Exposure Due to Interacting Air flows Between Two Persons

Bjørn, Erik; Nielsen, Peter V.

Publication date:
1996

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Bjørn, E., & Nielsen, P. V. (1996). *Exposure Due to Interacting Air flows Between Two Persons*. Dept. of Building Technology and Structural Engineering. Indoor Environmental Technology Vol. R9658 No. 66

INSTITUTTET FOR BYGNINGSTEKNIK
DEPT. OF BUILDING TECHNOLOGY AND STRUCTURAL ENGINEERING
AALBORG UNIVERSITET • AAU • AALBORG • DANMARK

INDOOR ENVIRONMENTAL TECHNOLOGY
PAPER NO. 66

Presented at the 5th International Conference on Air Distribution in Rooms
ROOMVENT '96, Yokohama, Japan, July 17-19, 1996

E. BJØRN & P. V. NIELSEN
EXPOSURE DUE TO INTERACTING AIR FLOWS BETWEEN TWO PERSONS
DECEMBER 1996 ISSN 1395-7953 R9658

The papers on INDOOR ENVIRONMENTAL TECHNOLOGY are issued for early dissemination of research results from the Indoor Environmental Technology Group at the University of Aalborg. These papers are generally submitted to scientific meetings, conferences or journals and should therefore not be widely distributed. Whenever possible reference should be given to the final publications (proceedings, journals, etc.) and not to the paper in this series.

Printed at Aalborg University

INSTITUTTET FOR BYGNINGSTEKNIK
DEPT. OF BUILDING TECHNOLOGY AND STRUCTURAL ENGINEERING
AALBORG UNIVERSITET • AAU • AALBORG • DANMARK

INDOOR ENVIRONMENTAL TECHNOLOGY
PAPER NO. 66

Presented at the 5th International Conference on Air Distribution in Rooms
ROOMVENT '96, Yokohama, Japan, July 17-19, 1996

E. BJØRN & P. V. NIELSEN
EXPOSURE DUE TO INTERACTING AIR FLOWS BETWEEN TWO PERSONS
DECEMBER 1996 ISSN 1395-7953 R9658

EXPOSURE DUE TO INTERACTING AIR FLOWS BETWEEN TWO PERSONS

Erik Bjørn
Doctoral Student
Aalborg University
DK-9000 Aalborg, Denmark
e-mail: i6erik@civil.auc.dk

Peter V. Nielsen
Professor
Aalborg University
DK-9000 Aalborg, Denmark
e-mail: i6pvn@civil.auc.dk

ABSTRACT

The contaminant concentration inhaled by an occupant (ie. the personal exposure) is usually less than the return concentration in displacement ventilated rooms. Two main questions are investigated: 1) Does the exhalation from one person penetrate the breathing zone of another person placed nearby, thus leading to larger personal exposure? 2) When two persons are placed close to each other, do the convective boundary layer flows interact so that the personal exposure to an ambient concentration field is altered? These problems are investigated experimentally: Full-scale experiments are made in a displacement ventilated room with two breathing thermal manikins. When the manikins are facing each other, interaction can take place, and the exposure is increased. Horizontal distance between manikins and horizontal inclination of exhalation flow are important parameters. If exhalation is directed towards the back, larger exposures do not occur. When two persons stand close together, the exposure to ambient concentration is not altered. Traditional one or two-zone models are not adequate for the case of face-to-face respiration. When people are standing close or respirating face-to-back, normal exposure levels for displacement ventilation can be expected.

KEYWORDS

Convection, exposure, experiments, respiration, thermal manikins.

INTRODUCTION

The objective of this research is to study the interaction taking place between air flows induced by the human body (respiration and convective boundary layer flow), namely in situations where more than one person is present. These phenomena may be interesting with respect to contaminant control, eg. in hospitals and clinics, in situations with passive smoking, and in the general improvement of indoor air quality. This is an experimental study. The experiments are restricted to simulate areas with low air velocity and with a vertical temperature gradient, as for example in case of displacement ventilation.

The experiments are all conducted in a room ventilated by the displacement principle. The concentration of airborne contaminants inhaled by an occupant (the personal exposure c_e), is usually less than the return concentration in the exhaust c_R, ie. the dimensionless exposure (c_e/c_R) will normally be less than 1 in such a room (see eg. Brohus and Nielsen 1994). In a room with complete (ideal) mixing, the exposure would be equal to 1.

