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# Concentration Distribution in the Centre Plane of a Ventilated Room under Isothermal Conditions

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## Abstract

*This paper presents a series of full-scale measurements of the concentration distribution in the centre plane of 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.*

**KEY WORDS:**
Concentration distribution, Isothermal mixing ventilation

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## 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 airflow 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 database established 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 airflow models and to show what 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.

## Experimental Set-Up

The measurements were performed in a full-scale test room located in a laboratory hall. Figure 1A shows a sketch of the geometry of the test room. The dimensions of the room are (length × width × height) = (4.2 m × 3.6 m × 2.4 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 1B). The generated airflow pattern is very typical of modern air terminal device design. The inlet is located in the middle of one of the end walls with the top of the diffuser 2.2 m above the floor (see Figure 1A). The dimensions of the inlet are (height × width) = (0.17 m × 0.70 m). The outlet is located below the inlet with the top of the outlet placed at a distance of 1.6 m above the floor. The dimensions of the outlet are (height × width) = (0.2 m × 0.3 m).

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.

The profiles of concentration are based on measurements at 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 at 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 measurement points are through a twelve point multipoint sampler connected to a gas analyser. The gas analyser works according to the absorption spectrometry principle and it makes use of the fact that different gases are able to absorb infrared light at certain wave lengths. The quantity of absorbed energy is an expression of the concentration of the gas.

The experiments took place under isothermal steady-state conditions. In the supply and in the exhaust openings the temperature did not deviate by more than 1 °C for a period of at least 30 min prior to and at any time during the measurements. The temperature difference between the supply air and

