Humans as a Source of Heat and Air Pollution

Hyldgård, Carl-Erik

Publication date:
1994

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

Link to publication from Aalborg University

Citation for published version (APA):
Hyldgård, C-E. (1994). *Humans as a Source of Heat and Air Pollution*. Dept. of Building Technology and Structural Engineering. Indoor Environmental Technology Vol. R9414 No. 39

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

INDOOR ENVIRONMENTAL TECHNOLOGY
PAPER NO. 39

Presented at ROOMVENT '94, Fourth International Conference on Air Distribution in Rooms, June 15-17, 1994, Cracow, Poland

C. E. HYLDGAARD
HUMANS AS A SOURCE OF HEAT AND AIR POLLUTION

JUNE 1994 ISSN 0902-7513 R9414

Humans as a Source of Heat and Air Pollution

Carl Erik Hyldgaard
Department of building technology
and structural engineering
Aalborg University
Aalborg, Denmark

Summary

This is the first part of a planned research into the effect of the human being on the indoor climate. The results are among other things intended for CFD calculations. This part deals with the influence from breathing, smoking, bioeffluents and vapour. The results are mainly based on measurements around a breathing thermal model placed in three fundamentally different types of indoor climates:

- Quiet surroundings, no ventilation

- Displacement ventilation

- Constant horizontal flow

Preface

Purpose

To determine the effect of the human being on the indoor climate in the form of convection current around a person, heat radiation, emission of bioeffluents and sweat, breathing and smoking.

Statement

Today we know which indoor climate a person is preferring to optain thermal and atmospheric comfort. Partly we also know how to create comfort and we are developing CFD, Computational Fluid Dynamics, while we are looking forward to be able to calculate comfort conditions in empty and furnished rooms. We also know, that a person placed in a room will affect the surrounding indoor climate considerably, but we do not know how and how much, and thus we are lacking the necessary input to CFD in this area.

The emission of heat from a person in comfort is known from P.O.Fanger's work [1]. The division of the heat between convection to the air, heat radiation to the surrounding surfaces and evaporation is also known, but the convection current around a person, which depends on the temperature and velocity of the surrounding air, is not sufficiently known yet to be fit input for CFD models.

The effect of the breathing on the indoor climate is yet unknown. We do not know whether the expiration is caught by the rising convection flow around the body and carried away over the head or wheather the expiration breaks through the convection flow and gets away from it.

The emission of bioeffluents and vapour is known. But we do not know if these gases are carried away upwards with the convection current, or if they diffuse through it at certain temperature and velocity circumstances.

You can find a great deal of literature on smoking concerning all the gases and particles which are in the smoke, how large the emitted quantities are, and on the damage effect on the human being. The smoke is always assumed to be totally mixed with the air in the room and this of course cannot be true. An examination of the movements of the smoke in the surrounding air after the expiration is lacking.

Tasks

1. To examine the effect of the breathing on the indoor climate depending on the position and the activity level of the person and the surrounding temperature and velocity field.

2. To examine the effect of smoking on the surroundings by following the movements of the smoke from expiration to exhaust by the ventilation. The momentum flow of the expiration has to be examined, and furthermore it has to be investigated if the smoke after the entry into the surrounding air has thermal buoyancy enough to move upwards in the room. These examinations have to be made at varying temperature and velocity field.

3. To examine how bioeffluents and vapour are emitted to the surroundings depending on the position and activity level of the person and on the surrounding temperature and velocity field.

4. To examine the convective current around a person depending on the position and activity level and the surrounding temperature and velocity field. The results must be presented in a form which makes them fit for input to CFD calculations.

This paper includes the first results within the first three areas.

Breathing

The condition of the inhaled air

The inhalation consists mainly of 79 vol.% N_2 and 21 vol.% O_2. The density of the air at 20 C and the barometer reading 1013 mBar is about 1.2 kg/m^3. The density is only slightly depending on the humidity but as known the density is varying a great deal with the temperature, e.g. it is about 1.15 kg/m^3 at 31 C [2].

The condition of the exhalation

For a sitting person with light physical work the exhaled air consists of 80.4 vol.% N_2, 16 vol.% O_2 and 3.6 vol.% CO_2. Because of the changed composition the exhalation has a density, which is 1.013 multiplied by the density of the inhalation at the same temperature.

For a person with light work the condition of the exhaled air is measured to be 31 C and 96% humidity. At this condition the density is 1.156 kg/m^3. The exhaled air is thus a good deal lighter than the surrounding air at comfort conditions and therefore it has a thermal buoyancy.

The amount of respiration

The respiration is depending on the activity level and the weight of the body because there is a direct connection between the combustion in the body and the amount of used O_2. At light sitting work a person of average size will have a respiration frequency of 10 each minute with an air volume of 0.6 litre per inhalation. So the respiration is about 6 litres per minute for a normal person at low activity level.

The inhalation

For the surrounding air the inhalation will have nearly no effect because the air is flowing equally from all sides to the mouth or nose. Assuming e.g. that air is taken from half a ball, the velocity will already at a distance of 5 cm from the mouth have decreased to 1.5 cm/s! The effect of the inhalation on the surrounding air will therefore be very little.

The exhalation

Like every injection of air into a room the exhalation will affect the surrounding air considerably. Thus it is necessary to find out how the breathing out is going on.

Exhalation can go through the mouth or through the nose. At low activity level almost all people are breathing through the nose so we will begin by looking closer at this case.

At measuring of the volume of the breathing by a spirometer it is seen that a normal breathing cycle at a breathing frequency of 10 times per minute is:

Inhalation in 2.5 s
Exhalation in 2.5 s
Pause in 1.0 s

The exhalation of the 6 litres/minute is taking place in 2.5 s out of the 6 s, which is the time for the breathing cycle. The air flow during the exhalation will be:

$$\frac{6l/\min \cdot 6}{2,5} = 14,4l/\min = 2,4 \cdot 10^{-4} m^3/s$$

The nostril area is measured to be 2 x 0.65 cm^2 on an average person. The velocity of the blowing out from the nostril will then be:

$$v_0=\frac{2{,}4\cdot 10^{-4}m^3/s}{2\cdot 0{,}65\cdot 10^{-4}m^2}=1{,}85m/s$$

The mass flow from each nostril is:

$$m=\frac{2{,}4\cdot 10^{-4}m^3/s\cdot 1{,}156kg/m^3}{2}=1{,}39\cdot 10^{-4}kg/s$$

The momentum flow from each nostril is thus:

$$mv_0=1{,}39\cdot 10^{-4}kg/s\cdot 1{,}85m/s=2{,}57\cdot 10^{-4}kgm/s^2$$

The direction of the exhalation

When breathing out is done through the nose and the head is held in a normal upright position, the direction of the exhalation is about 45 degrees below horizontal direction. The exhalation through the two nostrils creates two jets with an intervening angle of about 30 degrees, and those two jets do not collapse but will diffuse as two independent jets in the room.