Two main questions are investigated: 1) Does the exhalation from one person penetrate the breathing zone of another person placed nearby, thus leading to exposure, and if so, how does the expo-

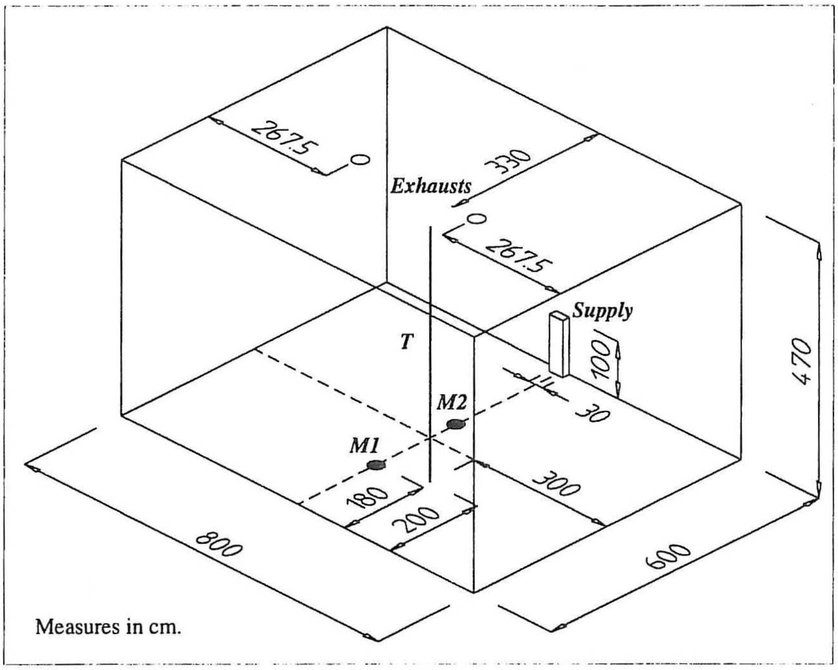

Figure 1 : Test room, situation of supply, exhausts, manikins (M1,M2), Tracer gas and temperature measurements (T).

sure depend on the horizontal distance between the persons? Furthermore, what is the difference between exhaling through the mouth or through the nose? 2) When two persons are placed close to each other, do the convective boundary layer flows interact so that the personal exposure to an ambient concentration field is altered? This question rises from observations, made by the authors of this paper, of an apparent "stack effect" when extensive heat sources are placed close to each other.

EXPERIMENTAL METHODS

The experiments are 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. 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). The fresh air supply rate is 160 m^3/h, and the supply air temperature is ca. 20°C. Human beings are simulated by two breathing thermal manikins, which are described in detail below.

Manikin no.1

This manikin is developed at the Danish Technical University. It is shaped as an average sized 1.7 m high woman. The naked 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 effect for each zone correspond to a person in thermal comfort. In all the present experiments, the total heat effect of the manikin is 75-80 W.

Manikin no.2

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 painted light brown. 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. In the present experiments, the total heat effect is kept constantly at 75 W. The mouth, which is used for exhalation in some experiments, consists of a circular opening with 12 mm diameter.

Artificial lungs

Both manikins are connected to artificial "lungs" that provide respiration through mouth and/or nose. An artificial lung is simply a cylinder with a piston driven by an electric motor. This produces pulsating, sinusoidal breathing, quite similar to reality. The chosen pulmonary ventilation is 6.0 liters/min, and respiration frequency is 10 min^{-1}, corresponding to a person at rest. Since real persons do not usually have exactly the same pulmonary ventilation and respiration frequency, the "lungs" of the two manikins are not synchronized, and have slightly different respiration frequencies. The exhaled air is heated to 32°C, which is the temperature of exhaled air from human beings (Cole 1982). The effect used for this purpose is not included in the above-mentioned "total heat effect" of 75 W.

Nasal geometry

With manikin no. 2, care has been taken to ensure a realistic momentum and direction of the flow exhaled from the nose. According to (Grymer et.al.1991) the mean area of an adult's nostril is 1.32 cm^2, which is the area of a circle with the diameter 13 mm. A diameter of 12 mm is used, since this was the closest possible choice of available commercial plastic tubes. According to (Hyldgaard 1994) the air is exhaled from the nose in two jets with directions ca. 45° below horizontal, and with an intervening angle of ca. 30°. These characteristics are retained.

Measurements

The air flow patterns are visualised with smoke. Temperatures are measured with thermocouples (type K, accuracy ±0.15 °C) and a data logger (type Fluke Helios 2287 A). Contaminant distributions are studied by tracer gas measurements using Dinitrogenoxide (N_2O) as tracer gas, and a gas analyser (type Brüel & Kjær 1302). N_2O is considered appropriate as tracer gas for the following reasons: 1) N_2O is added to air exhaled by a manikin. At equal temperatures, exhaled air is heavier than atmospheric air due to the content of CO_2. The concentrations of N_2O in these experiments (ca. 4%) are close to the natural concentration of CO_2 in exhalation air, and they have equal densities. 2) The excess temperature of the exhalation (ca. 10°C above ambient) is more important to the flow than the above-mentioned density differences.

Experiments

In all experiments, manikin no.1 stands upright, and the exposure is measured in air inhaled through the mouth. In experiments 1a-1d (figure 2). The two manikins face each other. Manikin no.2 alternatively exhales through the nose or mouth, and it is either standing or sitting. The distance Δx between the manikins varies from 0.4 - 1.2 m measured from mouth to mouth. In experiment 1c and 1d, the exhalation is inclined 45° below horizontal.

