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INDOOR ENVIRONMENTAL TECHNOLOGY
PAPER NO. 29

Presented at Lüftungsforschung für die Praxis, ETH, Zürich, May 1992

P. HEISELBERG
DISPERSION OF CONTAMINANTS IN INDOOR CLIMATE
MAY 1992 **ISSN 0902-7513 R9254**

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7] Nielsen, P.V. 1981. "Contaminant Distribution in Industrial Areas with Forced /entilation and Two-dimensional Flow". IIR-Joint Meeting, Commision E1, Essen.

8] Heiselberg, P. 1990. "Flow Conditions in Rooms with Mixing and Displacement /entilation". (in Danish). Ph.D.-Thesis, University of Aalborg, ISSN 0902-7513-R9015.

9] Murakami, S., Tanaka, T. and Kato, S. 1983. "Numerical Simulation of Air Flow and ;as Diffusion in Room Model - Correspondance between Numerical Simulation and Aodel Experiments". 4th Int. Symp. on the Use of Computers for Environmental Ingineering Related to Buildings, Tokyo.

10] Lemaire, A.D. 1989. "Testrooms, Identical Testrooms". Annex 20 working report I.I.1.3.

Dispersion of Contaminants in Indoor Climate

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In rooms ventilated by mixing ventilation, in order to remove contaminants from the occupied zone, the goal of the air distribution system is to achieve a low and even concentration distribution in the room.

The experiments showed that the contaminant distribution in a room always will depend on the location of the contamination source and in practice also on the supplied air flow rate and the contaminant density.

The results showed that it is important for the removal of contaminants in a room that the ventilation system is working in the same direction as the existing buoyancy forces.

1. Introduction

Within comfort ventilation a distinction can be made between two main principles, mixing ventilation and displacement ventilation, to removal of released contaminants in the indoor climate.

In rooms ventilated by mixing ventilation the goal of the air distribution system is to rarefy the contaminated air and to achieve a low and even concentration distribution in the whole room, the so-called complete mixing. On the other hand in rooms ventilated by displacement ventilation the goal of the air distribution system is to displace the contaminated air from the occupied zone and to achieve supply air quality here and exhaust air quality in the rest of the room.

In the following the results of a series of full-scale measurements will be presented and they show how the contaminant distribution in a full-scale test room ventilated by the mixing principle looks like under different flow conditions, and what it is important to be aware of if the goals of the air distribution system are to be achieved.

It is examined how the contaminant distribution is influenced by different air change rates in the room, by different locations of the contamination source and by different densities of the contaminant.

2. Experimental Set-Up

The experiments have taken place under isothermal steady state conditions as specified in [1] and [2].

2.1 The Test Room

The experiments have taken place in a full-scale test room located in a laboratory hall. A sketch of the geometry of the room is shown in figure 1. The specifications of the test room are (L × W × H) = (4.2 m × 3.6 m × 2.4 m), see [10].

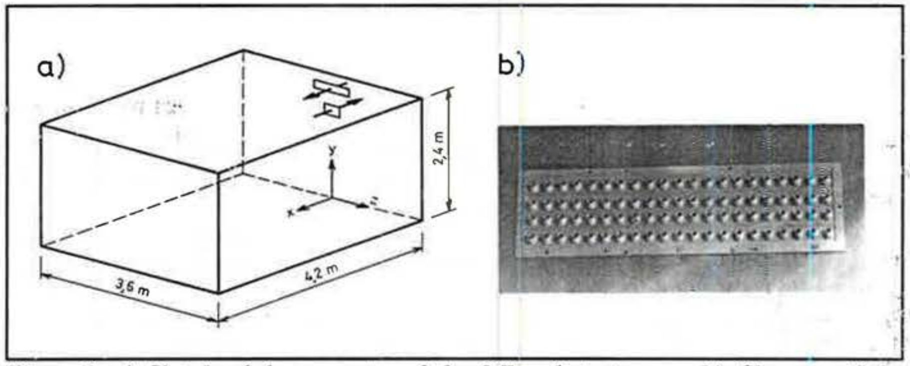

Figure 1. a) Sketch of the geometry of the full-scale test room. b) Close-up of the HESCO inlet device.

