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Concentration Distribution in a Ventilated Room under Isothermal Conditions

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Synopsis

The work in this paper contributes to the work in the IEA - Annex 20 "Air Flow Patterns within Buildings" and presents a series of full-scale measurements of the concentration distribution in a room with isothermal mixing ventilation.

Vertical profiles of the concentration in the middle of the room have been measured under different conditions. With the contamination source in the middle of the room the vertical profiles were changed radically with an increase of the air change rate from $n=1.5h^{-1}$ to $n=6h^{-1}$ due to a change in the flow structure in the room. With a constant air change rate the location of the contamination source in the room showed a great influence on the vertical profile. A high velocity around the contamination source resulted in a uniform contaminant distribution in the room, while a low velocity resulted in considerable differences.

Contours of concentration in the centre plane of the room have been measured using different contaminant densities. The densities were low, neutral and high in relation to the density of air. The results showed that the contaminant distribution in the room with the chosen flow conditions depended strongly on the contaminant density, and that the high density case gave the highest concentrations in the occupied zone.

1. Introduction

This paper contributes to the work in the IEA - Annex 20 "Air Flow Patterns within Buildings", subtask 1 "Room Air and Contaminant Flow". One of the objectives of subtask 1 is to acquire experimental data for the evaluation of the performance of air flow models in predicting air velocity, temperature and contaminant distribution.

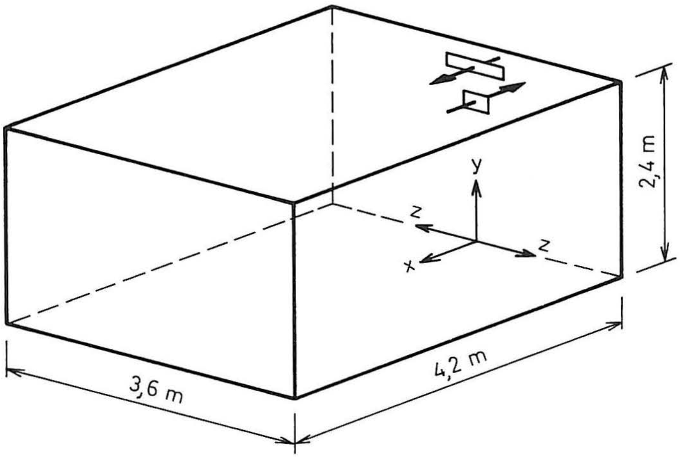
The approach is to make identical full-scale experiments in identical test rooms with identical inlet devices at different sites. Simultaneous numerical simulations for the measured configurations are carried out. The measured data are compared and a data base establised for the evaluation of the accuracy of the predictions made.

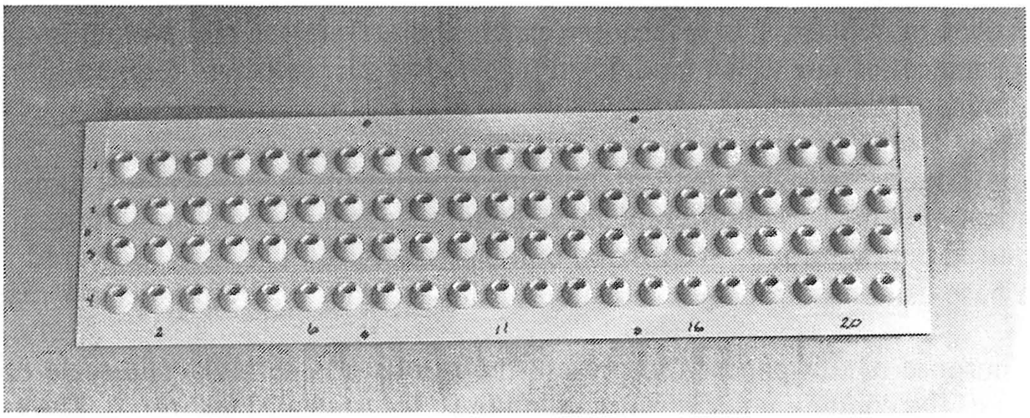
The purpose of this paper is to present the results of a series of full-scale experiments of the contaminant distribution in the IEA - Annex 20 test room. The results can be used for comparison with predictions made by air flow models and to show how the contaminant distribution in a full-scale room looks like under different practical flow conditions. In the experiments the contaminant distribution has been measured under isothermal steady state flow conditions at different air change rates, locations of the contamination source and contaminant densities.