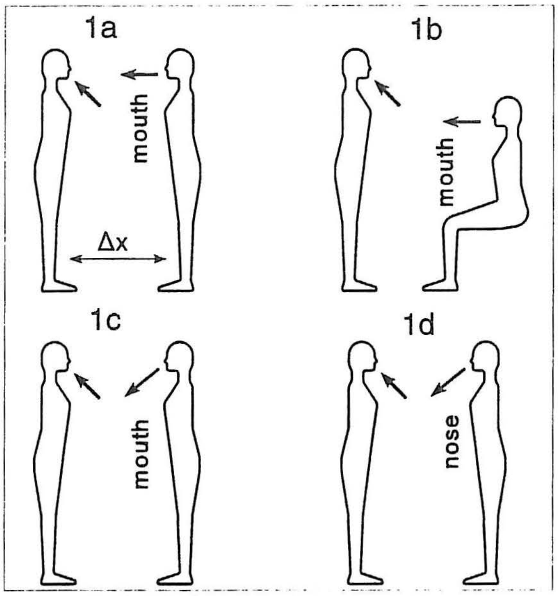

Figure 2 : Experiments 1a - 1d

In experiments 2a, 2b and 3 (figure 3), Δx is constant. In 2a, the two manikins touch each other shoulder to shoulder. In 2b, Δx is 0.4 m measured from mouth to mouth. In experiment 3, Δx is 0.4 m measured from mouth to neck. In 2a and 2b, the tracer gas is emitted above the manikins. In experiment 3, tracer gas is added to the exhalation (through the nose) of manikin no.2.

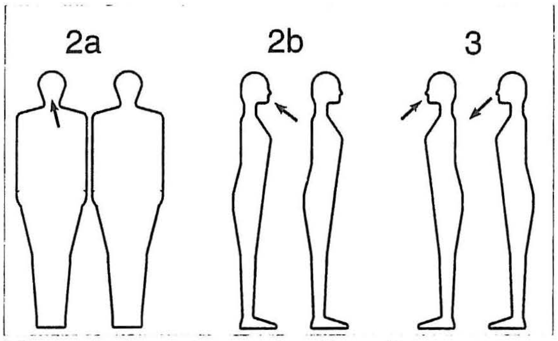

Figure 3 : Experiments 2a, 2b and 3

RESULTS

Figure 4 shows the ambient room air temperatures during the experiments.

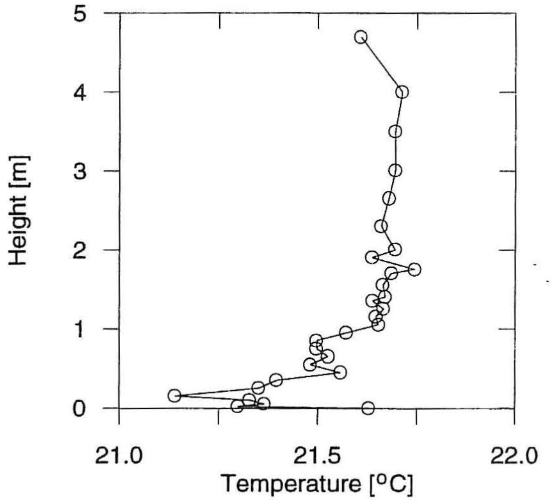

Figure 4 : Vertical temperature gradient

Figures 5, 6 and 7 are scattergrams of the measured exposure of manikin no.1 as a function of time (in experiment 1a). Manikin no.2 acts as the contaminant source, with tracer gas added to the exhalation, which is conducted horizontally through the mouth. The mutual distance between the manikins varies between 0.4 m - 1.2 m. The manikins face each other. Figures 5-7 show a characteristic trait in these experiments: Most of the concentration measurements are at a constant, relatively low level. A few of the measurements are at a much higher level, typically one order of magnitude higher. When Δx decreases, the measurements at high concentration level become more frequent, and the concentration level increases. The mean concentrations in these experiments are close to the minimum concentrations, whereas the maximum concentrations are larger.

