International Symposium on Room Air Convection and Ventilation Effectiveness
University of Tokyo, July 22 – 24, 1992

LOCAL VENTILATION EFFECTIVENESS IN THE BREATHING ZONE

Jorma O. Säteri
Helsinki University of Technology
SF-02150 ESPOO, FINLAND

ABSTRACT

This paper deals with the measurement of local ventilation effectiveness in a displacement ventilation system. The purpose of the study was to assess the distribution of air and breathing-originated contaminants within a room.

The convective plume of a person improves the delivery of fresh air from the near zone of the inlet into the breathing zone in a displacing air distribution system. This applies as well for a standing as for a sedentary person. Movements and other disturbances, which may alter the phenomenon, were not taken into account.

Human contaminants from exhalation rise to the upper zone due to the convective plume. The exposure of a neighboring person to the contaminants released from the other person was low in the studied air distribution system.

KEYWORDS Local Ventilation Effectiveness, Tracer Gas Measurement, Thermal Manikin, Displacement Ventilation.

INTRODUCTION

Ventilation and air-conditioning are major consumers of energy in buildings. Increasing knowledge on requirements for healthy and comfortable indoor environments increases the demand for ventilation as well the need for air-conditioning. Today, the air quality and thermal comfort required in the occupancy zone are commonly maintained throughout the whole building volume. Being able to concentrate on the occupancy zone, and allowing lower air quality in unoccupied areas, would lead to significant savings in energy costs without compromising health and comfort.

Displacement ventilation is a significant step towards better energy-efficiency. The air in the lower (occupancy) zone is kept fresh while the quality of the air above the head-level deteriorates. However, displacement ventilation should be considered only as a first step toward localized ventilation systems. Especially in industrial environments, there are numerous possibilities for improvements in both quality of air and energy-efficiency.

Earlier studies from displacement ventilation (Stymne et al 1991, Holmberg et al. 1990) have shown that the convective plume of a person improves the delivery of fresh air into the breathing zone. Unfortunately, the same applies for contaminants released in the lower zone, which deteriorate the quality of breathing air.

This paper deals with the measurement of local ventilation effectiveness in a displacement ventilation system. The purpose of the study was to assess the distribution of air and breathing-originated contaminants within a room.

THE FRAMEWORK FOR VENTILATION EFFECTIVENESS

Basic Concepts

Ventilation effectiveness has two aspects: the ability to deliver fresh air into the breathing zone, and the ability to remove contaminants from their place of origin. These two frameworks are needed because the flow pattern of fresh air is usually different from that of a contaminant. Our primary aim is to minimize human exposure to various contaminants. From this point of view, the contaminant removal effectiveness seems to be the appropriate tool for evaluating ventilation systems. However, each contaminant has different properties, which means that contaminant-removal effectiveness can not be used as a universal measure of a system's ability to remove contaminants. The ability to deliver fresh air is of a more universal nature. In developing new air distribution products, it is more reasonable to evaluate the primary function, the delivery of fresh air, rather than the secondary function, the removal of contaminants, unless the properties of the contaminants in situ are known.

The Ability of a Ventilation System to Deliver Fresh Air

The concepts used while studying the short-term performance of the ventilation system are presented in the following. The nominal time constant (τ_n) is the volume of the ventilated zone divided by the rate of the fresh airflow to the zone. The local age of air (τ_p) is the time it takes for the air molecule to travel from the air inlet to the studied point. The room mean age of air ($\langle\tau\rangle$) is the average of local ages of air. The air-exchange efficiency (ε_a) describes the replacement of room air with fresh air compared to an ideal (piston) flow pattern, and it is calculated as follows (Sandberg 1984):

$$\varepsilon_a=100*\tau_n/(2*\langle\tau\rangle), \tag{1}$$

where τ_n = nominal time constant, and $\langle\tau\rangle$ = room mean age of air.

The local air-exchange indicator (ε_i) is defined as the system's average nominal time constant divided by the local age of air at a point (Sandberg and Skåret 1989):

$$\varepsilon_i=100*\tau_n/\tau_p \tag{2}$$

where τ_n = the system's average nominal time constant, and τ_p = the local age of air at a point.

