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Experiments on the Microenvironment and Breathing of a Person in Isothermal and Stratified Surroundings

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SUMMARY
This study investigates the characteristics of human exhalation. Experiments are performed on a breathing thermal manikin in a test room. The manikin is heated, and an artificial lung is used to generate varying air flows with specific flow rates and temperatures for breathing. Smoke visualisation is used to show the formation, movement and disappearance of the exhalation jets from both nose and mouth. The exhalation of breathing without ventilation in the room, and with stratified surroundings (displacement ventilation) is analysed.

KEYWORDS
Exhalation, Breathing, Microenvironment, Displacement ventilation, Personal thermal plume.

INTRODUCTION
More and more people are spending a considerable amount of time in the indoor environment. It is therefore important to minimise the amount of contaminants that people are exposed to indoor to give an experience of good air quality and to minimise the danger of e.g. cross-infection. Different air distribution systems offer different possibilities of protection of people against contaminants. The contaminants are mixed in the room by the air distribution systems, as e.g. mixing ventilation, and they are removed by a dilution process (Qian et al. 2006).

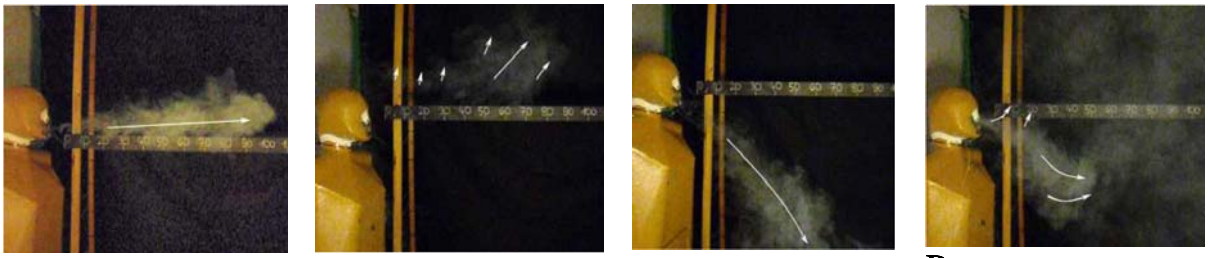
The different air distribution systems generate a characteristic macroenvironment (contaminant distribution, temperature distribution and velocity distribution) see Qian et al. (2006). The microenvironment close to the persons is not fully controlled by the air distribution system. Transport processes in the breathing flow have been reported by Marr et al. (2008), and the transport processes in the microenvironment between two people have been reported by Bjoern and Nielsen (2002) and Nielsen (2008). This paper deals with this microenvironment, especially the instantaneous exhalation through the mouth and the nose.

METHODS
The person is simulated by a life-size breathing thermal manikin. The manikin can either have exhalation through the mouth or the nose. The exhalation rate is set to15 times per minute, the volume of exhaled air is set to 0.75 l per exhalation, and the temperature is 34.0 ^{o}C for breathing through the mouth and 33.0 ^{o}C for breathing through the nose. There is no pause between exhalation and inhalation. The exhalation can also be isothermal. The manikin has a standing position, and it has a heat output of 94 W. Flow in the microenvironment is measured by smoke visualisation, velocities by Dantec 54R10 hot sphere anemometer, and temperatures by thermocouples type K. The experiments are performed in a 3.17 m (L) × 2.64 m (W) × 2.93 m (H) test room, either without ventilation or with displacement ventilation (to create the stratified flow in the occupied zone). Constant temperature conditions without

ventilation are achieved by using an open door to a large air volume in the laboratory. Room temperature at head height is 21.0 ^{o}C.

RESULTS AND DISCUSSION

Exhalation flow in a room without ventilation



A B C D

Figure 1. Exhalation 2.5 seconds after start of a sequence. A) Isothermal exhalation flow from mouth and isothermal manikin. B) Non-isothermal exhalation (34.0 ^{o}C) and heat output from manikin. C) Isothermal exhalation flow from nose and isothermal manikin. D) Non-isothermal exhalation (33.0 ^{o}C) from nose and heat output from manikin.

Figure 1 shows the exhalation flow and the influence of the plume around the manikin as well as the influence of the temperature of the exhalation. The isothermal exhalation in Figure 1A is directed slightly upwards according to the direction of the mouth. Figure 1B shows the situation with a combination of all the flow elements working in the microenvironment around the manikin. The exhalation flow forms a non-isothermal jet with an upward direction because of the influence of the body plume and temperature difference.

It is interesting to describe the velocity in the jet, because this area is the transport area for bacteria and viruses if the person is source of an airborne infection. (It should be noted that bacteria and viruses can also be attached to large particles and be spread at a short distance as droplet infection, but this is not considered here).