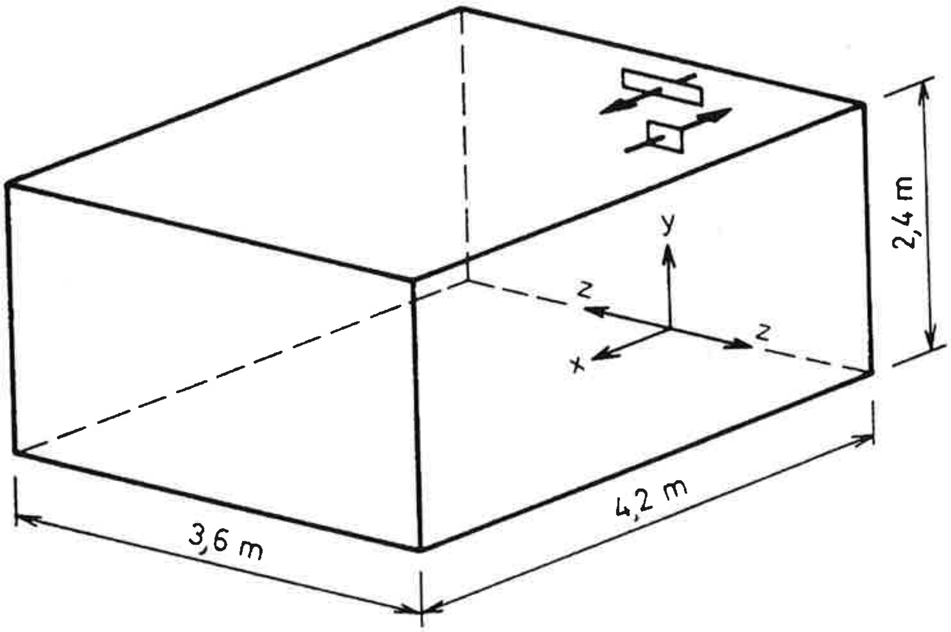


**Fig 1A** Sketch of the geometry of the full-scale test room.

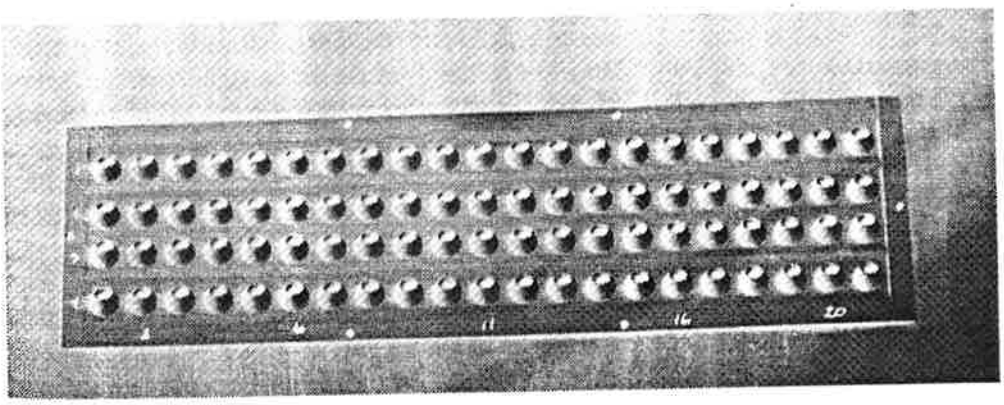

**Fig 1B** Close-up of the HESCO inlet device.

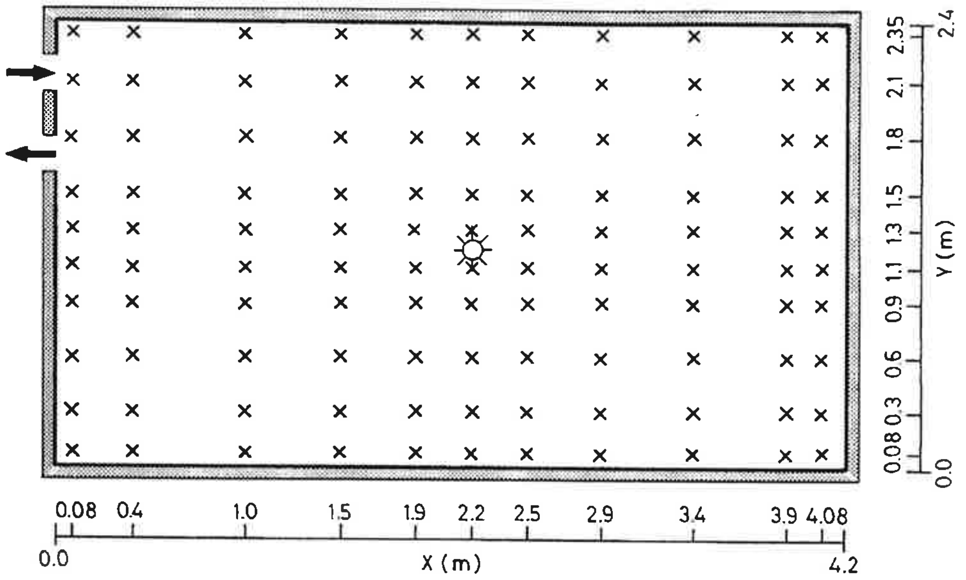


**Fig. 2.** Distribution of points for measurements of contours of concentration in the centre plane of the test room.

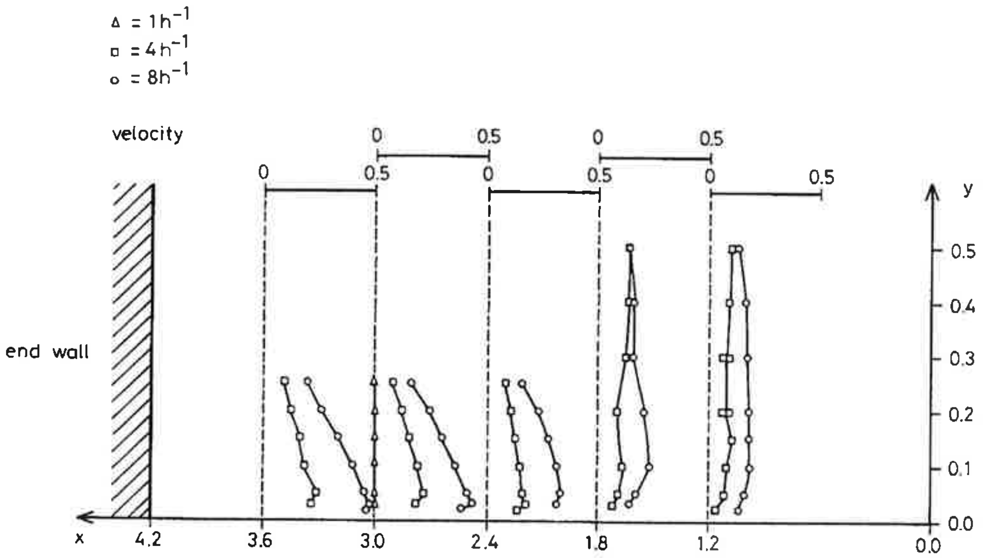


**Fig. 3.** Velocity profiles in the occupied zone at different distances from the inlet and at different air change rates. (Skovgaard et al., 1990).

the exhaust air was below 0.4 °C and the temperature gradient in the room was below 0.45 °C/m at any time during the measurements.

## 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 5 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 (Skovgaard et al., 1990 and Skovgaard and Nielsen, 1991). The airflow rate is