The Ability of a Ventilation System to Remove Contaminants

Contaminant-removal effectiveness (ε) is the nominal time constant divided by the actual turnover time (the mean age of contaminants in the exhaust) (Sandberg and Skåret 1989):

$$\varepsilon = 100*\tau_n/\tau_t \tag{3}$$

where τ_n = the system's average nominal time constant, and τ_t = the turnover time of the contaminant. With a constant airflow, Equation 3 can be expressed as follows (Sandberg and Skåret 1989):

$$\varepsilon = 100*C_e(\infty)/\langle C(\infty)\rangle \tag{4}$$

where $C_e(\infty)$ = the steady-state concentration in the exhaust, and $\langle C(\infty)\rangle$ = the volumetric average steady-state concentration in the system. The local contaminant-removal indicator (ε_p) is defined as the system's steady-state concentration in the exhaust divided by the steady-state concentration at a point (Sandberg and Skåret 1989):

$$\varepsilon_p = 100*C_e(\infty)/C_p(\infty) \tag{5}$$

where $C_p(\infty)$ = the steady-state concentration at a point (room), and $C_e(\infty)$ = the steady-state concentration in the exhaust.

THE MEASUREMENTS

The measurements were made in a test room as shown in Figure 1. The floor area of the test room is 16 m^2, the volume 42 m^3. A displacement ventilation system was used. The dimensions of the air inlet were 500 mm (w) x 1100 mm (h). Several heat loads were placed in the test room in order to simulate the cooling load. The total effect of these loads was approximately 30 W/m^2. The heat loads and breathing of people were simulated using a heated manikin with a piston system for breathing.

The ventilation effectiveness was measured using tracer gas techniques. Refrigerant 12 was injected into the supply air to study the movements of fresh air. Carbon dioxide was used to trace the movements of exhaled air. A 12-channel measurement system with two infrared analyzers was used.

Two sets of measurements were made. In the first set, a standing manikin was used. The purpose of these measurements was to study the quality of the air in the breathing zone of a standing person.

The second set of measurements was made using the manikin in sitting position. The main purpose of these measurements was to study the quality of the air in the breathing zone of a sitting person, and to study the exposure to contaminants released from a neighboring person. In two of these three measurements there was a sitting test person in addition to the manikin.