Measured velocities in the blowing out from the nose

It is difficult to measure exhalation velocities from a person. Firstly, the blowing out is taking so short time, for a resting person about 2.5 s, that the anemometer must be very quick. Secondly, the centre line of the jet with the maximum velocity has to be found within the 2.5 s, and thirdly it is difficult for a person to breath uniformly each time. This is the reason why the results to some extent must be spread out. Table 1 contains velocities measured in a jet from the nose of a resting person.

Distance x m	0,09	0,12	0,15	0,18	0,24	0,28
Velocity v_x m/s	0,8	0,6	0,5	0,6	0,3	0,3
v_x/v_0	0,43	0,32	0,27	0,32	0,16	0,16

Table 1. Measured velocities v_x in the jet from one nostril of a resting person. The exhaled flow is $2.4\cdot 10^{-4}$ m^3/s totally, the injection velocity v_o = 1.85 m/s.

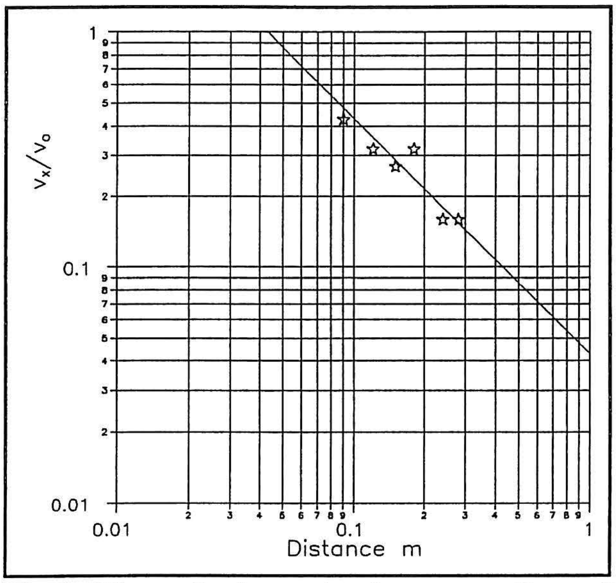

Fig.1. The velocity v_x in the centre line of the jet from the nose in relation to the inlet velocity v_o = 1.85 m/s for a resting person.

For a circular free jet the following equation is valid [3]:

$$\frac{v_x}{v_o}=C_c\frac{\sqrt{A_o}}{x}$$

or:

$$\log\frac{v_x}{v_o}=\log C_c+0{,}5\log A_o-\log x$$

This means a straight line with the slope -1 in double logarithmic depiction.

For v_x/v_o = 1 is read in fig.1: x = 0.043 m
Insertion of this together with $A_o=6{,}5\cdot10^{-5}$ m^2 gives:

$$0=\log C_c+0{,}5\log 6{,}5\cdot10^{-5}-\log 0{,}043$$

Which results in: $C_c=5{,}3$

If the contraction in the injection opening (the nostril) is ignored the jet is determined to be:

$$\frac{v_x}{v_o}=5{,}3\frac{\sqrt{6{,}5\cdot10^{-5}}}{x}$$

Or:

$$\frac{v_x}{v_o} = \frac{4{,}3 \cdot 10^{-2}}{x}$$

The injection jet is determined by this equation, x has to be inserted in m.

Of course individual differences in shape and injection area of the nose can be found but differences cannot change fig.1 very much. The invasion length of the jet into the surrounding air will not be changed very much with A_o either. Only a collapse between the two jets from the nostrils can change the invasion length remarkably, but this do not seem to be the fact for anybody.

The invasion of the exhalation into the surroundings

For the air surrounding a person the essential question is whether the exhalation from the nose is catched by the rising convection flow around the body or if it penetrates this and gets free of it.

To examine this question a living person who is called Pernille has been used together with a thermal breathing model called Comfortina.

With Pernille the spread of CO_2 from the breathing into the surroundings is examined with gas analysis equipment. In addition the invasion length for exhalation through the nose of a flow corresponding to a resting breathing is measured by means of cigarette smoke in the breathing out. Pernille has the advantage, in this connection, to be a smoker. Pernille has in principle only been used to verify that the thermal breathing model Comfortina can give the same effect on the surroundings as a living person. After this Comfortina has been used for the long series of experiments.

Comfortina is a thermal model constructed at the Technical University of Denmark. The model is heated in 16 parts, left hand, left arm and so on, and each part is regulated for comfort. If a greater heat emission is wanted the surrounding temperature is reduced or the air velocity is increased, and after this the regulating system increases the power input until the "skin" temperature again fulfils Fanger's comfort equation in relation to the surroundings. To Comfortina belongs moreover a breathing machine which is connected by tubes to mouth and nose, so a wanted combination of inhalation and exhalation through mouth or nose can be chosen. The breathing frequency and the amount of the respiration can be chosen within a large area.

At the breathing experiments with Comfortina the exhalation has been through the nose and the inhalation through the mouth. Hereby it has been possible to add N_2O to the exhalation and at the same time to measure the concentration in the inhalation, to look if the breathing out is inhaled again, which would be a sign that the exhalation does not get free of the convection flow around the body.

To avoid endless experiments the possibilities of indoor climate are reduced to the following three, in principle, different types:

a. Quiet surroundings, no ventilation
b. Displacement ventilation
c. Constant horizontal flow

Case a. Comfortina is placed in the positions standing, sitting and sitting at a table.

Case b. Comfortina is placed with the back or the face against the air inlet in the same positions as in case a.

Case c. Comfortina is placed standing or sitting with face or back against a horizontal airflow with the velocities 0.1 or 0.2 m/s.

All gas analysis measurements have shown equal results. The exhalation is almost always getting free of the convection flow around the body. Only in situations when a person is sitting at a table and the head is bent forward the blowing out can be pulled back to the chest but this happens at normal office work so rare that it can be ignored.

Figures 2-4 show a typical example of the concentration measurements, in this case for Comfortina in standing position, in a climate room without ventilation. It means that the concentration of N_2O in the room increases with the time. The measuring points 2 and 3 are placed at a higher level than the exhalation jet from the nose which, as mentioned earlier, has a direction of 45 degrees below horizontal direction.

Fig.2 shows the position of the concentration measuring points.