2. Experimental Set-Up

The identical test room for subtask 1 is specified in Lemaire[2]. A sketch of the geometry of the full-scale test room used in these experiments is shown in figure 1. The test room corresponds to the specifications except for the room height of 2.4m (Lemaire[2] specifies 2.5 m).

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 Nielsen[1]. The generated flow pattern is very typical of modern air terminal device design.





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

The contamination source consists of a ping pong ball (diameter 30mm) with 6 evenly distributed holes with a diameter of 1 mm each. If another location of the source is not stated it is placed approximately in the middle of the test room in the point (x,y,z) = (2.2,1.2,0.0) as specified in Skåret[4]. 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.

The profiles of concentration are based on measurements 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 contours of concentration in the centre plane of the test room are based on measurements in 110 points. Figure 2 shows the distribution of the points in the test room. 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 concentrations are measured with a BINOS I.R.-analyzer.

The experiments have taken place under isothermal steady state conditions as specified in Heikkinen[3].

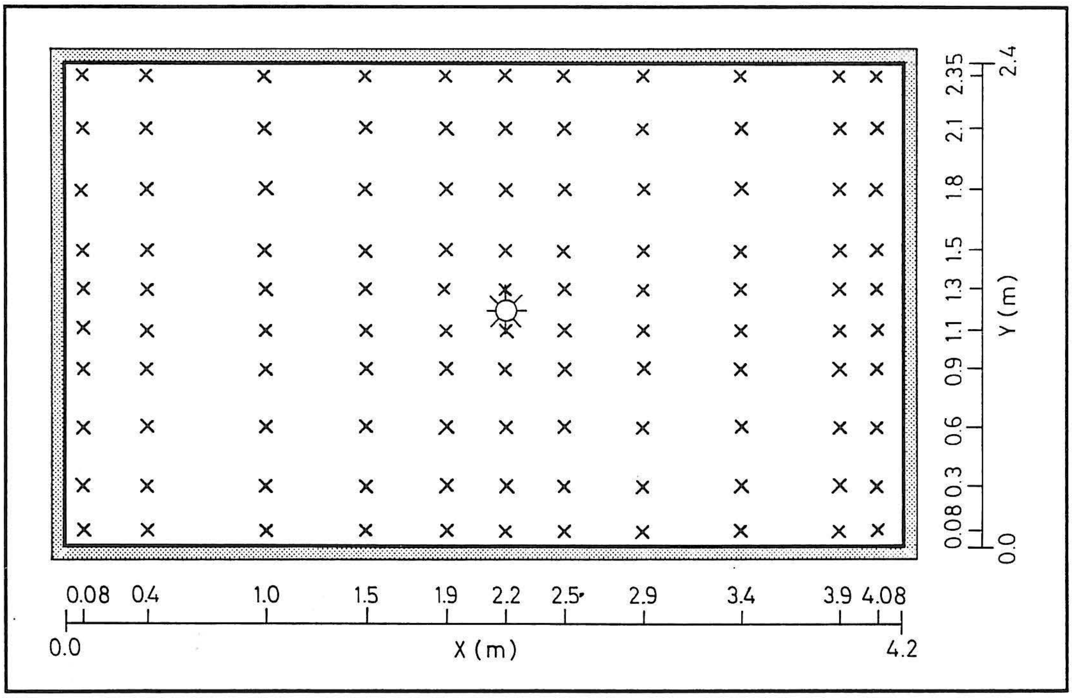


Figure 2. Distribution of points for measurements of contours of concentration in the centre plane of the test room.