2.2 The Inlet and Outlet Devices

The inlet device is of the HESCO-type. The diffuser consists of 4 rows with 21 nozzles which can be adjusted to different directions. For these experiments the nozzles have been adjusted to an angle of 40° upwards, see figure 1 and [3]. The dimensions are (H × W) = (0.17 m × 0.7 m). The inlet is located in the middle of one of the end walls with the top of the inlet 2.2 m above the floor. The generated flow pattern is very typical of modern air terminal device design. The outlet is located below the inlet with the top of the outlet at a distance of 1.6 m above the floor. The dimensions are (H × W) = (0.2 m × 0.3 m).

2.4 The Contamination Source

The contamination source consists of a ping pong ball (diameter 30 mm) with 6 evenly distributed holes with a diameter of 1 mm each. The tracer gas CO_2 has been used as a contaminant. It has been mixed with the carrier gases N_2 or He in order to give a total contaminant flow rate of 0.025 l/s and different contaminant densities.

2.5 The Location of Measuring Points

The concentration profiles were measured in 10 points. The points were distributed along a vertical line placed in the centre plane of the test room 2.2 m from the supply opening. The calculation of concentration contours in the centre plane of the test room are based on measurements in 110 points. The points are concentrated around the contamination source where large gradients are expected, at the end wall to see how far the supply air jet penetrates into the room and at the boundary surfaces. The

contaminant distribution will approximate the distribution at high turbulent fl conditions, see experiments in [6], [8] and [9].

4. Conclusion

In rooms ventilated by mixing ventilation, in order to remove contaminants from t occupied zone, the goal of the air distribution system is to achieve an even concentrati distribution in the room. This is not always possible, however, but the full-sca experiments have shown at large air change rates with high air velocities where t contamination sources are located that the differences will be relatively small. He sources located in the room will together with the fact that there will be persons walki about contribute to a better mixing in the room in practice.

The contours of concentration in the centre plane of the room showed at an change rate of $n=1.5$ h^{-1} considerable differences between the test cases with differe contaminant densities. The results showed that it is important for the removal contaminants in a room that the ventilation system is working in the same direction the existing buoyancy forces. A contaminant with a high density will flow towards t floor region. With an exhaust placed near the floor the ventilation system will be able remove the contaminant, regardless of the fact that the supply air jet is able to fl through the whole room, and a situation with high levels of concentration as in figure will be prevented.

The experiments showed that the contaminant distribution in a room always w depend on the location of the contamination source and, in practice, also on the suppli air flow rate and the contaminant density. High turbulent flow conditions will occur the room at large air change rates but the velocities in the occupied zone will then above the acceptable level of comfort.

5. References

[1] Heikkinen, J. 1989. "Specification of Testcase B (Forced Convection, Isothermal Annex 20 working report R.I.1.13.

[2] Skåret, E. 1989. "Specification of Testcase F (Forced Convection, Isothermal w Contaminants)". Annex 20 working report R.I.1.31.

[3] Nielsen, P.V. 1988. "Selection of Air Terminal Device". Annex 20 working rep R.I.1.2. University of Aalborg, ISSN 0902-7513-R8838.

[4] Skovgaard, M., Hyldgaard, C.E. and Nielsen, P.V. 1990. "High and low Reyno Number Measurements in a Room with an Impinging Isothermal Jet". Int. Co ROOMVENT '90, Oslo.

[5] Oppl, L. 1969. "Luftströmung in gelüfteten Raümen". Öl- und Gasfeuerung, Nr.

[6] Heiselberg, P. and Nielsen, P.V. 1987. "The Contaminant Distribution in a Ventila Room with Different Air Terminal Devices". Int. Conf. ROOMVENT '87, Stockholr