approximately the minimum value required to ventilate an office room. Measurements in Skovgaard et al. (1990) show that the throw of the jet is about 4/5 of the room length. The throw of the jet is defined, in this paper, as the distance the air stream travels after leaving the diffuser before the maximum stream velocity is reduced to 0.2 m/s. Figure 3 shows the velocity profiles in the occupied zone at different distances from the inlet and at different air change rates. The velocity in the occupied zone is very low and Figure 4 shows that the maximum velocity is below 0.1 m/s. The test case with an air change rate of $n = 3h^{-1}$ represents the basic case where the airflow rate is about

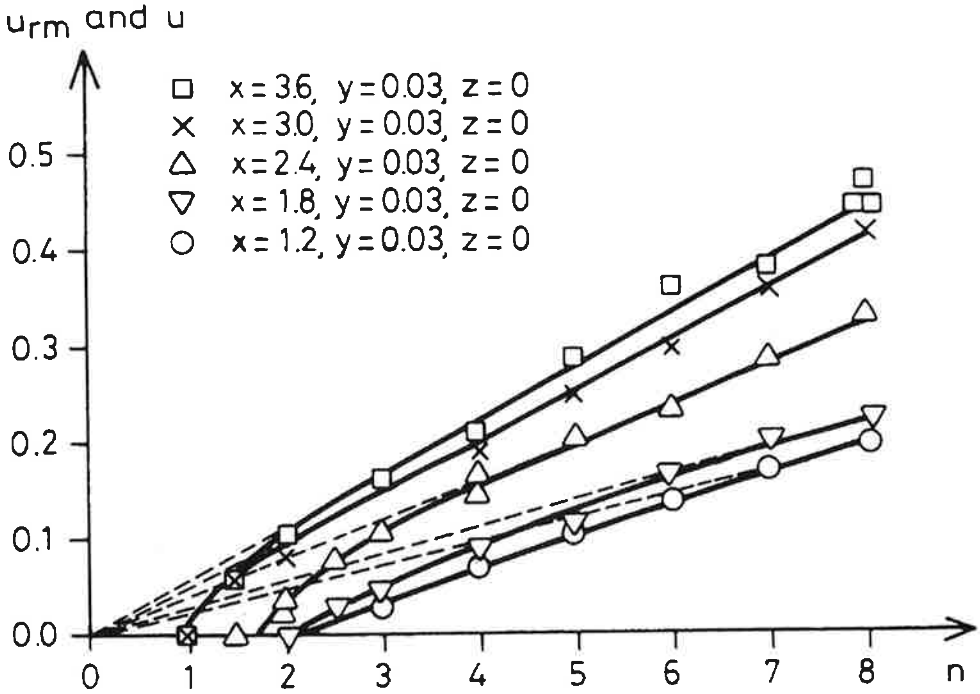


**Fig. 4.** Maximum velocity in the occupied zone at different locations as a function of the air change rate. (Skovgaard et al., 1990).