3. Profiles of Concentration

Vertical profiles of the concentration in the middle of the test room have been measured for 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 3 shows the profiles for three air change rates. The test case with an air change rate of $n=1.5h^{-1}$ represents a small Reynolds number case where low Reynolds number effects are seen in the inlet flow from the diffuser and in the flow structure in the room, see Skovgaard et al.[5] and Skovgaard et al.[6]. The air flow rate is approximately the minimum value required to ventilate an office room. Measurements in Skovgaard et al.[5] show that the throw of the jet is about 4/5 of the room length and that the maximum velocity in the occupied zone is below 0.1 m/s. The test case with an air change rate of $n=3h^{-1}$ represents the basic case where the air flow rate is about the usual value in office rooms. According to Skovgaard et al.[5] 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. The test case with an air change rate of $n=6h^{-1}$ represents a high Reynolds number case and it is important for the comparison of the measured and the calculated results. The maximum velocity in the occupied zone is according to Skovgaard et al.[5] about 0.33 m/s.

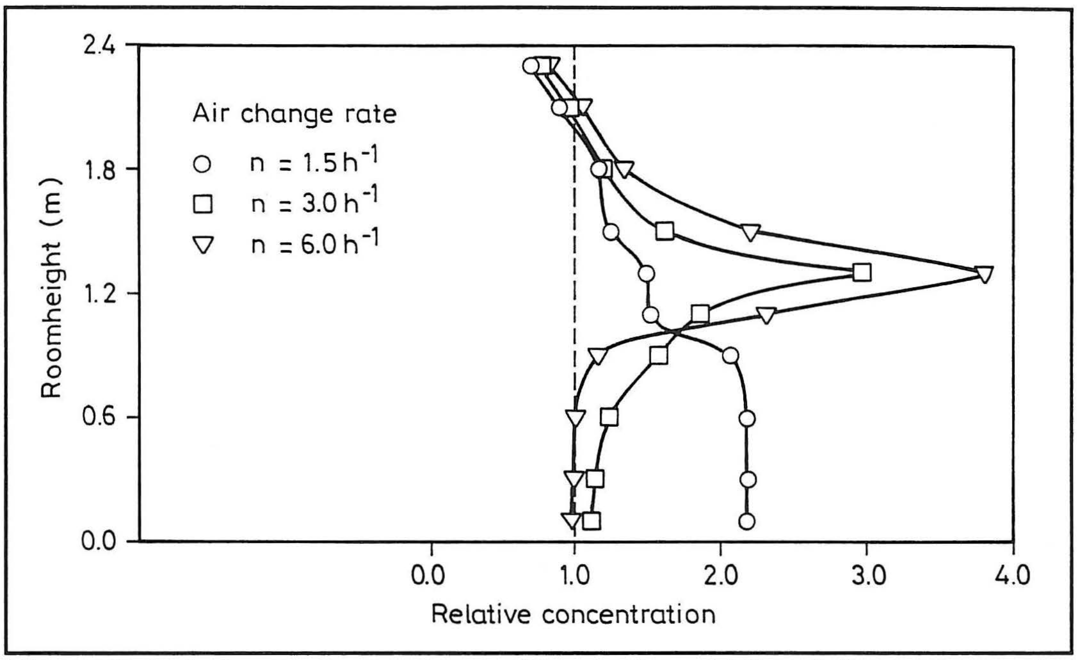


Figure 3. Relative concentration profiles in the middle of the test room for three different air change rates. The contamination source is placed in the middle of the room 1.2 m above the floor. The contaminant density is 1.2 kg/m³.

The results in figure 3 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 $n=1.5h^{-1}$ to $n=3h^{-1}$ due to a change in the flow structure in the room.

At an air change rate of $n=1.5h^{-1}$ 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 6.