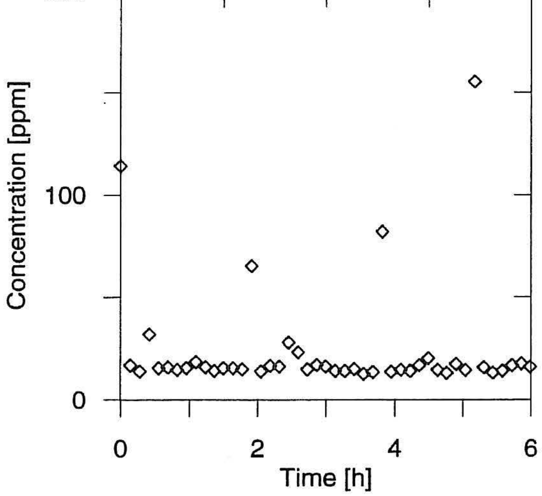

Figure 5 : Exposure, exp. 1a, Δx = 1.2 m

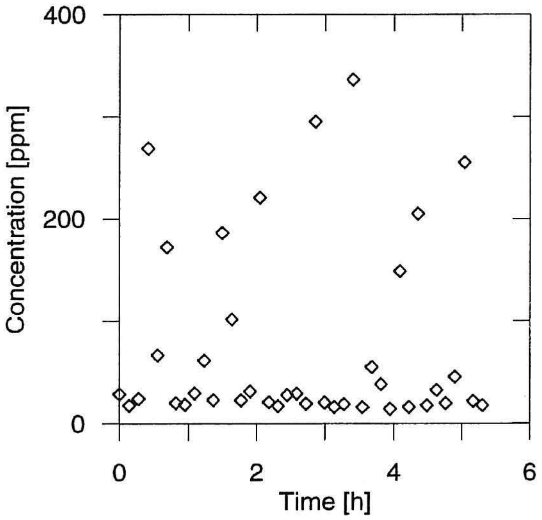

Figure 6 : Exposure, exp. 1a, Δx = 0.8 m

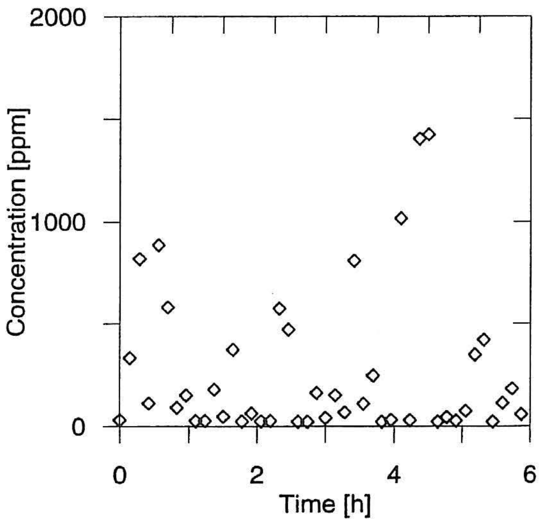

Figure 7 : Exposure, exp. 1a, Δx = 0.4 m

In figures 8 and 9, the mean and maximum concentrations are shown for all the experiments of this type. The concentrations are made dimensionless by dividing with the return concentration c_R.