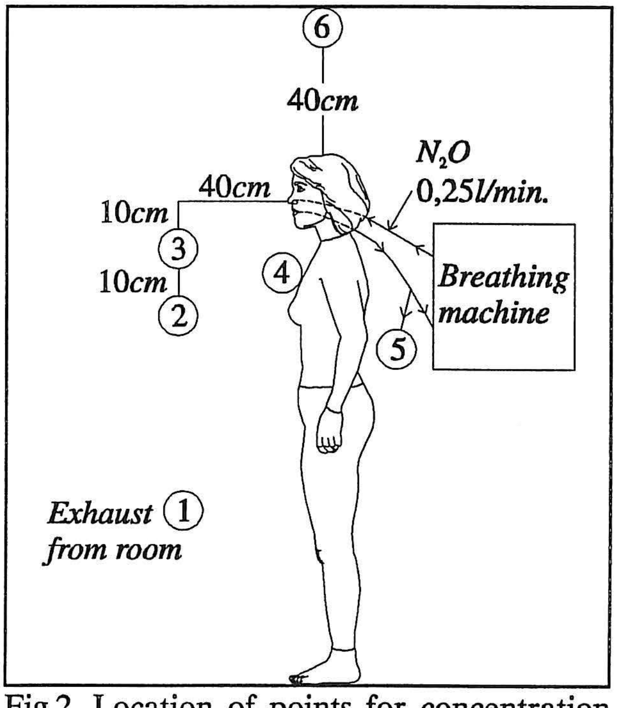

Fig.2. Location of points for concentration measurements.

Figure 3 is showing that only in the points 2 and 3 concentrations are measured which are higher than the level in the background which is seen in measuring point 1.

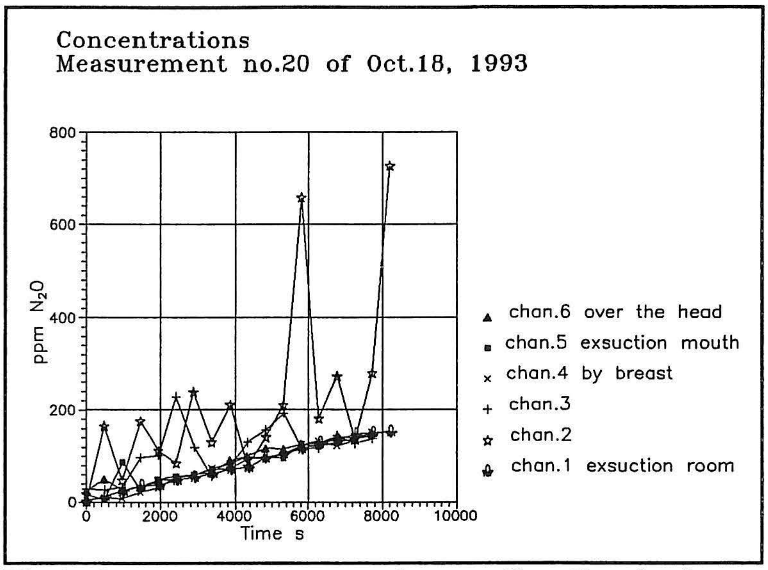

Fig.3. Concentrations around a standing Comfortina at rest. N_2O added to the expiration from the nose into a concentration of about 40000 ppm.

In figure 4 channel 5 is showing a very little short circuit between the exhalation from the nose and the inhalation through the mouth, remembering that the concentration of N_2O in the exhalation is 40000 ppm. Channel 6 which is placed in the convection flow above the head is showing no influence at all from the exhalation, which is also proving that the exhalation is penetrating the rising convection flow around the body and moves away from it.

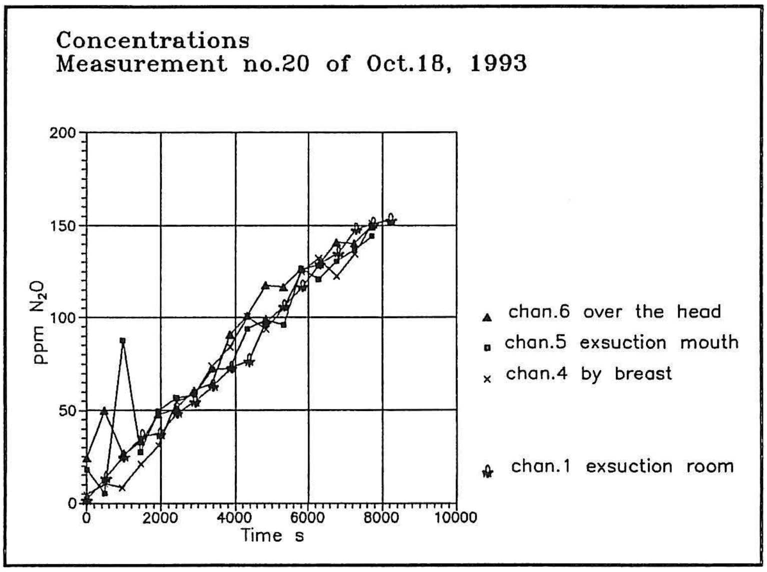

Fig.4. Concentrations in the same situation as in fig.3, only chan. 2 and 3 are removed.

As mentioned before this picture is repeating itself for all ventilation methods and all positions which have been examined, therefore no more results will be shown.

But Comfortina is also giving a possibility for smoke tests. A smoke generator is by means of a spirometer adjusted to give a flow according to a breathing at rest. The exhaled smoke is heated to 31 C which is the normal temperature for a breathing at rest. Figure 5 shows an example of this.