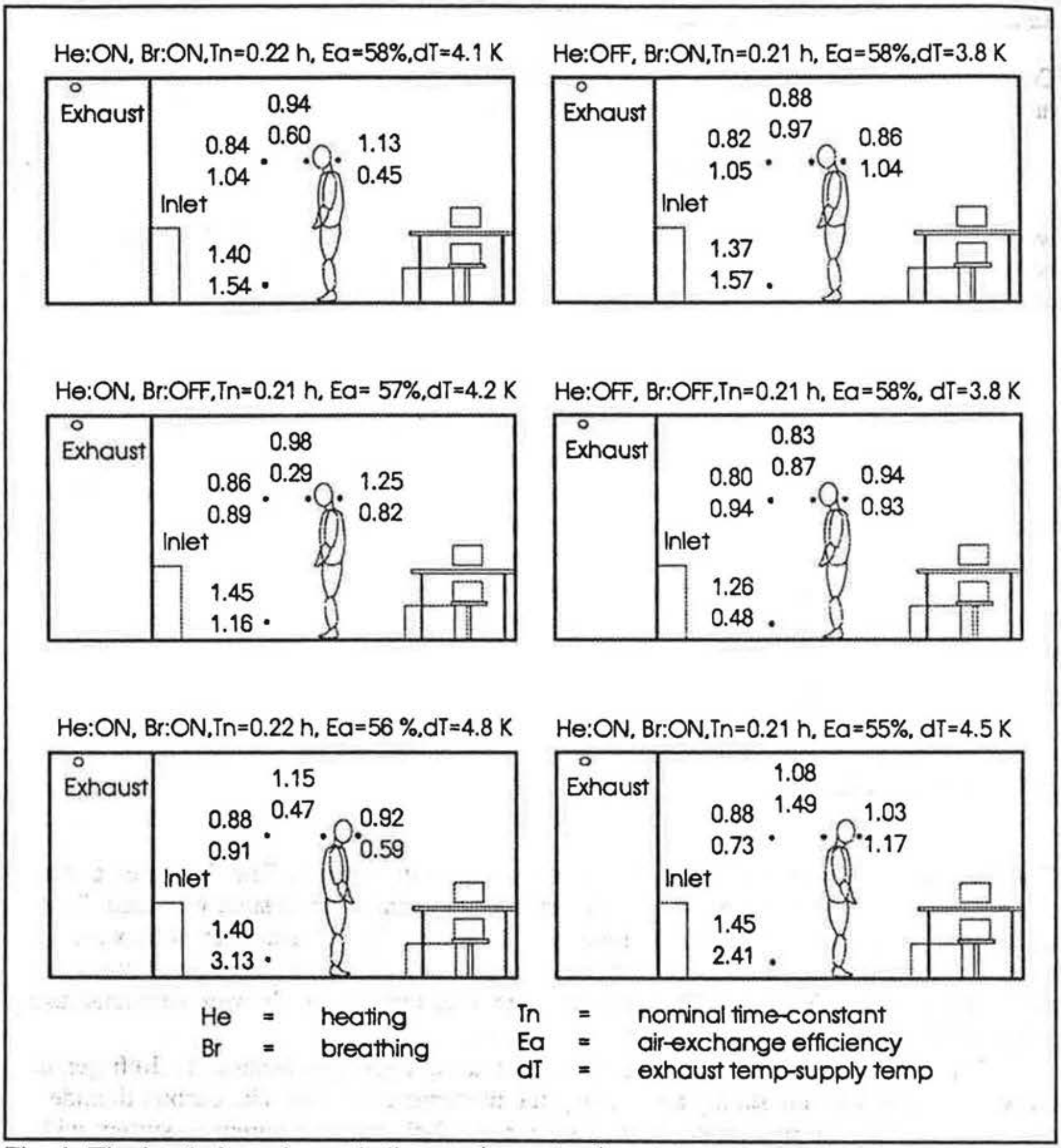

Fig. 1. The local air exchange indicators (top values) and the local contaminant-removal indicators (bottom value) in the breathing zone of a (simulated) standing person.

THE RESULTS

The Delivery of Fresh Air into the Breathing Zone

The local air-exchange indicators in the first set of measurements are shown in Figure 1. A higher value means better air quality. The local air-exchange indicator got systematically better values at the points located within the breathing zone than at the point located at the same height but outside the plume of the manikin. When cases with heated and unheated manikin were compared, it could be seen that better values were obtained using a heated