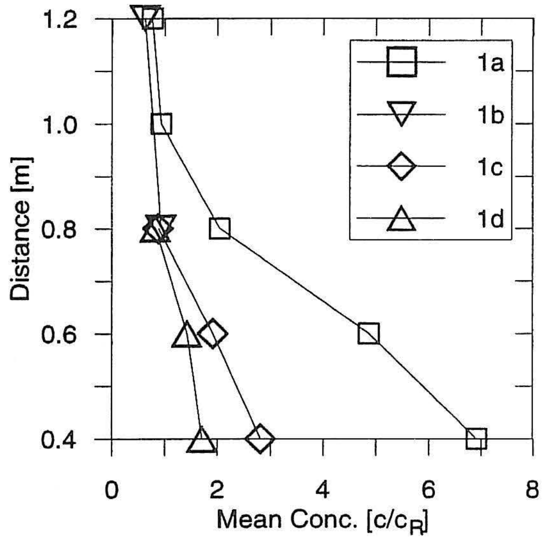

Figure 8 : Mean exposures in exp. 1a - 1d

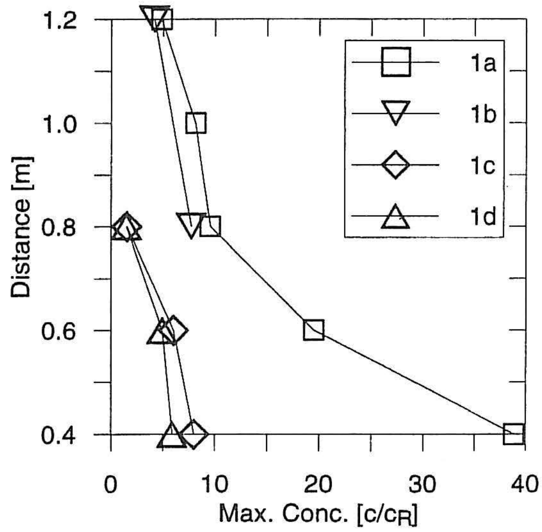

Figure 9 : Maximum exposures in exp. 1a - 1d

Smoke Visualizations

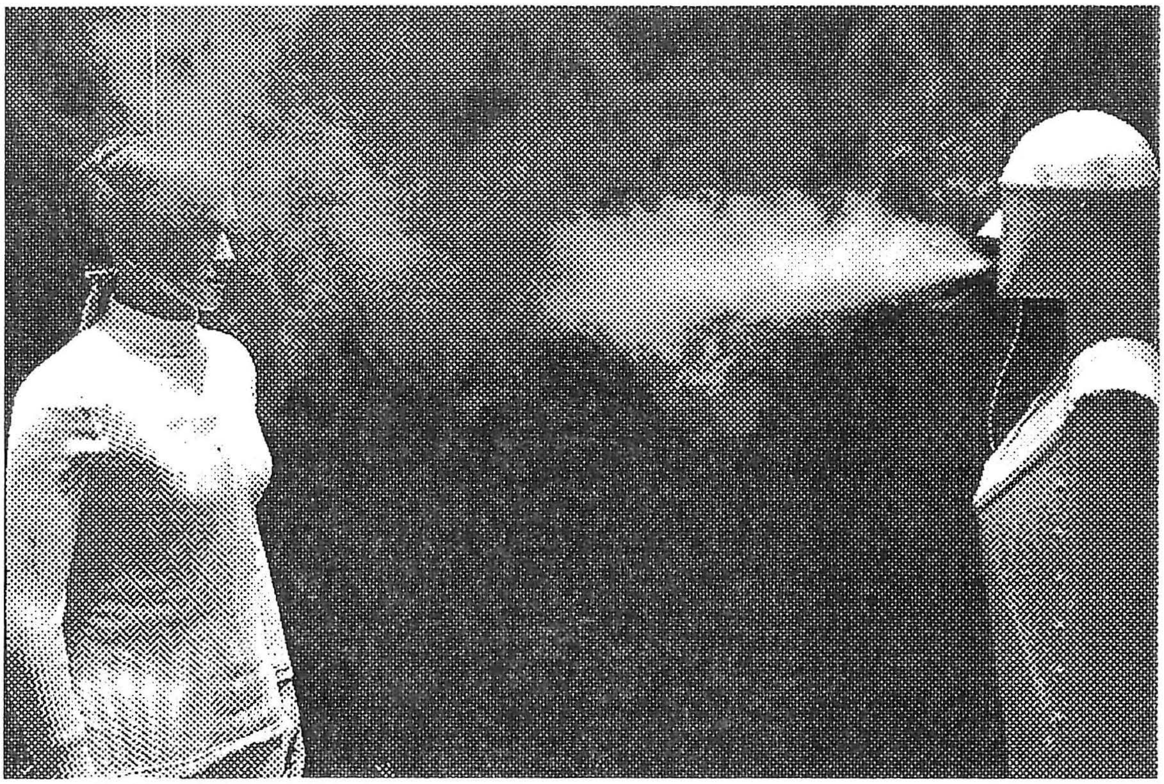

Figure 10: Experiment 1a, $\Delta x = 1.2$ m.