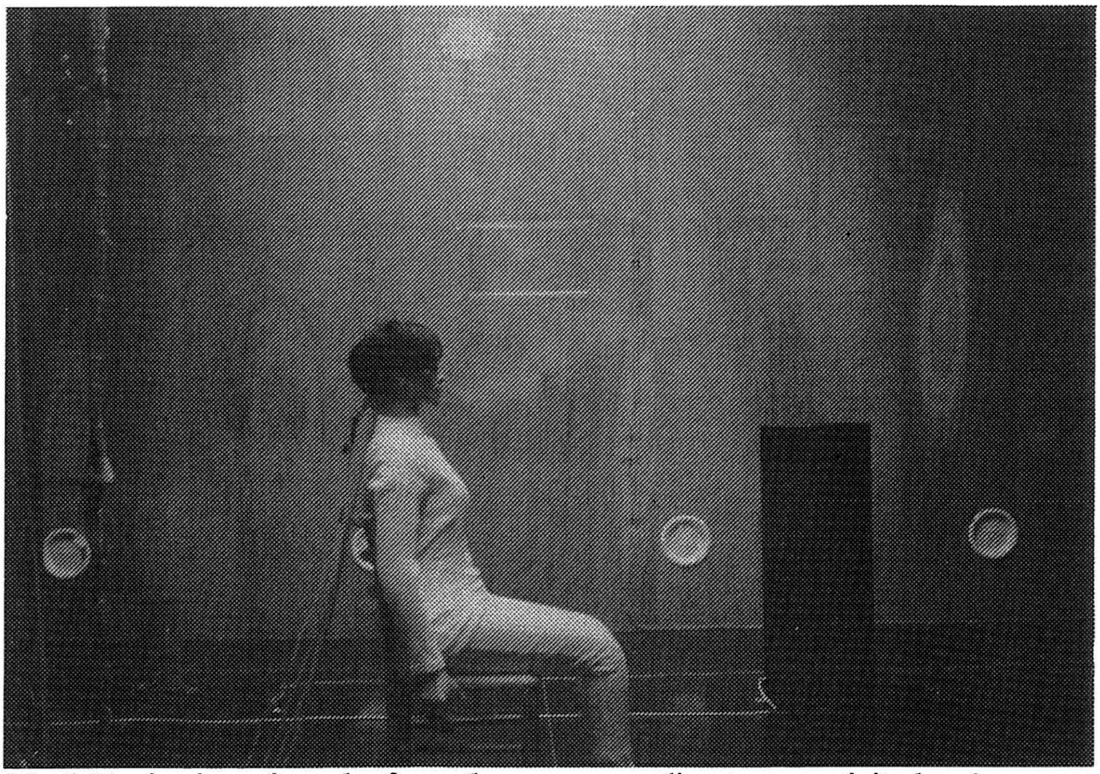

Fig.5. Expiration of smoke from the nose according to an activity level at rest. No ventilation of the room, no stratification, the surroundings are quiet and of equal temperature.

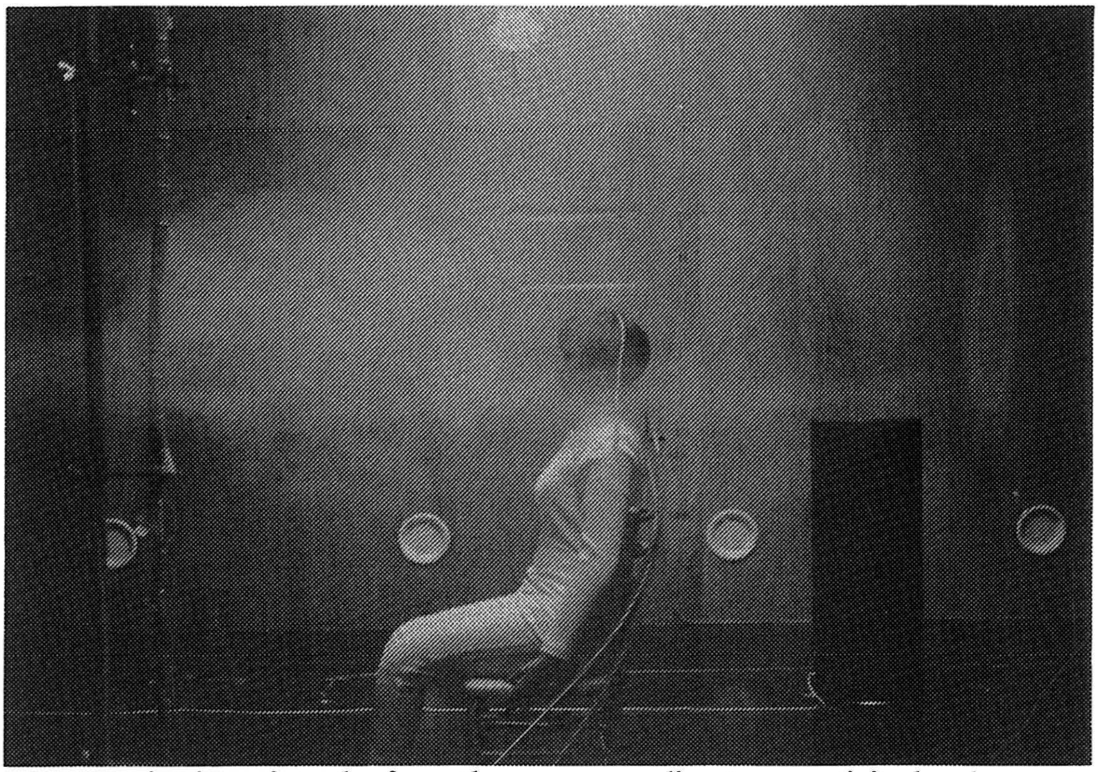

Fig.6. Expiration of smoke from the nose according to an activity level at rest. Displacement ventilation of the room. The belonging stratification is seen in fig. 7.

Fig.5 is showing how the exhalation from the nose is penetrating the convection current around the body, that the invasion length is about 30-40 cm and that the thermal buoyancy after the invasion is sufficient to make the exhalation rise to the ceiling.

Fig.6 is showing that the exhalation from the nose is staying in the occupied zone at displacement ventilation when the temperature gradient is breaking above the height of the head, because the exhalation after invading the surrounding air does not have buoyancy enough left to move upwards through an increasing temperature field.

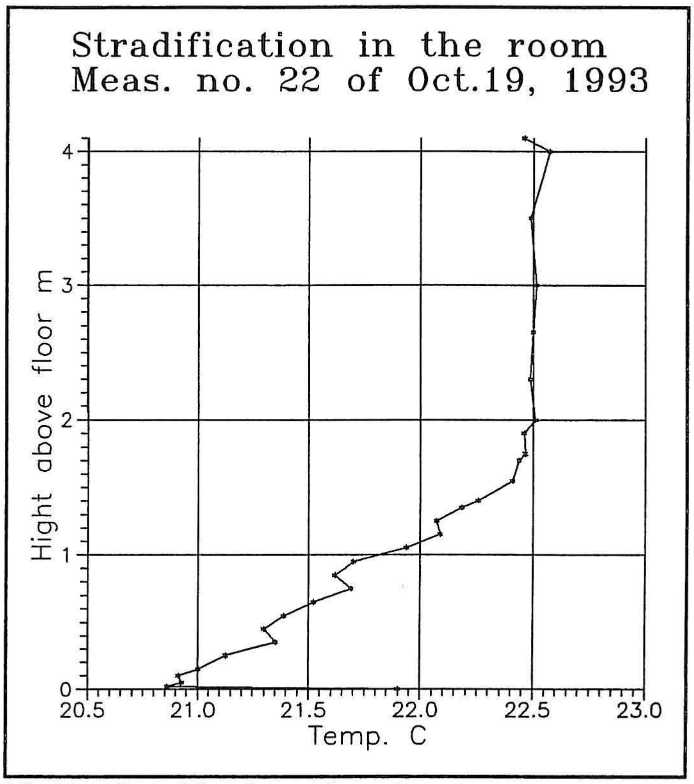

Fig.7. Stratification in the test room at displacement ventilation.