At an air change rate of $n=3h^{-1}$ the supply air jet reaches the floor in the room and there will be a recirculating flow with large velocities at floor level, see Skovgaard et al.[5]. 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 by Oppl[7] and full-scale experiments by Heiselberg et al.[8] 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 Nielsen[9]. The maximum velocity in the occupied zone will, however, be above the acceptable comfort level for office rooms. The contaminant distribution in a room will for practical purposes therefore depend on the supplied air flow rate.

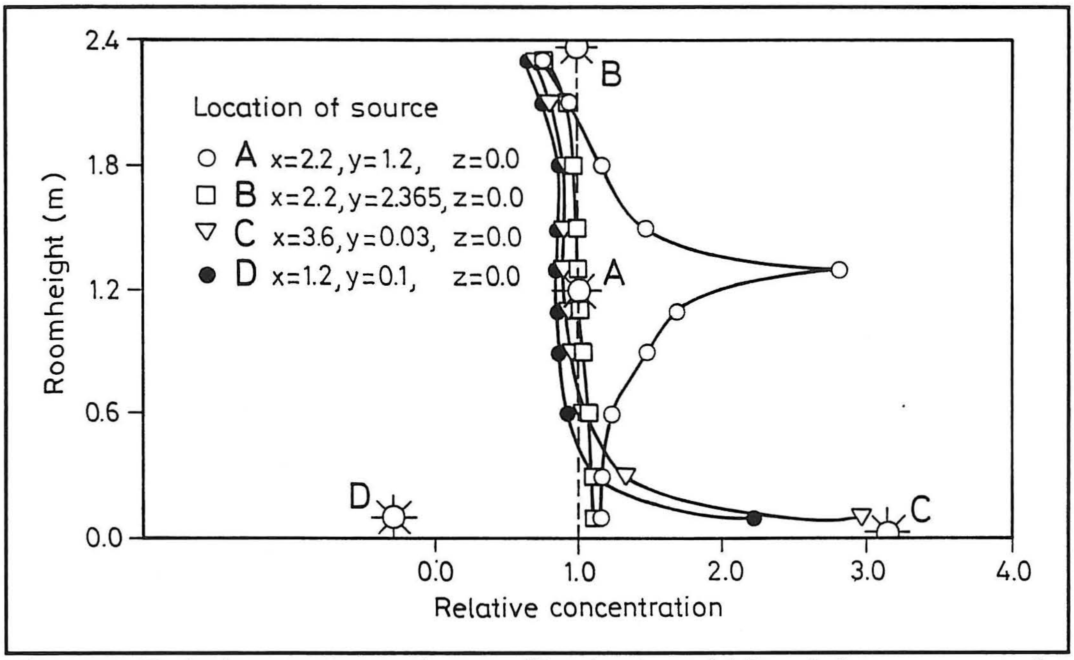


Figure 4. Relative concentration profiles in the middle of the test room for four different locations of the contamination source. The air change rate is $n=3h^{-1}$. The contaminant density is 1.2 kg/m^3.

Figure 4 shows the profiles of concentration for four locations of the contamination source in the room. Location A) is in the middle of the room as specified in Skåret[4]. Here the velocities are very low. Location B) is in the primary jet where the maximum velocity has been measured. Location C) is in the occupied zone where the maximum velocity in the recirculating flow has been measured. Location D) is at floor level where a low velocity has been measured. The velocity measurements are from Skovgaard et al.[5].

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 a homogeneous contaminant distribution in the whole room. A location of the contamination source at floor level gives a uniform concentration in the upper part of the room and only high concentration in the immediate vicinity of the floor. Corresponding results are found by Oppl[7] and Nielsen[9].

4. Contours of Concentration

Contours of concentration in the centre plane of the test room have been measured for three different contaminant densities. The three test cases with contaminant densities of $s=0.8$ kg/m^3, $s=1.2$ kg/m^3 and $s=1.8$ kg/m^3 represent respectively a case with low density of the contamination source with a tendensy of the contaminant to migrate to the ceiling region, a basic case with neutral density and a case with high density of the contamination source with a tendensy of the contaminant to migrate to the floor region.