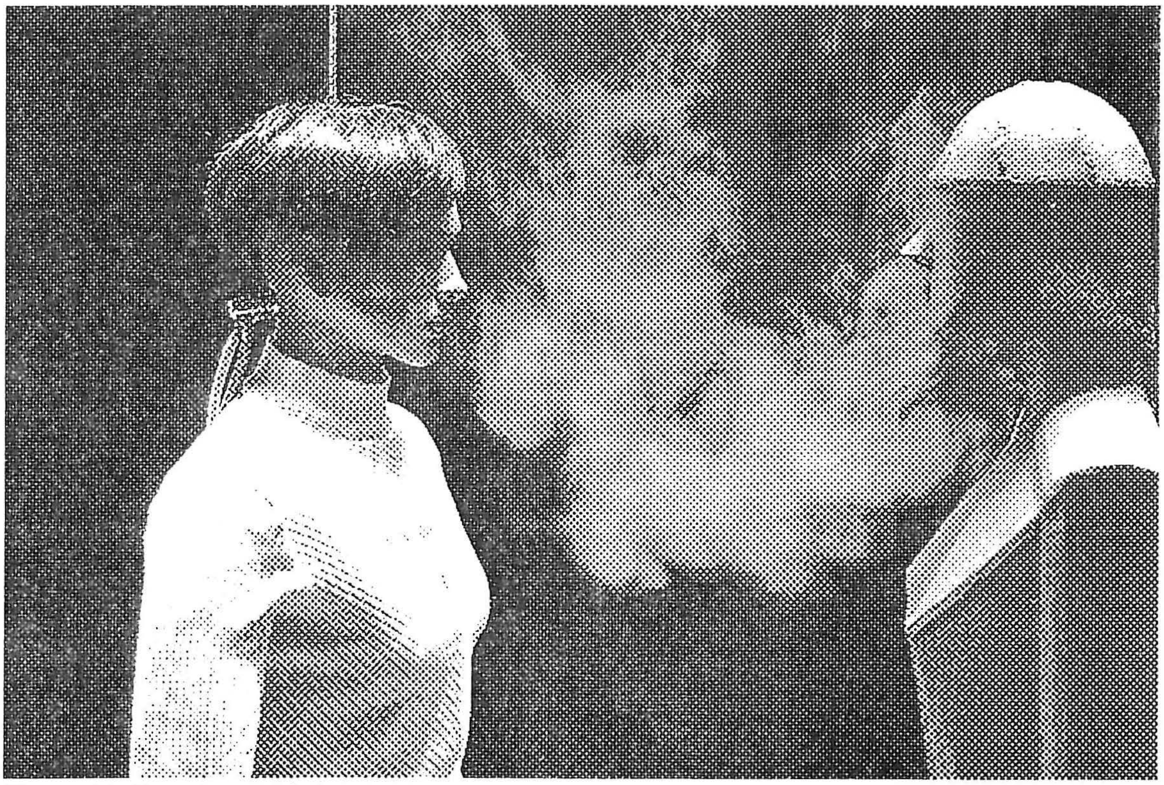

Figure 11: Experiment 1d, $\Delta x = 0.4$ m.

Figure 12 shows the results of experiments 2a and 2b, which were intended to show a possible interaction of the boundary layer flows of the two manikins.

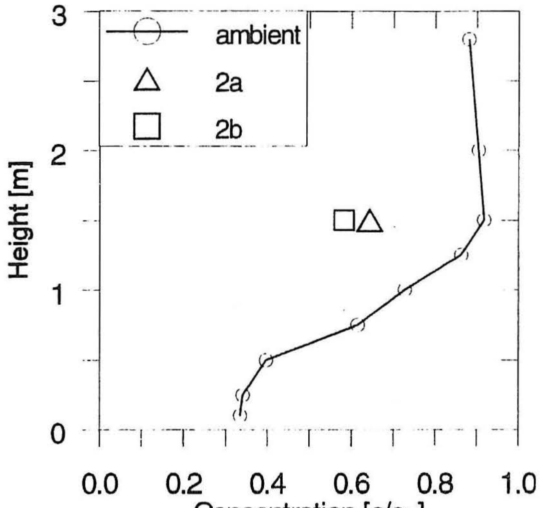

Figure 12 : Ambient concentration and exposures in experiments 2a and 2b

Figure 13 shows the results of experiment 3, where manikin no.2 exhaled towards the back of manikin no.1. The results are compared with exp. 1d, Δx = 0.8 m, which was a similar experiment, except that the manikins faced each other.

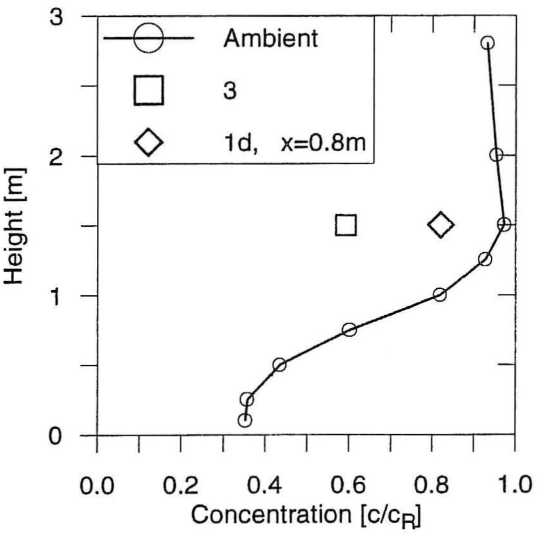

Figure 13 : Ambient concentration and exposures in exp. 3 & 1d,Δx=0.8m

DISCUSSION

The experiments 1a - 1d, with one manikin exhaling directly towards another manikin, produce dimensionless exposures (c_e/c_R) substantially larger than 1, proving that simplified models for exposure (e.g. assuming complete mixing or a two-zone model) are not sufficient in such cases. Experiment 3, where one manikin exhales towards the back of another manikin (at a short distance) shows an exposure level that is consistent with the level usually observed in displacement ventilated rooms, i.e. $c_e/c_R < 1$. This means that the exhalation flow need not be taken into account in such cases (e.g. people in an audience facing in the same direction).

Figures 5-7 suggest that the convective boundary layer close to the body offers some protection from the exhalation flow from another person. The exposure is generally at a low level, which means that the boundary layer flow removes contaminants from the breathing zone. A "short circuit" of exhalation and inhalation occurs only occasionally. See also the photo in figure 11.

The experiments 1a - 1d show that the horizontal distance between two persons is an important parameter with respect to the phenomenon of one person's exhalation penetrating the convective boundary layer flow of another person (figure 8 + 9). This was to be expected, since the exhalation flow has the character of a buoyant jet (two jets in case of exhalation through the nose), and a jet loses momentum when the distance increases. The inclination of these jets from horizontal direction is also a very important parameter (experiment 1a & 1b compared with experiments 1c & 1d, figures 8+9). In case of a 45° inclination below horizontal, the exposure is 2-4 times lower than with horizontal exhalation. This is not surprising either, since the exhalation flow has an initial excess temperature of ca. 10°C, creating a buoyancy force, of which the vertical composant counteracts the momentum of the exhalation jet. More surprising perhaps is the very weak influence of exhaling through the nose instead of the mouth. When comparing experiments 1c and 1d (figures 8 + 9), the area through which the exhalation is conducted is doubled, but no great difference in exposure is observed. Also, no great difference is observed of exhalation made by a standing person instead of a sitting person (exp. 1a compared with 1b).