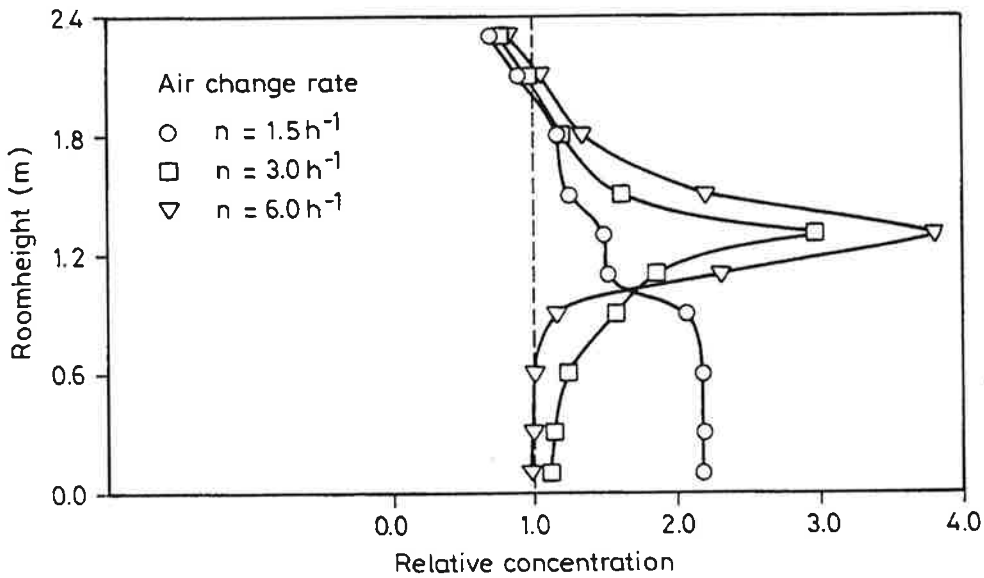


**Fig. 5.** Relative concentration profiles in the middle of the test room for three different air change rates. The contamination source is placed in the middle of the room 1.2 m above the floor. The contaminant density is 1.2 kg/m$^3$.

the usual value in office rooms. According to Skovgaard et al. (1990), the throw of the jet is approximately room length plus room height. Figure 3 shows that there will be a recirculating flow at floor level and in Figure 4 it can be seen that 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 Figure 4, about 0.33 m/s.

The results in Figure 5 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 reaches only the upper part of the occupied zone and the recirculating flow takes place there. 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 8).

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 Figure 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 by Oppl (1969) and full-scale experiments by Heiselberg and Nielsen (1987) 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 approximates the distribution at high turbulent flow conditions in the room. This distribution is independent of the air change rate (Nielsen, 1981). The maximum velocity in the occupied zone will, however, be above the acceptable comfort level for office rooms. Therefore, for practical purposes, contaminant distribution in a room will depend on the supplied airflow rate.

Figure 6 shows the profiles of concentration for four locations of the contamination source in the room. Location A) is in the middle of the room where 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 (see Figure 4). Location D) is at floor level where a low velocity has been measured (see Figure 4).

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 entrainment of the contaminant 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 a high concentration only in the immediate vicinity of the floor. Corresponding results are found by Oppl (1969) and Nielsen (1981).

## Contours of Concentration

Contours of concentration in the centre plane of the test room have been measured at three different contaminant densities at an air change rate of $n = 1.5h^{-1}$. 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 tendency 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 tendency of the contaminant to migrate to the floor region.

