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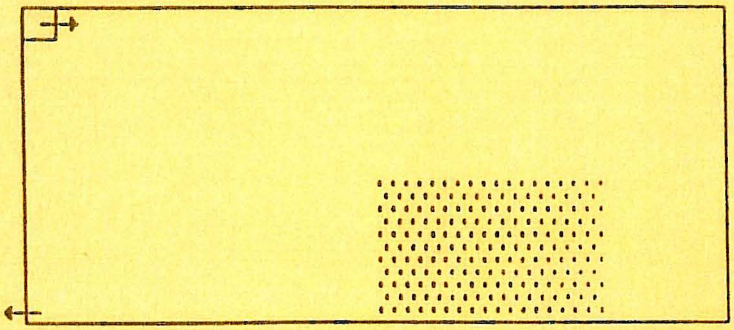

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PAPER NO. 57

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

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OBSTACLES IN THE OCCUPIED ZONE OF A ROOM WITH MIXING VENTILATION

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ABSTRACT

Two-dimensional, isothermal full-scale experiments and CFD (Computational Fluid Dynamics) simulations are used to investigate the influence of obstacles in the occupied zone.

The shape of the vertical velocity profiles, the maximum velocities in the occupied zone, the velocity decay through the room, and the momentum flow are investigated.

It is found that the maximum velocity in the occupied zone, and the velocity level in the entire room decrease when obstacles are present in the room. The velocity profile changes shape and the maximum velocity in the lower part of the room is located higher above the floor than in the empty room. It is found that the obstacles influence the flow in the entire room, and because the obstacles not only redistribute the velocity profile but also decrease the overall velocity level in the room the momentum flow is reduced.

KEYWORDS

Mixing Ventilation, CFD, Obstacles, Occupied Zone, Maximum Velocity, Momentum Flow.

INTRODUCTION

It is important to maintain thermal comfort in ventilated rooms and the air velocity is a vital factor. To calculate the maximum velocity in the occupied zone of a room formulas implying an empty room usually are used. This is very seldom the case because furniture, people and other thermal loads occupy the room. It has not yet been examined how these obstacles affect the air movements in the room and the maximum velocity in the occupied zone. This paper contains an investigation of a room with mixing ventilation under two-dimensional, isothermal conditions. Full-scale experiments and Computational Fluid Dynamics (CFD) simulations have been carried out to examine the effects of obstacles in the occupied zone.

In a room with mixing ventilation the maximum velocity in the occupied zone is located close to the floor at a distance of ≈ 2/3L from the supply opening (Nielsen 1995 p.31), and the obstacles are placed on the floor in this area. The purpose of this research is to study whether the maximum velocity in the occupied zone increases, because the free cross section area in the room is decreased by the obstacles, or decreases because the obstacles function as a resistance to the flow in the room. Furthermore, the shape of the velocity profile is studied to see if the maximum velocity in the occupied zone is found in another height above the floor than usually. It is also studied whether the obstacles influence the air movements in the reverse flow only or they influence the air movements in the entire room. These investigations are made in a room with two different set-ups. The investigations are based on full-scale experiments and simulations of one of the set-ups. Finally, it is studied if the obstacles act as a resistance to the flow. To investigate this problem simulation in a room with two different lengths are made.

EXPERIMENTS AND SIMULATIONS

Full-scale experiments and simulations are carried out in a room with the dimensions (H×W×L) 2.5×3.6×5.4 m. Only thetwo-dimensional case is studied. The inlet and the outlet are located at the same end of the room. The inlet is located at the ceiling 0.25 m from the wall. To create a two-dimensional jet the inlet covers the full width of the room. The supply opening is 1.0 cm heigh and is placed 2.3 cm below the ceiling. The outlet is located at the floor. In all the experiments and simulations described in this paper the inlet velocity is 3.47 m/s.