This shows something very essential, that displacement ventilation is not suitable to remove the contamination from human breathing. Displacement ventilation is only fit when heat and contamination source are combined and this is exactly shown not to be the case for the breathing contamination and the heat convection flow from the human being.

Within a constant horizontal flow everything is looking rather different from the previous two cases. If the person is facing the flow, even a small air velocity of 0.05 m/s will cause that the exhaled air, after the invasion into the surrounding air, is brought towards the body again, but because of the ingenious formed nose, the flow is divided into two jets which are carried in separate ways around the body. Behind the back there is a rising convection flow which is also mentioned later. At higher velocities this flow picture is not changed, but the turbulence behind the back increases.

If the person has the back towards a constant horizontal flow the exhalation is only carried away from the person after the entrance into the surrounding air.

If a person has the side towards a constant horizontal flow the exhalation is only deflected.

Smoking

Smoking habits

To day the vast majority of people are smoking cigarettes, so the following text will be about this type of smoking.

When a person is drawing on a cigarette it causes the so called mainstream of smoke. No sucking makes the cigarette smoke itself and hereby it produces the so-called sidestream of smoke.

A sitting smoker is in the time between the sucking holding the cigarette at a distance of nearly the length of an arm, or has placed the cigarette in an ashtray at the same distance in order to avoid sidestream smoke coming into the eyes. The smoker is in this way consciously holding the cigarette outside the influence from the convection flow of the body to avoid getting smoke into the eyes.

The average of smokers is to day 40% and 60% of non smokers. Each of the smokers is smoking 1.5 cigarette per hour on an average.

Smoke quantity

One of the most critical contaminants from smoke is the amount of totally emitted particles. The particles are so small, smaller than 2μm, that they are floating in the air and come into the lungs with the breathing. According to [4] a cigarette by mainstream is producing 36.2 mg and by sidestream 25.8 mg floating dust. According to the same reference 70% of the particles in the mainstream is filtered out in the smokers' lungs, so that the emission to the surrounding air is $0.3 \cdot 36.2 + 25.8$ mg = 36.7 mg from each smoked cigarette. This corresponds well with our own measurements.

Emission of smoke

Great variations in the velocity of blowing out smoke are measured, varying from 1 to 2.5 times the velocity at breathing at rest. If the smoke is blown out through the nose the inlet velocity and the invasion length are varying accordingly. If the smoker choses to blow out the smoke through the mouth, he or she will normally take care of blowing it away with a high velocity in order to avoid getting it into the eyes. So the smoke is blowed through the convection flow around the body with nearly the same velocity as when it is blown out through the nose, but from the mouth the direction is mostly a little below horizontal direction.

So the figures 5 and 6 can also be a picture of smoking, only the invasion length for the smoke can vary within a period of 1 to 2.5 times the shown. But the picture of flow in the two cases - quiet isothermal air and displacement ventilation -is identical in principle irrespective the inlet velocity.

If a person is placed in a constant horizontal flow the smoke will of course be turned off. Flow fields within the comfort area, that is with velocities below about 0.1 m/s, do not change very much in the flow picture when back or side is against the flow. Only with the person facing the flow the flow field will be changed because, in this case, the smoke after the entrance into the surrounding air will be carried against and round the body and after that it will participate in the rising convection flow along the back.

For the mainstream of smoke it can be counted on a blowing out flow varying from about $2.4 \cdot 10^{-4}$ m^3/s to $6 \cdot 10^{-4}$ m^3/s according to a velocity in the inlet through the nose at 1.85 m/s to 4.6 m/s.

The sidestream of smoke has a superheating so large, that it with no difficulties penetrates to the ceiling even through a rising temperature field. Because the emitted amount of particles floating in the air is greatest for the sidestream, the exhaust in rooms with smoking ought to be placed high.

For the many different gases produced by smoking the case is rather different. Because of different burning temperatures the distribution between mainstream and sidestream is differing for the different gases. So in principle each gas has to be treated separately.

Concerning the sidestream the temperature will be so great that all sorts of gases must be expected to be lighter than the surrounding air, so the gases will join the smoke particles on their way to the ceiling.

For mainstream gases the case is more complicated. Some of the gases are absorbed in the lungs. The rest of those gases are emitted together with the smoke particles and at first they are following the inlet jet. When the kinetic energy is used the movement of the gases will depend on the air movements in the room.

With no or very small air movements in the room the heavy gases can diffuse down to the floor while the light gases are diffusing to the ceiling. Of course the gases diffuse into the the room air, but this takes time, so the concentration of heavy gases above the floor can very well be higher than elsewhere and those gases can be carried up to inhalation with the convection flow around the body. To avoid this the exhaust opening can be placed at a low level in the room, but by this you will get an inferior ventilation effectiveness for the light gases lying below the ceiling. Movements from people in a room can of course mix the air and the gases, but then we would not have small air movements in the room.

With greater air movements in the room the influence of the gas diffusion will disappear. The gases are mixed with the air and are following the air movements. Yet smoke emitted by sidestream will still have a superheating so large that the smoke will rise to the ceiling. As mentioned before the mainstream too will rise to the ceiling when the temperature gradient in the room is small. So, placing of the exhaust opening at a high level is to prefer.

Conclusion on smoking

For rooms with smoking the conclusion is:

a. Quiet surroundings, no ventilation
Smoking ought not to be allowed

b. Displacement ventilation
Ought not to be installed in rooms with smoking because the concentration of contaminants in the inhalation zone is too high.

c. Horizontal flow
The smoker ought not to be placed with the back against the flow. The exhaust ought to be placed high in the room and the air inlet must give a mixing in the room sufficient to avoid that heavy gases and contamination particles are moving to the floor and from there are carried to inhalation with the convection flow of the body.

Bioeffluents and vapour

The main question of the emission of gases is to what extent they are carried upwards with the convection flow of the body and to what extent they are diffusing through this.

Measuring method

It is not easy to measure all gases emitted from the body, but this is presumably not necessary either. The gases which are lighter than the air must have a greater ability to follow the convection flow of the body upwards than the gases which are heavier than the air. If a tracer gas, which is heavier than the air, does not diffuse through the convection flow to a degree worth mentioning, the light contamination gases will probably not be able to diffuse either.