In the case of horizontal exhalation, c_e/c_R drops below 1 when the horizontal distance Δx exceeds ca. 1.2 m. In situations with the exhalation inclined 45°, this happens at Δx > ca. 0.8 m. However, at these distances some interaction still takes place (see figures 5, 10 and 13).

Experiments 2a and 2b show no effect of interacting convective boundary layer flows. This might however be the case at smaller horizontal distances than those used in experiment 2b.

There are certain limitations to the interpretation of the experimental results. No parameter variation has been attempted of the following parameters: Heat output from the manikins, lung ventilation, room air temperature, stratification height. These parameters have been chosen to represent typical office work conditions. The results are restricted to rooms with displacement ventilation or areas with very low velocities (ie. not typical mixing ventilation situations).

CONCLUSIONS

Increased personal exposures are obtained in experiments with two manikins facing each other, one of them exhaling directly towards the other. This shows that simplified models for exposure (as e.g. one or two-zone models) are not sufficient in such cases. With face-to-face exhalation, the mutual horizontal distance between the manikins, and the horizontal inclination of the exhalation, are decisive parameters. An experiment with one manikin exhaling towards the back of another manikin (at a short distance) shows an exposure level consistent with the level usually observed in displacement ventilated rooms. This means that the exhalation flow need not be taken into account in such cases (eg. people in an audience facing in the same direction). This is also the result of experiments with the manikins standing close. No interaction takes place that alters the exposure to ambient concentration. The results are restricted to rooms with displacement ventilation or areas with very low velocities (ie. not typical mixing ventilation situations), and to persons at a low activity level (e.g. office work).

ACKNOWLEDGEMENTS

This research was supported financially by the Danish Technical Research Council (STVF) as part of the research programme "Healthy Buildings", 1993-97.

REFERENCES

Luisa F. Grymer et.al. 1991. *Acoustic rhinometry: Values from adults with subjective normal nasal patency.* Rhinology, Vol. 29, 35-47, 1991.

C.E.Hyldgaard 1994. *Humans as a source of heat and air pollution.* Proc. ROOMVENT '94, Krakow.

Philip Cole 1982. Chap. 14 in: *Proctor/Andersen (eds), The Nose: Upper airway physiology and the atmospheric environment.* Elsevier Biomedical Press.

H.Brohus and P.V.Nielsen 1994. *Contaminant distribution around persons in rooms ventilated by displacement ventilation.* Proc. ROOMVENT '94, Krakow.

PAPERS ON INDOOR ENVIRONMENTAL TECHNOLOGY

PAPER NO. 34: T. V. Jacobsen, P. V. Nielsen: *Numerical Modelling of Thermal Environment in a Displacement-Ventilated Room.* ISSN 0902-7513 R9337.

PAPER NO. 35: P. Heiselberg: *Draught Risk from Cold Vertical Surfaces.* ISSN 0902-7513 R9338.

PAPER NO. 36: P. V. Nielsen: *Model Experiments for the Determination of Airflow in Large Spaces.* ISSN 0902-7513 R9339.

PAPER NO. 37: K. Svidt: *Numerical Prediction of Buoyant Air Flow in Livestock Buildings.* ISSN 0902-7513 R9351.

PAPER NO. 38: K. Svidt: *Investigation of Inlet Boundary Conditions Numerical Prediction of Air Flow in Livestock Buildings.* ISSN 0902-7513 R9407.

PAPER NO. 39: C. E. Hyldgaard: *Humans as a Source of Heat and Air Pollution.* ISSN 0902-7513 R9414.

PAPER NO. 40: H. Brohus, P. V. Nielsen: *Contaminant Distribution around Persons in Rooms Ventilated by Displacement Ventilation.* ISSN 0902-7513 R9415.

PAPER NO. 41: P. V. Nielsen: *Air Distribution in Rooms - Research and Design Methods.* ISSN 0902-7513 R9416.

PAPER NO. 42: H. Overby: *Measurement and Calculation of Vertical Temperature Gradients in Rooms with Convective Flows.* ISSN 0902-7513 R9417.

PAPER NO. 43: H. Brohus, P. V. Nielsen: *Personal Exposure in a Ventilated Room with Concentration Gradients.* ISSN 0902-7513 R9424.

PAPER NO. 44: P. Heiselberg: *Interaction between Flow Elements in Large Enclosures.* ISSN 0902-7513 R9427.