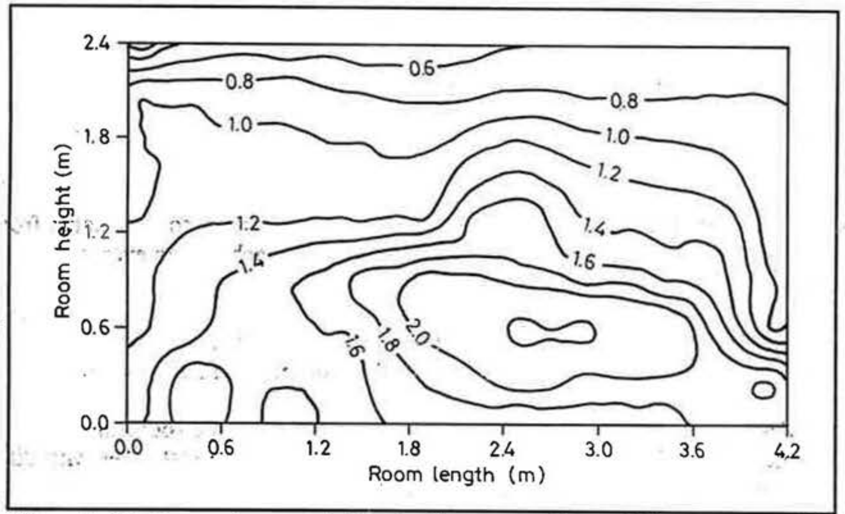

Figure 5. Contours of concentration in the centre plane of the test room. The contaminant density is 1.2 kg/m³.

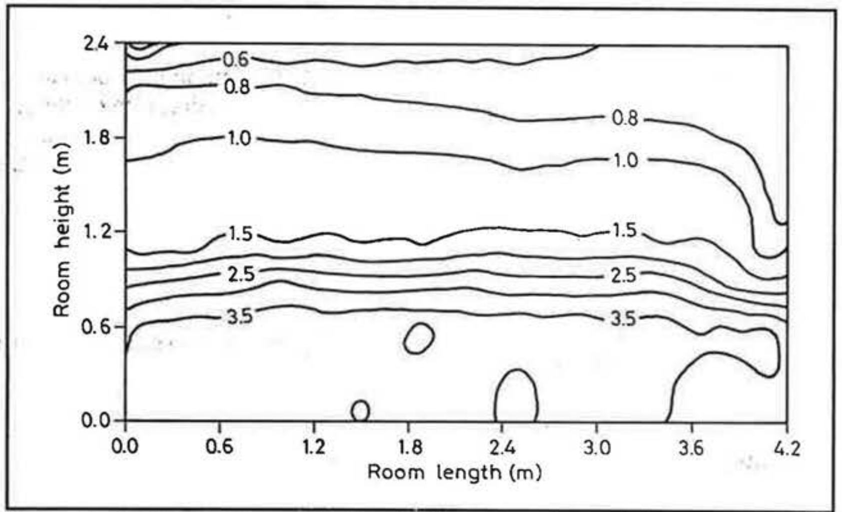

Figure 6. Contours of concentration in the centre plane of the test room. The contaminant density is 1.8 kg/m³.

concentration in large areas of the occupied zone because of the low velocities and ow exchange of air in this region of the room.

Contours of concentration at the low density case in figure 4 show high levels of ncentration above the contamination source where the contaminant is flowing towards e ceiling and is here entrained by the supply air jet. There are also high levels of ncentration below the contamination source.

The considerable differences found between the three test cases will be reduced th an increasing air change rate. The buoyancy effects will decrease and the

3. Measuring Results

The measuring results show how the contaminant distribution is influenced by different air change rates in the test room, by different locations of the contamination source and by different densities of the contaminant. The results show in which situations the air distribution system is capable of creating a low and even concentration distribution in the whole room.

3.1 Profiles of Concentration

Vertical profiles of the concentration in the middle of the test room have been measured at different air change rates and locations of the contamination source. The profiles of concentration are presented as concentration ratios where the reference concentration is the concentration in the exhaust opening.

Figure 2 shows the profiles for three air change rates with the contamination source located in the middle of the room, location A, and a contaminant density of 1.2 kg/m³. In the test case with an air change rate of $n=1.5\ h^{-1}$ the air flow rate is approximately the minimum value required to ventilate an office room. The throw of the jet is about 4/5 of the room length and the maximum velocity in the occupied zone is below 0.1 m/s. The test case with an air change rate of $n=3\ h^{-1}$ represents the basic case where the air flow rate is about the usual value in office rooms. The throw of the jet is approximately room length plus room height and the maximum velocity in the occupied zone is 0.16 m/s which is the maximum velocity that can be accepted in an office. In the test case with an air change rate of $n=6\ h^{-1}$ the maximum velocity in the occupied zone is about 0.33 m/s. The velocity measurements can be seen in [4].