The results in Figures 7-9 show that the supply

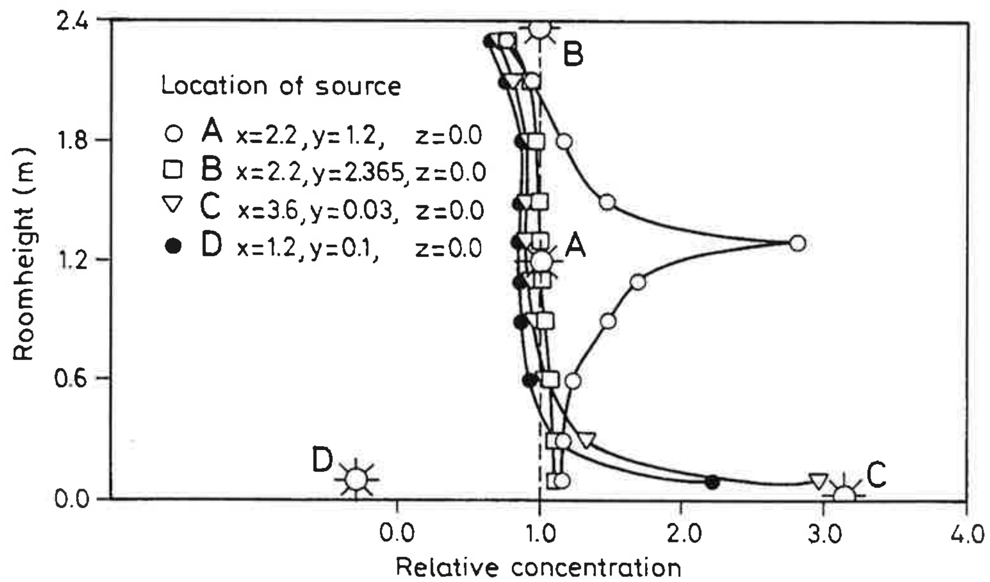


**Fig. 6.** Relative concentration profiles in the middle of the test room for four different locations of the contamination source. The air change rate is $n = 3h^{-1}$. The contaminant density is 1.2 kg/m$^3$.

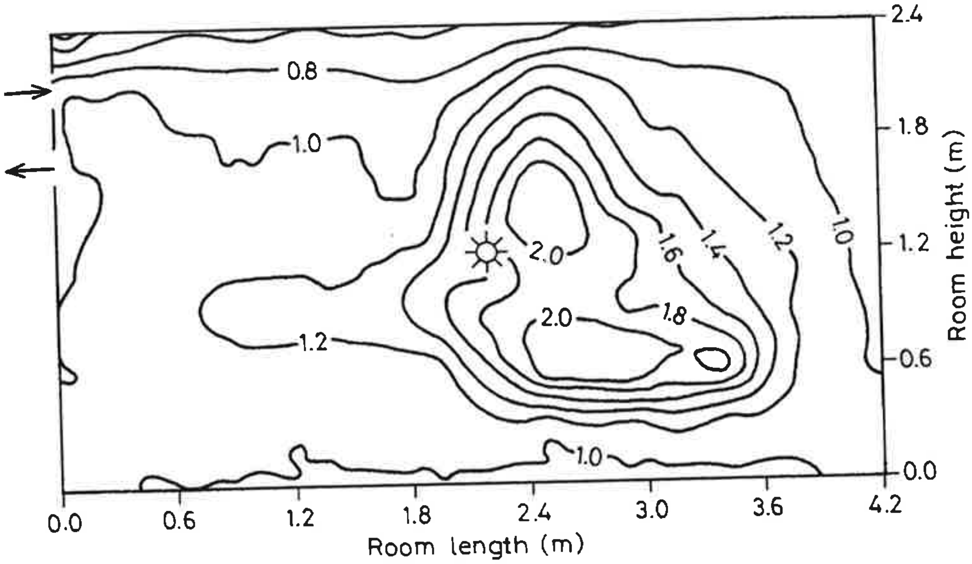


**Fig. 7.** Contours of concentration in the centre plane of the test room. The contamination source is placed in the middle of the room 1.2 m above the floor. The contaminant density is 0.8 kg/m³ and the air change rate is $n = 1.5h^{-1}$.