The obstacles are placed on the floor in the area of the maximum velocity to obtain the largest disturbance of the flow. The obstacles used in the experiments are chipboard boxes (L×W×H) 0.72×0.72×1.1 m. The boxes are used

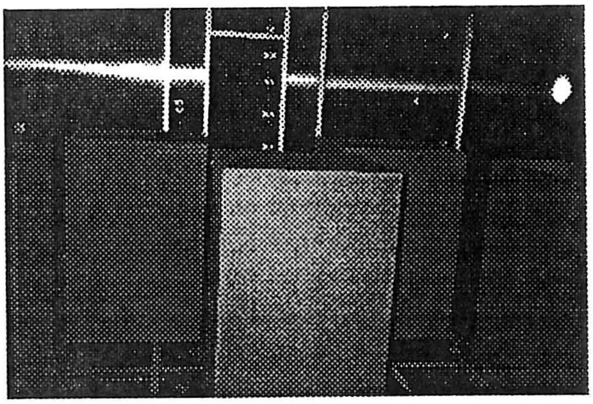

FIGURE 1.a Photo of the set-up with distributed obstacles.

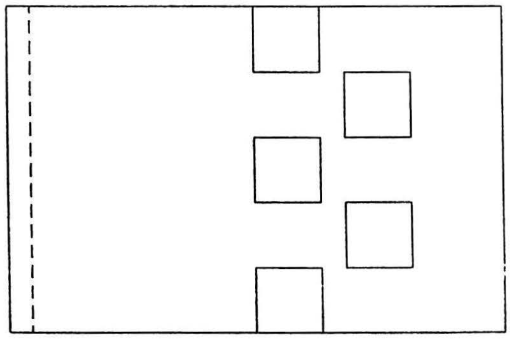

FIGURE 1.b Set-up with distributed obstacles.

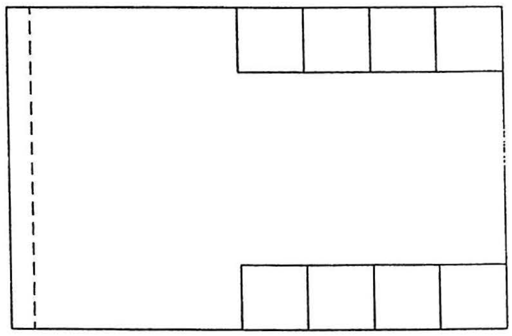

FIGURE 1.c Set-up with obstacles at the sides.

in two different set-ups (see Figure 1).

In the first set-up five obstacles are placed in the middle of the room symmetrically around the centreline of the room (see Figures 1.a and 1.b). The obstacles are placed so that the side closest to the inlet is flush with the middle of the room. The distance between the two rows of obstacles is 0.27 m, and the distance between two obstacles in the same row is 0.72 m. This set-up is made to imitate distributed furniture and is named "distributed obstacles". In the other set-up eight obstacles are placed at the walls with four in each side of the room (see Figure 1.c). This set-up is made to imitate e.g. shelves and is named "obstacles at the sides".

Only the situation with distributed obstacles is simulated. The two-dimensional simulations are based on the equation for continuity and the equations for x- and y-momentum (Navier-Stoke), as well as on the k-ϵ turbulence model. The obstacles are not inserted individuallybut are represented by a volume resistance that causes a pressure drop (see Figure 2.a).

The volume resistance covers the height and the total length of the group of physical obstacles; thereby the size is (L×H) 1.71×1.1 m. The pressure drop through the volume resistance is calculated by (Flovent 1994 p.4-137):

$$\frac{\partial p}{\partial x} = \frac{f}{2} \rho u^2 \qquad (1)$$

where

$\partial p/\partial x$ = pressure drop per m [Pa/m]
f = loss coefficient
ρ = air density; 1.19 kg/m^3
u = velocity [m/s]

The flow through the face of the obstacles and through the face of the volume resistance, that is flush with the

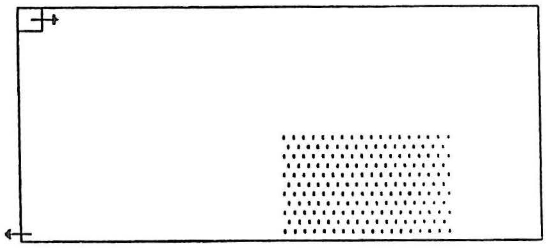

FIGURE 2.a The volume resistance used in the short room in the simulations of distributed obstacles.