The results in figure 2 show in the upper part of the room a concentration distribution in the wall jet created by entrainment of the contaminated room air into the primary air. The concentration distribution is nearly the same for all three air change rates.

In the occupied zone the concentration distribution is dependent on the air change rate and it changes radically when the air change rate is changed from $n=1.5\ h^{-1}$ to $n=3\ h^{-1}$ due to a change in the flow structure in the room. At an air change rate of $n=1.5\ h^{-1}$ the supply air jet only reaches the upper part of the occupied zone and the recirculating flow takes place here. In the lower part of the room there are small velocities and a slow exchange of air and therefore a high level of concentration, see also figure 5. At an air change rate of $n=3\ h^{-1}$ the supply air jet reaches the floor in the room and there will be a recirculating flow with large velocities at floor level, see [4]. The contamination source is placed almost in the centre of the recirculating flow where the velocities and the exchange of air are very small. The level of concentration therefore becomes very high before the contaminant is entrained and discharged with the other air in the room. Model experiments in [5]) and full-scale experiments in [6] show a similar effect when the source is placed in an area with a low velocity.

With an increasing air change rate the contaminant distribution is approximating the distribution at high turbulent flow conditions in the room. This distribution is independent of the air change rate, see [7]. The maximum velocity in the occupied zone will, however, be above the acceptable comfort level for office rooms. Therefore the contaminant distribution in a room will depend on the supplied air flow rate in practice.

Figure 3 shows the profiles of concentration for four locations of the contamination source in the room at an air change rate of $n=3\ h^{-1}$ and at a contaminant density

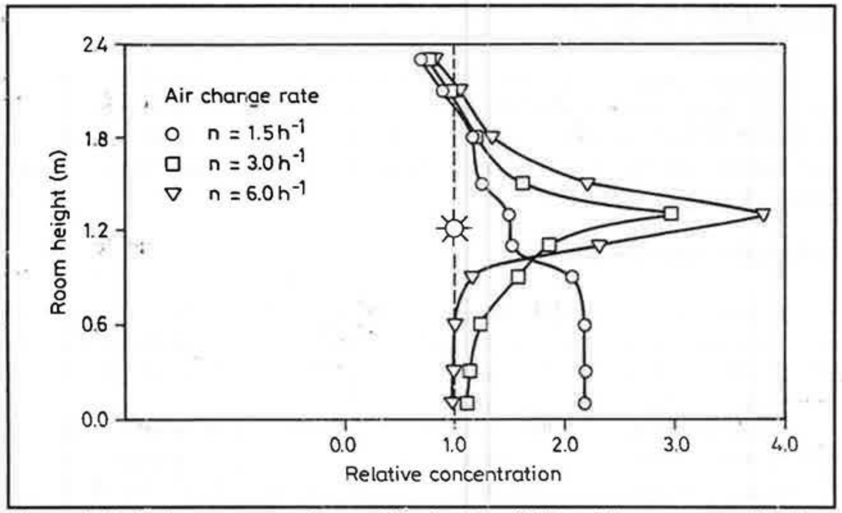

Figure 2. Relative concentration profiles in the middle of the test room for three different air change rates.