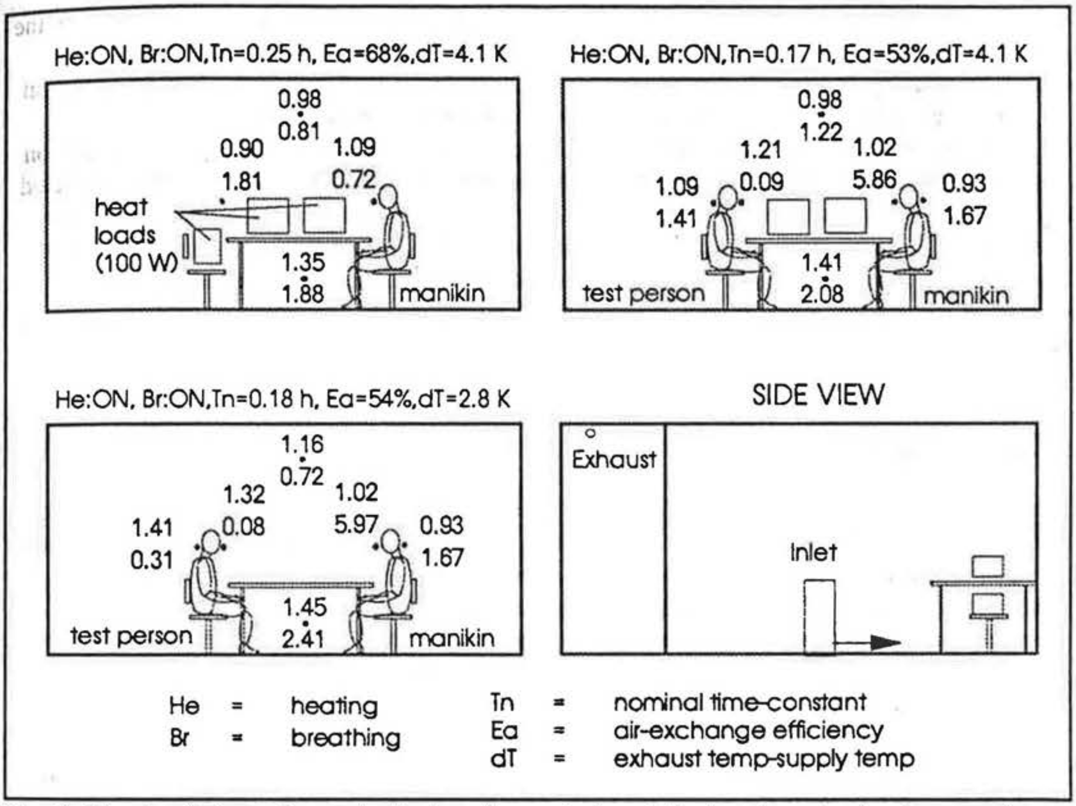

Fig. 2. The local air-exchange indicators (top value) and the local contaminant removal indicators in the breathing zones of a sitting test person and a sitting manikin.

manikin. The best values occur at the point located close to the near zone of the air inlet. The difference between the nose of the manikin and the point outside the plume of the manikin was insignificant (the inaccuracy of the measurement is estimated to be 12 %). For the standing manikin it seems that the fresh air passes the nose from the neck side. Smoke tests with a test person showed a similar phenomenon, but further measurements are needed to establish this. Movement and other disturbances may, of course, alter the situation.

In the second set of measurements (Figure 2), the manikin was used in a sitting position. In the first measurement, in which the manikin was alone, the fresh air entered the breathing zone faster than the reference point at the same height on the other side of the table. In the two measurements, in which the manikin shared the room with the test person, the best values outside the near zone occurred in the breathing zone of the test person. This become more emphasized when the heat loads on the table were turned off.

The Dispersion of Human Contaminants

The local contaminant removal indicators in the first set of measurements are shown in Figure 1. A higher value means better removal of contaminants and lower concentration.

Close to the near zone, the local contaminant removal effectiveness is good, except for the case 'heating off, breathing off'. In that particular case the carbon dioxide, having 1.5 times the density of air, fell directly to the floor. In order to simulate the human emission of carbon dioxide, either a heated manikin or a breathing simulator should be used.

In the second set of measurements (Figure 2), the exposure of a neighboring person to the contaminants exhaled by the other person, was studied. The carbon dioxide exhaled by the test person was used as contaminant. The local contaminant-removal indicators measured at a point in the breathing zone of the manikin reveal little exposure to carbon dioxide. The lowest values were found, obviously, from the breathing zone of the test person. Same results were obtained when the carbon dioxide was released in the breathing air of the manikin (first measurement).

CONCLUSIONS

The convective plume of a person improves the delivery of fresh air from the near zone of the inlet into the breathing zone in a displacing air distribution system. This applies as well for a standing as for a sedentary person. Movements and other disturbances, which may alter the phenomenon, were not taken into account.

Human contaminants from exhalation rise to the upper zone due to the convective plume. The exposure of a neighboring person to the contaminants released from the other person was low in the studied air distribution system.

ACKNOWLEDGEMENTS

This study was funded from the LVIS-2000-research programme of the Finnish Ministry of Trade and Industry.

REFERENCES

Holmberg, R.B.; Eliasson, L.; Folkesson, K.; and Strindehag, O. 1990. Inhalation-zone air quality provided by displacement ventilation. In Proceedings of the ROOMVENT '90-conference, Oslo, Norway. Session B2-2. 9 pages.

Sandberg, M. 1984. The multi-chamber theory reconsidered from the viewpoint of air quality studies. Building and Environment, Vol. 19, No. 4, pp. 221-233.

Sandberg, M.; and Skåret, E. 1989. Luftbytes- och ventilationseffektivitetet -nya hjälpmedel för ventilationskonstruktörer. Swedish Institute for Building Research, Technical Report M:22, Gävle, Sweden.

Stymne, H.; and Sandberg, M. 1991. Dispersion pattern of contaminants in a displacement ventilated room. In Proceedings of the 12th AIVC Conference, Ottawa, Canada. Vol. 1. pp.173-192.