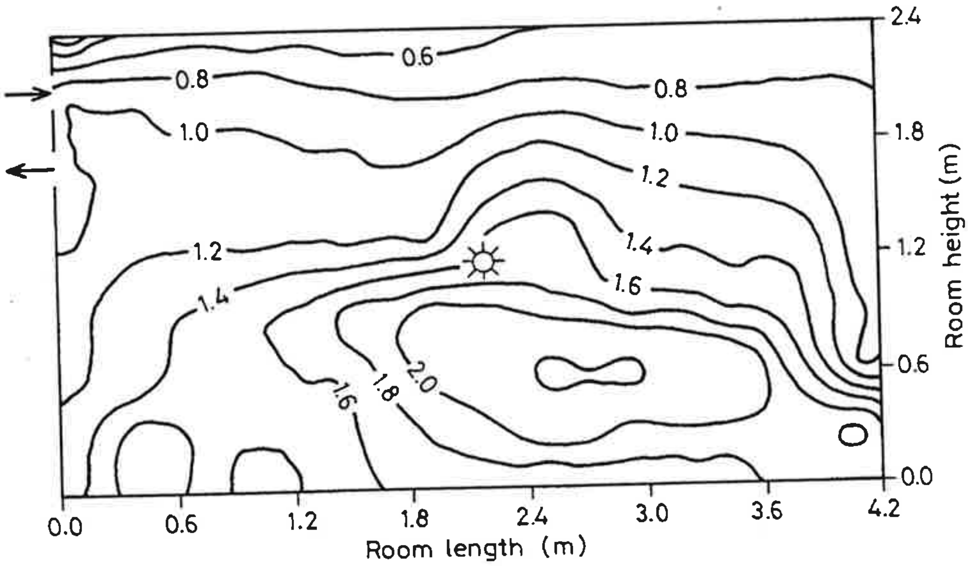


**Fig. 8.** Contours of concentration in the centre plane of the test room. The contamination source is placed in the middle of the room 1.2 m above the floor. The contaminant density is 1.2 kg/m³ and the air change rate is $n = 1.5h^{-1}$.

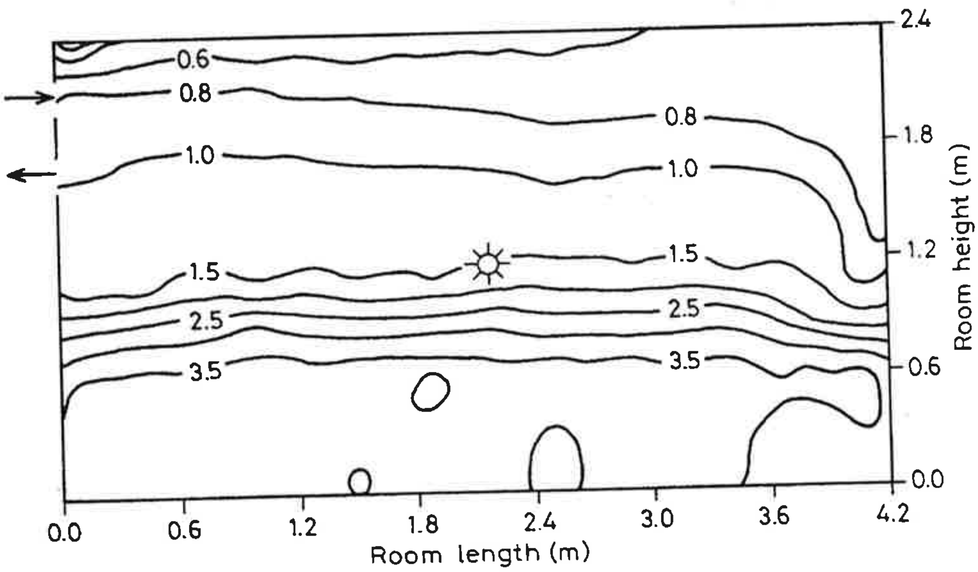


**Fig. 9.** Contours of concentration in the centre plane of the test room. The contamination source is placed in the middle of the room 1.2 m above the floor. The contaminant density is 1.8 kg/m³ and the air change rate is $n = 1.5h^{-1}$.

air jet reaches half 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 9 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 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 8 show that the contaminant distributed to the upper part of the room has been entrained by 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 7 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 increase of the air change rate from $n=1.5h^{-1}$ to $n=3.0h^{-1}$ or $n=6.0h^{-1}$. The buoyancy effects will decrease and the contaminant distribution will approximate the distribution at high turbulent flow conditions (Heiselberg and Nielsen, 1987; Heiselberg, 1990; and Murakami et al., 1983).

It is not possible from Figures 7-9 to see how the three-dimensional flow conditions in the room influence the contaminant distribution in the centre plane.

## Conclusion

Results of a series of full-scale experiments of the contaminant distribution in a test room are presented. The results make it possible to evaluate the performance of airflow 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. Contours of concentration in the centre plane of the room showed 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.

The experiments showed that the contaminant distribution in a room will depend on the location of the contamination source and for practical purposes also on the supplied airflow 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.

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