The results in the figures 5-7 show that the supply air jet reaches half the way down the opposite end wall and that the recirculating flow takes place in the upper part of the room above the level of the contamination source. The contours of concentration show considerable differences between the three test cases.

Contours of concentration for the high density case in figure 7 show clearly that the contaminant is streaming towards the floor region. Because the supply air jet is not able to flow through the whole room an even stratification of the contaminant arises

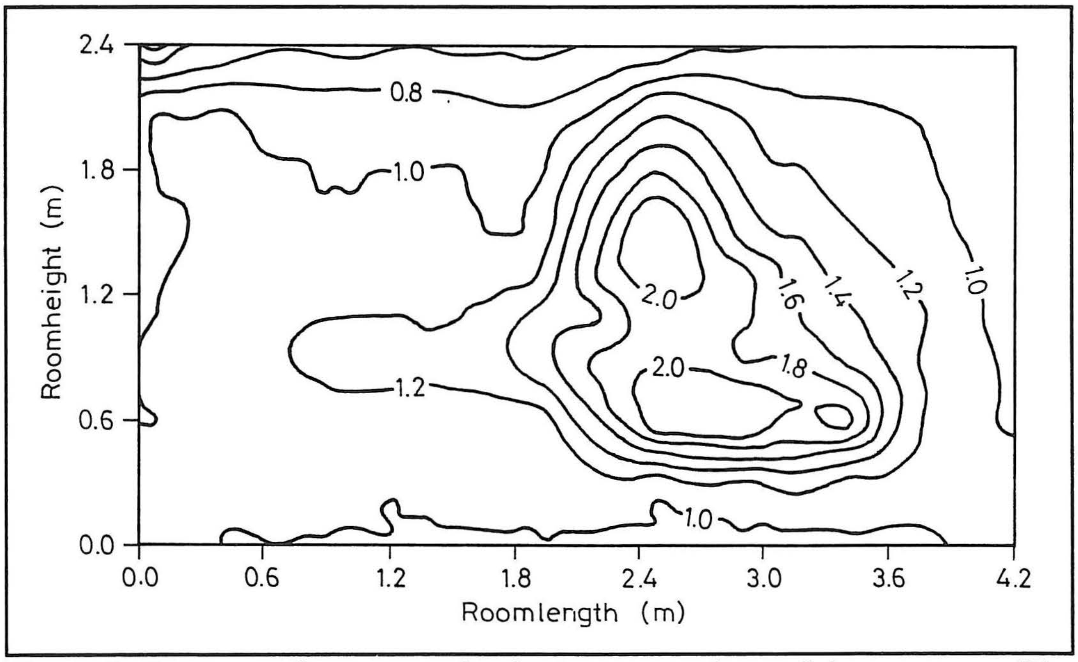


Figure 5. Contours of concentration in the centre plane of the test room. The contamination source is placed in the middle of the room 1.2 m above the floor. The contaminant density is 0.8 kg/m^3.