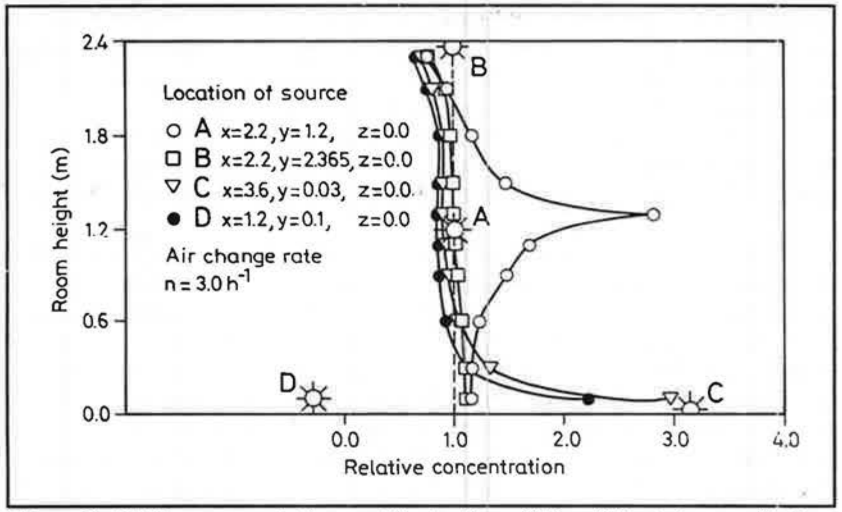

Figure 3. Relative concentration profiles in the middle of the test room for four different locations of the contamination source.

of 1.2 kg/m^3. Location A) is in the middle of the room as specified in [2]. Here the velocities are very low. Location B) is in the primary jet. Location C) and D) is in the occupied zone where the maximum velocity in the recirculating flow and a low velocity have been measured, respectively.

The profiles of concentration in the middle of the room depend on the location of the contamination source. A location in the middle of the room where the velocities are very small gives a high level of concentration just around the source because the exchange of air is slow. A location in the primary jet results in a very good mixing of the

contaminant and the supply air and gives a quick removal of the contaminant and homogeneous contaminant distribution in the whole room. A location of the contami ation source at floor level gives a uniform concentration in the upper part of the roc and only high concentration in the immediate vicinity of the floor. Corresponding resu are found in [5] and [7].

3.2 Contours of Concentration

Contours of concentration in the centre plane of the test room have be measured for three different contaminant densities with the contamination source locat in location A) and at an air change rate of $n=1.5$ h^{-1}. The three test cases wi contaminant densities of $s=0.8$ kg/m^3, $s=1.2$ kg/m^3 and $s=1.8$ kg/m^3 represent a ca with low density of the contamination source with a tendency of the contaminant migrate to the ceiling region, a basic case with neutral density and a case with hi density of the contamination source with a tendency of the contaminant to migrate to t floor region, respectively.

The results in the figures 4-6 show that the supply air jet reaches halfway do the opposite end wall and that the recirculating flow takes place in the upper part of t room above the level of the contamination source. The contours of concentration sh considerable differences between the three test cases.

Contours of concentration at the high density case in figure 6 show clearly th the contaminant is streaming towards the floor region. Because the supply air jet is n able to flow through the whole room an even stratification of the contaminant arises in the lower part with a large contaminant gradient just below the contamination sour and large concentrations near the floor.

Contours of concentration at the neutral density case in figure 5 show that t contaminant distributed to the upper part of the room is mixed with the recirculati room air. The contaminant distributed to the lower part of the room causes a high lev

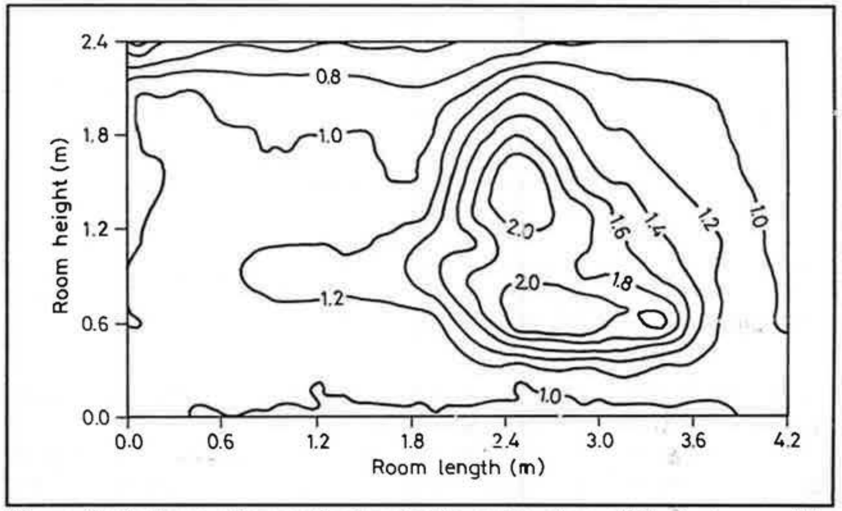

Figure 4. Contours of concentration in the centre plane of the test room. The contaminant density is 0.8 kg/m^3.