To examination of these circumstances the thermal model Comfortina is used again. A perforated plastic tube is twisted around legs and body inside the outside layer of clothes and N_2O is conducted to the tube. Measuring points for gas analysis are placed above the head and beside the body to show the movements of the tracer gas. Concerning the breathing exhalation through the nose and inhalation through the mouth are chosen in order to be able to disclose how much of the emitted bioeffluents oneself will inhale at the different positions and surroundings by measuring the concentration in the inhaled air.

a. Quiet surroundings, no ventilation

In this case the measurements have shown no remarkable difference for the person placed standing or sitting. So here is shown only the results for Comfortina sitting at a table.

The placing of measuring points is shown in fig.8.

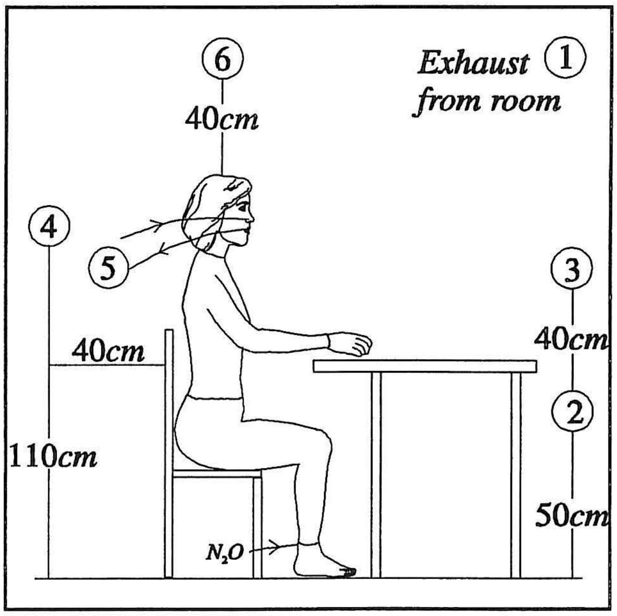

Fig.8. Location of points for concentration measurements.

In fig.9 it is seen that the emitted gas is carried with the convection flow up above the head (measuring point 6). Some of the tracer gas is with the convection flow carried up to inhalation (measuring point 5). The measuring points 2 and 4 are not higher than the background concentration in the room (channel 1), but in point 3 the concentration is higher because some of the gas following the convection flow upwards passes the nose and is carried with the exhalation against point 3.

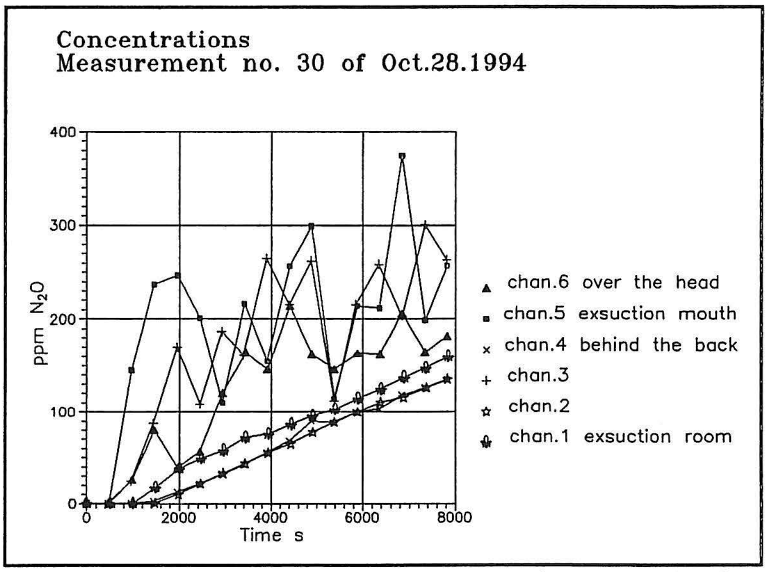

Fig.9. Concentrations around a resting Comfortina sitting at a table. No ventilation. Measuring points are shown in fig.8.

b. Displacement ventilation

At this form of ventilation different positions have been examined. Comfortina has been placed standing, sitting and sitting at a table. She has been facing the inlet and the back has been turned against the inlet. For all those cases the results have been very equal and therefore only one typical case will be shown here. This is Comfortina sitting at a table facing the air inlet, the air velocity around the feet has been about 0.15 m/s.

In figure 10 is seen a tendency as in figure 9. Most of the contamination is carried with the convection flow up over the head (measuring point 6). At point 5, it is seen that some of the convection flow is inhaled. Point 4 does not exceed the concentration in the background (channel 1). The measuring points 2 and 3 are now and then receiving higher concentrations with the exhalation.

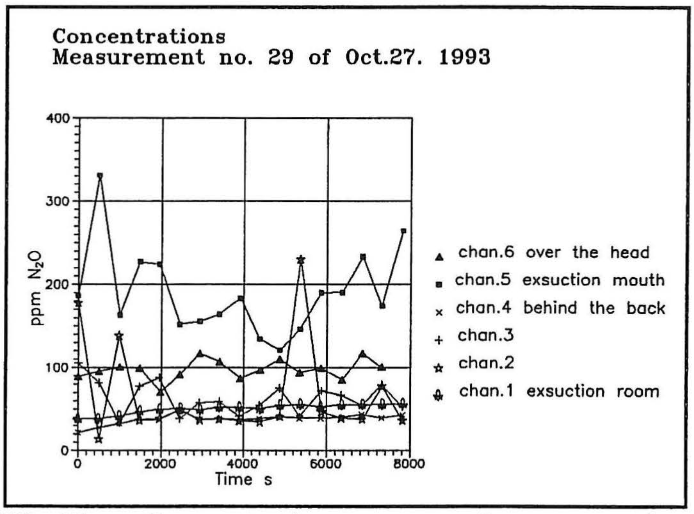

Fig.10. Concentrations around a resting Comfortina sitting at a table. Displacement ventilation. Measuring points is shown in fig.8.

To examine if vapour is acting different from N_2O, measurements are carried out with Comfortina in wet clothes. The concentrations of vapour are measured in the same positions (fig.8). The results do not differ from those achieved with N_2O and the perforated tube. So the conclusion is that the different bioeffluents will behave in the same way and thus be carried upwards over the head with the convection flow around the body.

c. Constant horizontal flow

The constant horizontal flow is produced in a wind tunnel placed in the climate room. The front area is B x H = 1.2m x 2.46m and the length L is = 2.4m. The front edges are rounded with diam. 500 mm ventilation pipes halved lengthwise. By this is obtained nearly equal air velocity over the area where a person is placed. When a person is placed in the wind tunnel the velocities will of course be changed, but all the following velocities are measured before Comfortina is placed in the tunnel.