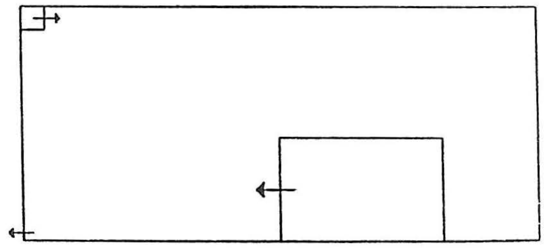

FIGURE 2.b Location of reference surface in the experiments and the simulations.

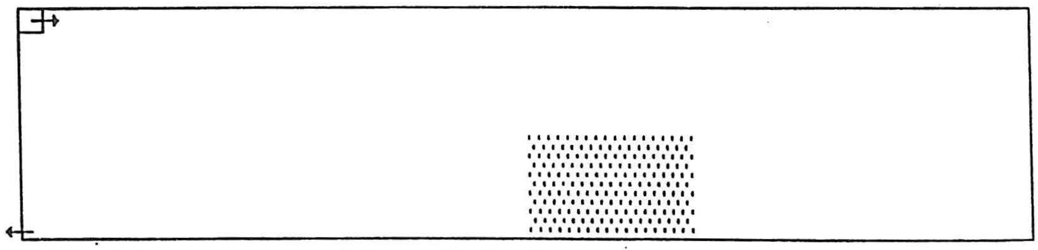

FIGURE 2.c The volume resistance in the long room.

middle of the room, is examined to find a volume resistance that equals the measurement (see Figure 2.b). A loss coefficient, f, of 2.5 equals the flow through the reference suface when the set-up is distributed obstacles.

To investigate the behaviour of the momentum flow a simulation is made in a room twice the length of the short room. This room is 10.55 m long, and a volume resistance having the same size and loss coefficient as used in the short room is inserted so that the end closest to the inlet is located in the middle of the room (see Figure 2.c).

RESULTS AND DISCUSSION

In this section the results found in the experiments and the simulations are discussed. The issues are the shape of the vertical velocity profile, the maximum velocity in the occupied zone, the velocity decay through the room and the momentum flow.

Shape of the Velocity Profile

The measured and the simulated vertical velocity profile of the two set-ups is plotted to examine if the velocity profile changes shape, and if the maximum velocity in the occupied zone is located at another height than the usually close to the floor. The profiles are shown at the position 2.09 m from the supply opening. In situations where the direction of the measured velocity is ambiguous both the positive value and the negative value of the velocity are drawn.

In the situation with distributed obstacles, the shape of the velocity profile changes and the maximum velocity in the occupied zone decreases and is located higher above the floor than in the empty room. The experiment and the simulation with distributed obstacles and a volume resistance, respectively, show that a complete agreement is not achieved which is especially expressed by the maximum velocity in the occupied zone. One reason is that the volume resistance is total permeable contrary to

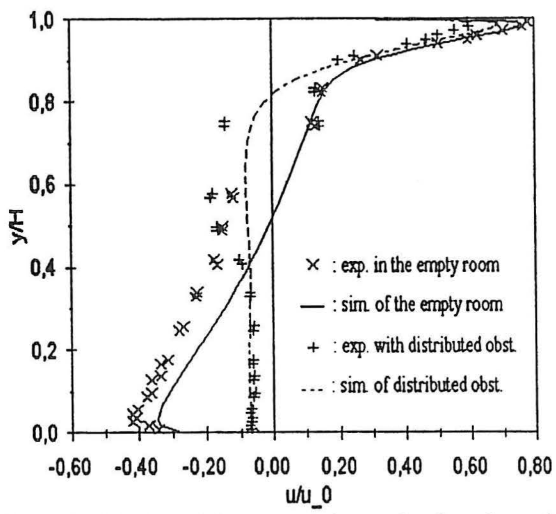

FIGURE 3.a Measured and simulated velocity profiles in the empty room and in the room with distributed obstacles. u_0 is the initial velocity and H is the height of the room.