The peak velocities in the flow from the exhalation are described by the following expression

$$\frac{u_x}{u_o} = K_{exh} \cdot \frac{\sqrt{a_o}}{x} \qquad (1)$$

where u_o, u_x, a_o and x are peak exhalation velocity, peak velocity at distance x, area of mouth and distance x, respectively. This equation is in structure similar to the equation for steady state jet flow in ventilation.

The peak outlet velocity u_o from the mouth is 2.93 m/s and the area a_o is 100 mm^2. The peak velocity u_x is easy to indentify close to the manikin, but turbulence hides this velocity when the distance is larger than 50 cm.

The graphical representation of equation (1) in Figure 2 shows that the expression gives a good description of the time-dependent flow at different distances x. (Equation (1) is given as a straight line with a slope of -1 in the log-log depiction in Figure 2). The factor $K_{exh,m}$ is 7.8

for a standing person exhaling through the mouth into an isothermal room without ventilation under the conditions described in the section “Methods”.

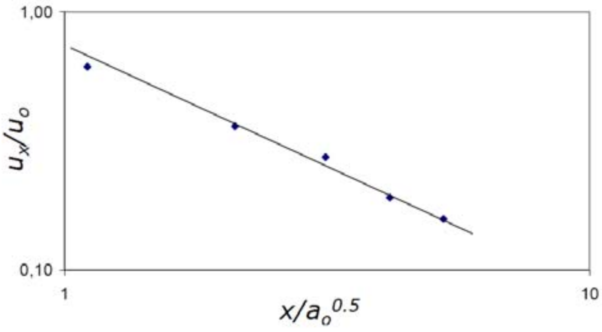
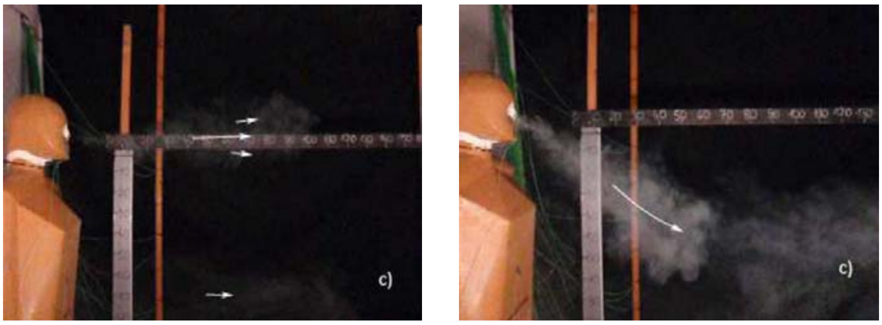


Figure 2. The graphical representation of equation (1).

The flow from the nose consists of two symmetrical jets (a_o = 50 mm^2) with 30º between the jets and a 45º inclination towards the chest. Figures 1C and 1D show that both the plume around the person and the temperature of the exhalation influence the flow from the nose. The peak velocity u_o is measured to be 3.96 m/s, but the velocity decay in the jets is large and $K_{exh,n}$ is 5.0. Both the velocity and the momentum flow are low in the jets compared to the flow in the exhalation jet from the mouth.

Exhalation flow in a room with displacement ventilation



A B

Figure 3. Exhalation 2.5 seconds after start of a sequence. There is a heat output from the manikin and non-isothermal exhalation. A) Exhalation through mouth. B) Exhalation through nose.

The flow in the microenvironment around a manikin changes when the manikin is located in surroundings with a vertical temperature gradient (6 ^{o}C between floor and ceiling). Figure 3A shows that the exhalation from the mouth forms a horizontal jet because the flow is “locked” in the temperature gradient, and because the plume around the manikin is weak in the case of displacement ventilation, see Liu et al. (2009). $K_{exp,m}$ is equal to 7.6, almost the same value as in the situation without ventilation.

The exhalation through the nose shows also a flow different from the flow in the case without ventilation. The downward jets turn to a horizontal flow, Figure 3B, probably because of locking of the flow in the vertical temperature gradient. $K_{exp,n}$ is equal to 6.3. This value is larger than the value in a non-ventilated room. The reason could be that the temperature gradient decreases the turbulent mixing between the jet and the surroundings.

CONCLUSIONS

The plume around the body and the temperature differences between the exhalation and the surroundings influence the exhalation flow from a person, whether the flow comes from the mouth or the nose.

The plume around the body and the temperature difference lead the exhalation flow in an upward direction in case of undisturbed surroundings.

The exhalation flow is also dependent on the macroenvironment (type of air distribution system).

The vertical temperature gradient in displacement ventilation and the reduced flow in the plume around the body support a stratified flow in the exhalation jets.

An expression for the peak velocities in the time-dependent exhalation flow has been developed, see equation (1). The equation has the same structure as the equation for a steady state free jet flow.

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