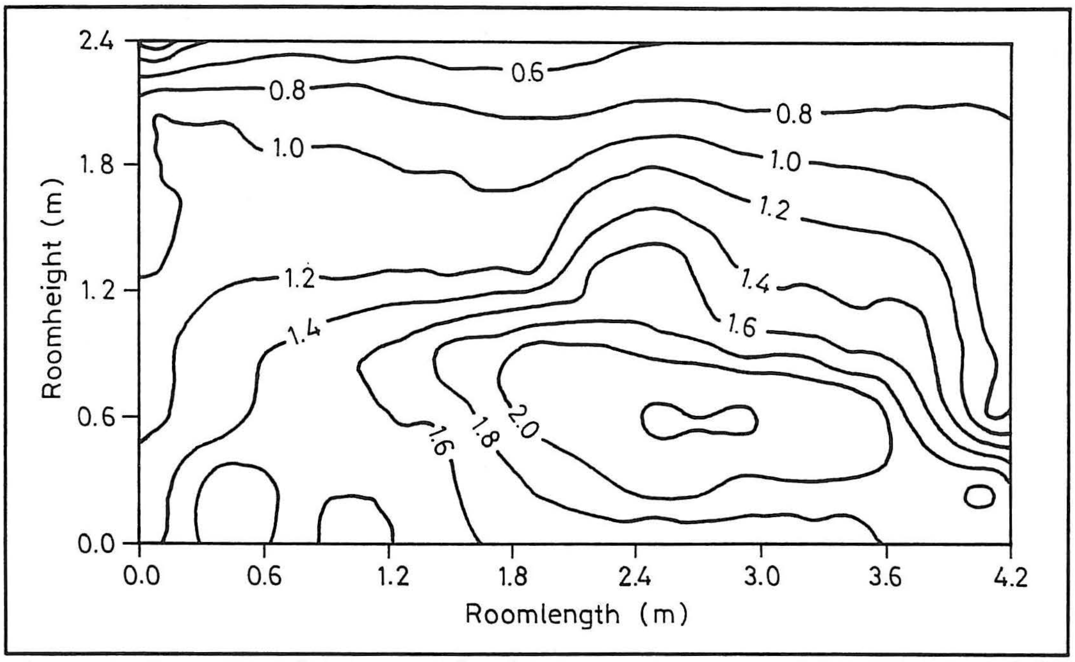


Figure 6. Contours of concentration in the centre plane of the test room. The contamination source is placed in the middle of the room 1.2 m above the floor. The contaminant density is 1.2 kg/m^3.

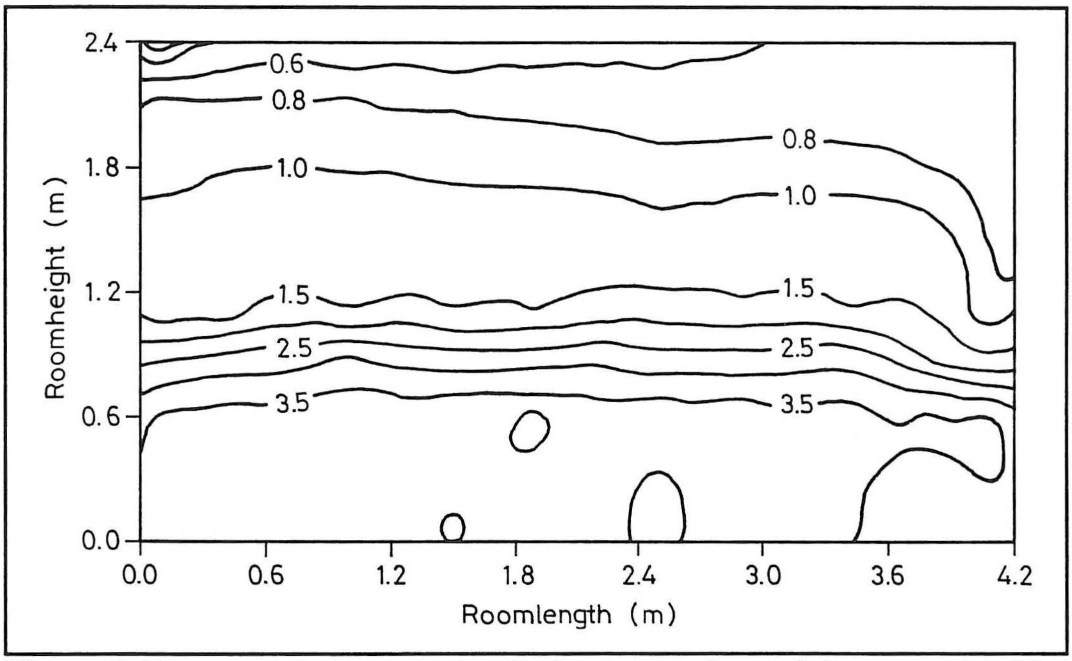


Figure 7. Contours of concentration in the centre plane of the test room. The contamination source is placed in the middle of the room 1.2 m above the floor. The contaminant density is 1.8 kg/m^3.

in the lower part with a large contaminant gradient just below the contamination source and large concentrations near the floor.

