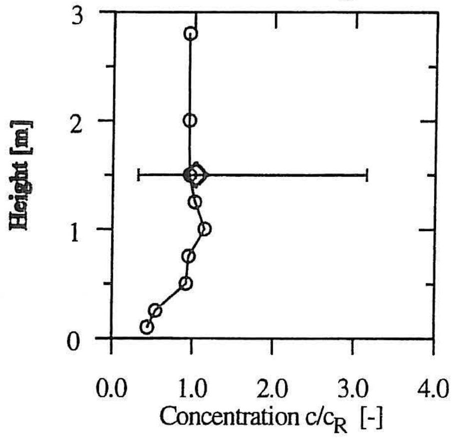
Pictures to the right:
All symbols as in exp.no.1. Concentrations are made dimensionless by dividing with return concentration c_R. The horisontal lines show the full range of exposure measurements, from minimum to maximum.





Experiment no. 3





Experiment no. 4

DISCUSSION

In these experiments, it is demonstrated that the exhalation flow may stratify because of density differences, and that high concentrations can occur in the breathing zone. In (exp.1, standing) the exposure is much larger than one would usually expect. The convective boundary layer close to the human body modifies the concentration field locally, so that the inhaled concentration is different from the ambient concentration at the same height. If the exhalation is to give rise to unusually high levels of exposure, the stratified layer must be situated below breathing height (Exp.1, standing). In other cases, the stratified exhalation flow will be entrained by plumes from other heat sources, and this will ensure mixing of the stratified flow into the entire upper zone. Many heat sources will generally give rise to effective mixing.

The vertical temperature gradient is assumed to play a role with regard to the stratification height of the exhalation. It seems that a steep gradient means low stratification height. In many practical situations, the gradient will be steeper than in these experiments. This probably means that stratification of exhalation will occur at low height, thus reducing the effectiveness of the system. However, this is only indicated by the present research.

The absolute temperature difference between the exhaled air and the room air was not exactly the same in all experiments. This did not have any obvious effect on the results, indicating that the flow pattern is not sensitive to minor deviations of this parameter.

The results may be distorted by downdraft at walls. Furthermore, the exhalation is a very weak flow, so the stratification height is sensible to small changes in temperature gradients, and there may also be density differences between parrafin smoke and tracer gas. There may be horisontal gradients with regard to temperatures and concentrations, and these are only measured at one horizontal locality. Finally, the smoke observations only cover a very short period of time, while the tracer gas measurments are taken for many hours.

One can not be sure that tobacco smoke will behave in exactly the same way as the tracer gas. The tobacco smoke contains a multitude of particles and gases, which do not neccesarily all behave alike with regard to the buoyant forces. The "smoking behaviours" of individual smokers are not taken into account, and the "sidestream" of smoke from cigarettes is not considered. Thus, the present experiments are not intended to reproduce in every detail, say, a smoking lounge, but rather to demonstrate some interesting properties which must be taken into account..

ACKNOWLEDGEMENTS

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