The horizontal flow has given a number of remarkable results. The following figures are showing results for Comfortina placed in different positions at different velocities. For each mesuring point a normalized concentration is mentioned, and this is the average concentration for the measuring time, which has been a night or a day, divided by the average concentration in the exhaust from the wind tunnel.

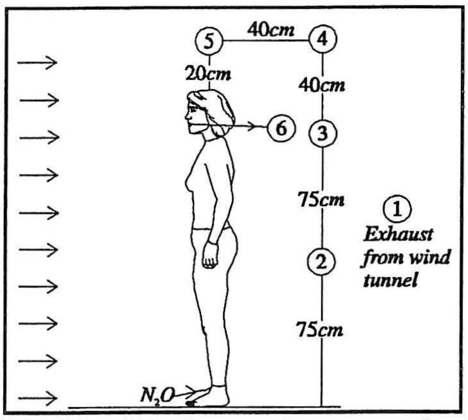

Fig.11. Placing of measuring points. Comfortina standing facing the horizontal flow.

Vel.	Point				
m/s	2	3	4	5	6
0.05	1.26	2.17	2.30	1.60	1.05
0.10	3.34	3.32	3.11	0.36	0.29
0.15	7.30	5.63	1.82	0.13	0.14
0.20	7.64	6.00	1.65	0.13	0.13
0.30	9.14	3.57	0.40	0.14	0.14
0.40	8.63	3.11	0.31	0.23	0.16

Table 2. Concentrations divided by the concentration in the exhaust (point 1). Arrangement as shown in fig.11. Comfortina standing with the face against the flow.

Table 2 shows that the inhalation already at a velocity of 0.1 m/s is quite unaffected by the body convection flow. In this set-up it is not possible to reach a concentration lower than about 0.14. This minimum value depends partly on the front velocity because a little of the tracer gas will get out in the surrounding climate room and thus the supplied airflow cannot be quite clean.

Table 2 is also showing that in point 5, placed above the head, there is an influence of the convection flow at 0.05 and 0.10 m/s, but above 0.15 m/s the convection flow around the body is bent so it does not reach point 5. At the velocity 0.30 m/s the influence on measuring point 4 is little.

Those concentration measurements can not show what happens in the immediate vicinity of the body, but when smoke is conducted to the perforated tube it can clearly be seen. At the side of the body turned against the flow no upward convection flow is built up at all, but the front side is "blowed clean" already at a velocity of 0.05-0.10 m/s. On the leeward side of the body, in this case behind the back, you can find the vertical convection flow even at front velocities as high as 0.4 m/s which was not to be expected. Yet much turbulence is found at the highest front velocities. Unfortunately, this flow picture is impossible to show in snap shots.

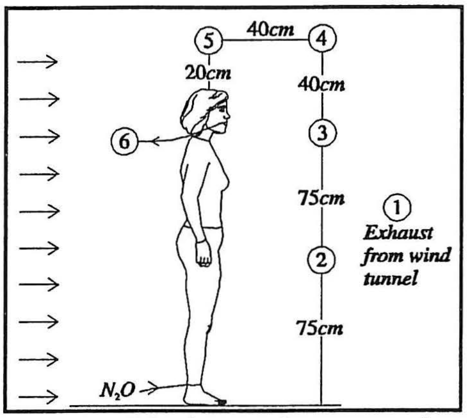

Fig.12. Placing of measuring points. Comfortina standing with the back against the horizontal flow.

Vel.	Point				
m/s	2	3	4	5	6
0.05	2.00	1.74	2.06	1.81	4.43
0.10	1.35	3.42	3.53	0.11	9.14
0.15	2.15	4.94	3.49	0.12	12.4
0.20	3.99	4.71	1.66	0.10	12.9
0.30	6.96	3.28	0.45	0.13	10.5
0.40	5.04	1.90	0.54	0.29	7.06

Table 3. Concentrations divided by the contration in the exhaust (point 1). Arrangement as shown in fig.12. Comfortina standing with the back against the flow.

Figure 12 and table 3 are containing some surprises. Point 6, which is measuring on the concentration in the inhalation through the mouth, is showing an increasing influence of N_2O at increasing velocity and the concentration does not begin to decrease again until the highest velocities 0.30 and 0.40 m/s are reached. So the upward body convection flow on the leeward side is intact even at horizontal flow velocities much above comfort. So, when the back is against the flow you inhale the upward convection flow containing the bioeffluents emitted from yourself. Likely there is a possibility that heavy gases lying at the floor are carried up to inhalation.

A comparison between table 2 and 3 for the other measuring points shows some differences caused by the breathing. With the back against the flow (table 3) the jet from the nose will carry some of the body convection flow away but as it is passing below measuring point 3, lower values in the points 2 and 3 are measured.

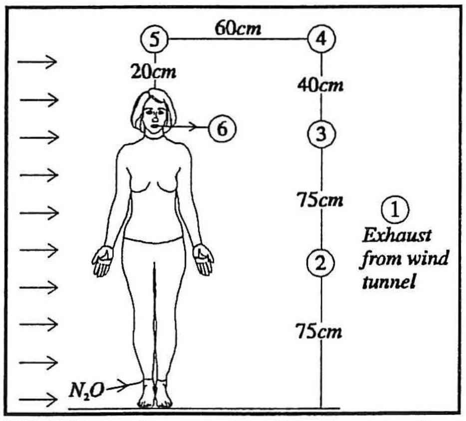

Fig.13 Placing of measuring points. Comfortina standing with the side against the horizontal flow.

Vel.	Point				
m/s	2	3	4	5	6
0.05	2.26	1.83	2.14	0.64	0.88
0.10	1.81	4.07	3.25	0.24	0.38
0.15	4.56	7.20	2.70	0.16	0.50
0.20	3.19	9.15	2.92	0.13	1.73
0.30	4.19	5.87	1.11	0.29	1.60
0.40	5.09	4.48	0.78	0.33	1.33

Table 4. Concentrations divided by the concentration in the exhaust (point 1). Arrangement as shown in fig.13. Comfortina standing with the side against the flow.

Looking at table 4 it is astonishing that the inhalation measured in point 6 is influenced by contamination at all velocities. This is examined by smoke and by this a development of so much turbulence around the body and especially at the shoulder is revealed that it is impossible to get clean inhalation from the side at the velocities which we have tried here. The rest of the measuring points are showing nothing surprising.