PAPER NO. 45: P. V. Nielsen: *Prospects for Computational Fluid Dynamics in Room Air Contaminant Control.* ISSN 0902-7513 R9446.

PAPER NO. 46: P. Heiselberg, H. Overby, & E. Bjørn: *The Effect of Obstacles on the Boundary Layer Flow at a Vertical Surface.* ISSN 0902-7513 R9454.

PAPER NO. 47: U. Madsen, G. Aubertin, N. O. Breum, J. R. Fontaine & P. V. Nielsen: *Tracer Gas Technique versus a Control Box Method for Estimating Direct Capture Efficiency of Exhaust Systems.* ISSN 0902-7513 R9457.

PAPER NO. 48: Peter V. Nielsen: *Vertical Temperature Distribution in a Room with Displacement Ventilation.* ISSN 0902-7513 R9509.

PAPER NO. 49: Kjeld Svidt & Per Heiselberg: *CFD Calculations of the Air Flow along a Cold Vertical Wall with an Obstacle.* ISSN 0902-7513 R9510.

PAPER NO. 50: Gunnar P. Jensen & Peter V. Nielsen: *Transfer of Emission Test Data from Small Scale to Full Scale.* ISSN 1395-7953 R9537.

PAPER NO. 51: Peter V. Nielsen: *Healthy Buildings and Air Distribution in Rooms.* ISSN 1395-7953 R9538.

PAPERS ON INDOOR ENVIRONMENTAL TECHNOLOGY

PAPER NO. 52: Lars Davidson & Peter V. Nielsen: *Calculation of the Two-Dimensional Airflow in Facial Regions and Nasal Cavity using an Unstructured Finite Volume Solver.* ISSN 1395-7953 R9539.

PAPER NO. 53: Henrik Brohus & Peter V. Nielsen: *Personal Exposure to Contaminant Sources in a Uniform Velocity Field.* ISSN 1395-7953 R9540.

PAPER NO. 54: Erik Bjørn & Peter V. Nielsen: *Merging Thermal Plumes in the Indoor Environment.* ISSN 1395-7953 R9541.

PAPER NO. 55: K. Svidt, P. Heiselberg & O. J. Hendriksen: *Natural Ventilation in Atria - A Case Study.* ISSN 1395-7953 R9647.

PAPER NO. 56: K. Svidt & B. Bjerg: *Computer Prediction of Air Quality in Livestock Buildings.* ISSN 1395-7953 R9648.

PAPER NO. 57: J. R. Nielsen, P. V. Nielsen & K. Svidt: *Obstacles in the Occupied Zone of a Room with Mixing Ventilation.* ISSN 1395-7953 R9649.

PAPER NO. 58: C. Topp & P. Heiselberg: *Obstacles, an Energy-Efficient Method to Reduce Downdraught from Large Glazed Surfaces.* ISSN 1395-7953 R9650.

PAPER NO. 59: L. Davidson & P. V. Nielsen: *Large Eddy Simulations of the Flow in a Three-Dimensional Ventilated Room.* ISSN 1395-7953 R9651.

PAPER NO. 60: H. Brohus & P. V. Nielsen: *CFD Models of Persons Evaluated by Full-Scale Wind Channel Experiments.* ISSN 1395-7953 R9652.

PAPER NO. 61: H. Brohus, H. N. Knudsen, P. V. Nielsen, G. Clausen & P. O. Fanger: *Perceived Air Quality in a Displacement Ventilated Room.* ISSN 1395-7953 R9653.

PAPER NO. 62: P. Heiselberg, H. Overby & E. Bjørn: *Energy-Efficient Measures to Avoid Downdraft from Large Glazed Facades.* ISSN 1395-7953 R9654.

PAPER NO. 63: O. J. Hendriksen, C. E. Madsen, P. Heiselberg & K. Svidt: *Indoor Climate of Large Glazed Spaces.* ISSN 1395-7953 R9655.

PAPER NO. 64: P. Heiselberg: *Analysis and Prediction Techniques.* ISSN 1395-7953 R9656.

PAPER NO. 65: P. Heiselberg & P. V. Nielsen: *Flow Element Models.* ISSN 1395-7953 R9657.

PAPER NO. 66: Erik Bjørn & P. V. Nielsen: *Exposure due to Interacting Air Flows between Two Persons.* ISSN 1395-7953 R9658.

PAPER NO. 67: P. V. Nielsen: *Temperature Distribution in a Displacement Ventilated Room.* ISSN 1395-7953 R9659.

PAPER NO. 68: G. Zhang, J. C. Bennetsen, B. Bjerg & K. Svidt: *Analysis of Air Movement Measured in a Ventilated Enclosure.* ISSN 139995-7953 R9660.

Department of Building Technology and Structural Engineering
Aalborg University, Sohngaardsholmsvej 57. DK 9000 Aalborg
Telephone: +45 9635 8080 Telefax: +45 9814 8243