Contours of concentration for the neutral density case in figure 6 show that the contaminant distributed to the upper part of the room is mixed with the recirculating room air. The contaminant distributed to the lower part of the room causes a high level of concentration in large areas of the occupied zone because of the low velocities and slow exchange of air in this region of the room.

Contours of concentration for the low density case in figure 5 show high levels of concentration above the contamination source where the contaminant is flowing towards the ceiling and is here entrained by the supply air jet. There are also high levels of concentration below the contamination source.

The considerable differences found between the three test cases will be reduced with an increasing air change rate. The buoyancy effects will decrease and the contaminant distribution will approximate the distribution at high turbulent flow conditions, see experiments by Heiselberg et al.[8], Heiselberg[10] and Murakami et al.[11]

It is not possible from the figures 5-7 to see how the three-dimensional flow conditions in the room are influencing the contaminant distribution in the centre plane.

5. Conclusion

Results of a series of full-scale experiments of the contaminant distribution in the IEA - Annex 20 test room are presented. The results make it possible to evaluate the performance of air flow models in predicting the contaminant distribution in a room for different supply air change rates, locations of the contamination source and contaminant densities.

In rooms ventilated by mixing ventilation, in order to remove contaminants from the occupied zone, the goal for the air distribution system is to achieve an even concentration distribution in the room. This is not always possible, however, but the full-scale experiments have shown that by using as large an air change rate as possible without exceeding the comfort limit for the velocity in the occupied zone, and by making sure that the contamination source is placed in an area of the room with a high velocity the differences can be reduced to a minimum.

The contours of concentration in the centre plane of the room showed at an air change rate of $n = 1.5h^{-1}$ considerable differences between the test cases with different contaminant densities. 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. A contaminant with a high density will flow towards the floor region. With an exhaust placed near the floor the ventilation system will be able to remove the contaminant regardless of the fact that the supply air jet is able to flow through the whole room, and a situation with high levels of concentration as in figure 7 will be prevented.

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

6. References

[1] Nielsen, P.V.
"Selection of air terminal device".
Annex 20 working report R.I.1.2. University of Aalborg, 1988, ISSN 0902-7513-R8838.

[2] Lemaire, A.D.
"Testrooms, Identical Testrooms".
Annex 20 working report R.I.1.3, May 1989.

[3] Heikkinen, J.
"Specifikation of testcase B (forced convection, isothermal)".
Annex 20 working report R.I.1.13, April 1989.

[4] Skåret, E.
"Specification of testcase F (forced convection, isothermal with contaminants".
Annex 20 working report R.I.1.31, Oct. 1989.

[5] Skovgaard, M., Hyldgaard, C.E. and Nielsen, P.V.
"High and low Reynolds number measurements in a room with an impinging isothermal jet".
Int. Conf. ROOMVENT '90, Oslo 1990.

[6] Skovgaard, M. and Nielsen, P.V.
"Modelling complex inlet geometries in CFD - applied to air flow in ventilated rooms".
12th AIVC Conference, Ottawa Canada, Sept. 1991.

[7] Oppl, L.
"Luftströmung in gelüfteten Raümen".
Öl- und Gasfeuerung, Nr. 9, 1969.

[8] Heiselberg, P. and Nielsen, P.V.
"The contaminant distribution in a ventilated room with different air terminal devices".
Int. Conf. ROOMVENT '87, Stockholm, 1987.

[9] Nielsen, P.V.
"Contaminant distribution in industrial areas with forced ventilation and two-dimensional flow".
IIR-Joint Meeting, Commision E1, Essen, Sept. 1981.

[10] Heiselberg, P.
"Flow conditions in rooms with mixing and displacement ventilation".
(in Danish)
Ph.D.-Thesis, University of Aalborg, Maj 1990, ISSN 0902-7513-R9015.

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

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