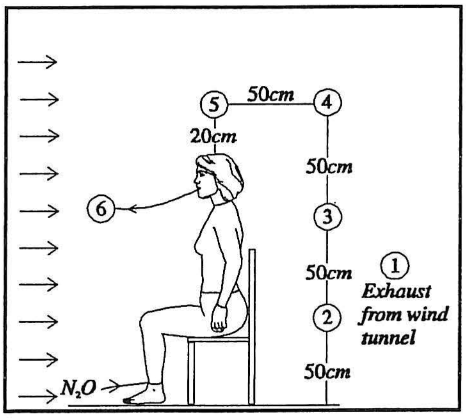

Fig.14. Placing of measuring points. Comfortina sitting facing the horizontal flow.

Vel. m/s	Point 2	3	4	5	6
0.05	0.35	0.87	1.31	0.39	0.69
0.10	0.89	2.74	1.39	0.21	0.22
0.15	1.55	4.21	2.74	0.21	0.23
0.20	2.20	8.69	3.64	0.22	0.23
0.30	5.77	8.10	1.31	0.23	0.26
0.40	5.01	7.51	0.87	0.26	0.25

Table 5. Concentrations divided by the concentration in the exhaust (point 1). Arrangement as shown in fig.14. Comfortina sitting facing the flow.

Table 5 is showing that also in sitting position very little velocity towards the front of a person is enough to give a clean inhalation provided that the horizontal flow is clean. At measuring point 5 is seen that already 0.05 m/s prevents a build up of the convection flow at the front side. Smoke examination shows that the convection flow is found behind the back like in the case with a standing person.

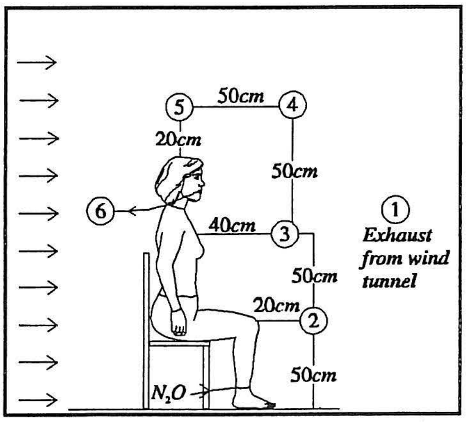

Fig.15. Placing of measuring points. Comfortina sitting with the back against the horizontal flow.

Vel. m/s	Point 2	3	4	5	6
0.05	2.17	2.42	1.78	0.45	3.39
0.10	6.51	4.28	2.28	0.21	5.64
0.15	4.24	5.27	2.51	0.19	9.96
0.20	4.50	7.34	2.63	0.19	15.8
0.30	3.01	6.09	0.68	0.25	15.7
0.40	3.83	4.83	0.61	0.26	11.6

Table 6. Concentrations divided by the concentration in the exhaust (point1). Arrangement as shown in fig.15. Comfortina sitting with the back against the flow.

Table 6 and figure 15 are showing that even the highest velocities from the back cannot prevent inhalation of the convection flow from the front side. The highest concentrations are in addition found at 0.2 and 0.3 m/s and those are some of the highest relative concentrations measured at all. The rest of the measuring points are showing nothing unusual in relation to previous cases.

Conclusions about bioeffluents and vapour

a. Quiet surroundings, no ventilation

Bioeffluents and vapour emitted from the skin surface are diffusing through the clothes and participate in the vertical convection flow around the body continuing above the head. The inhalation is taken from the vertical body convection flow.

b. Displacement ventilation

Like case a.

c. Constant horizontal flow

In a room with horizontal flow in the occupied zone it is much better to stand or sit facing the flow than having the back or the side against it. Even velocities so small as 0.05-0.10 m/s prevent a build up of a vertical convection flow on the windward side of the body. Instead of this the flow is following the body to its outline from which a whirl emission is created. On the leeward side of the body is created a vertical convection flow. If the back is turned against the flow the inhalation is taken from the convection flow and if heavy gases are concentrated at the floor they can be carried up to inhalation. With a side against the horizontal flow the inhalation is also partly taken from the body convection flow.

Acknowledgement

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

References

[1] Fanger P.O. "Thermal Comfort". Robert E. Krieger Publishing Company, Malabar, Florida, 1982.

[2] Henne Erich "Luft Befeuchtung". C.F.Müller Verlag, Karlsruhe, 1972.

[3] Peter V. Nielsen "Air movements in rooms" from "Varme- og Klimateknik" Danvak grundbog. Teknisk Forlag København 1987. (in Danish).

[4] Wadden Richard A. and Cheff Peter A. "Indoor air pollution". John Wiley & Sons 1983.

[5] Straub H.E., Nelson P.R., Toft H.R. "Evaluation of smoking lounge ventilation designs". ASHRAE transactions, Vol.99, Pt 1, 1993, pp 466-475.

PAPERS ON INDOOR ENVIRONMENTAL TECHNOLOGY

PAPER NO. 25: P. V. Nielsen: *Air Distribution Systems - Room Air Movement and Ventilation Effectiveness.* ISSN 0902-7513 R9250.

PAPER NO. 26: P. V. Nielsen: *Description of Supply Openings in Numerical Models for Room Air Distribution* ISSN 0902-7513 R9251.

PAPER NO. 27: P. V. Nielsen: *Velocity Distribution in the Flow from a Wall-mounted Diffuser in Rooms with Displacement Ventilation.* ISSN 0902-7513 R9252.

PAPER NO. 28: T. V. Jacobsen & P. V. Nielsen: *Velocity and Temperature Distribution in Flow from an Inlet Device in Rooms with Displacement Ventilation.* ISSN 0902-7513 R9253.

PAPER NO. 29: P. Heiselberg: *Dispersion of Contaminants in Indoor Climate.* ISSN 0902-7513 R9254.

PAPER NO. 30: P. Heiselberg & N. C. Bergsøe: *Measurements of Contaminant Dispersion in Ventilated Rooms by a Passive Tracer Gas Technique.* ISSN 0902-7513 R9255.

PAPER NO. 31: K. S. Christensen: *Numerical Prediction of Airflow in a Room with Ceiling-Mounted Obstacles.* ISSN 0902-7513 R9256.

PAPER NO. 32: S. G. Fox & P. V. Nielsen: *Model Experiments in 1990 and On-Site Validation in 1992 of the Air Movement in the Danish Pavilion in Seville.* ISSN 0902-7513 R9335.

PAPER NO. 33: U. Madsen, N. O. Breum & P. V. Nielsen: *Local Exhaust Ventilation - a Numerical and Experimental Study of Capture Efficiency.* ISSN 0902-7513 R9336.

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.

Department of Building Technology and Structural Engineering
Aalborg University, Sohngaardsholmsvej 57. DK 9000 Aalborg
Telephone: +45 98 15 85 22 Telefax: +45 98 14 82 43