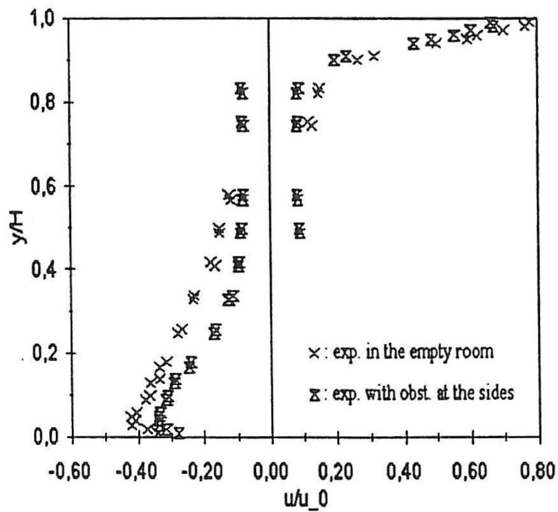

FIGURE 3.b Measured velocity profiles in the empty room and in the room with obstacles at the sides. u_0 is the initial velocity and H is the height of the room.

the physical obstacles that are solid in certain areas, which results in air being forced up above the obstacles in the experimental case.

In the situation with obstacles at the sides, the obstacles have a slight influence on the velocity profile.

Maximum Velocity in the Occupied Zone

In the occupied zone, the maximum velocity in the set-ups with obstacles is compared with the maximum velocity in the empty room. The velocity in the experiments is compared with the measured velocity in the empty room, and the velocity in the simulation is compared with the simulated velocity in the empty room. Table 1 shows these ratios. In all the cases the maximum velocity is found 3.8 m from the supply opening, and the measured maximum velocity in the empty room is 0.505 m/s and in the simulated room it is 0.378 m/s.

TABLE 1 The maximum velocity in the occupied zone compared with the maximum velocity in the empty room.

Situation	$u_{max}/u_{max,0}$
experiment with distributed obstacles	0.59
simulation of distributed obstacles	0.52
experiment with obstacles at the sides	0.79

In all the cases Table 1 shows that the maximum velocity in the occupied zone decreases when the obstacles are placed in the room. This was reported by Nielsen (1992). In the set-up with obstacles at the side the maximum velocity in the occupied zone is only 79 % of the velocity in the empty room; in the set-up with distributed obstacles the reduction is larger. The difference between the measured and the simulated value is due to the phenomenon explained earlier: the boxes in the experiment force the air up above them and, thereby, the velocity increases compared with the simulated value.

It is observed that the obstacles generally decrease the velocity level in the occupied zone which also has been found by Brohus (1992), Svidt (1994), and Ulrich (1994). The question is: do the obstacles influence the air movements in the entire room or do they only influence the air movements in the lower part of the room, so that the jet at the ceiling is unaffected? This question is examined by studying the velocity decay through the room. By studying the momentum flow it is examined whether the reduction of velocity takes place as a reduction of the momentum flow, as a redistribution of the velocity profile, or as a combination of both. The investigation of momentum flow is carried out by simulations both in the short and in the long room.

Velocity Decay through the Room

It can be decided whether the obstacles influence the air movements in the entire room, or only in the lower part of the room by looking at the velocity decay through the room.

In Figure 4 the maximum velocity, u_{max}, compared with the inlet velocity, u_0, is shown as a function of the distance from the supply opening, x, compared with the height of the supply opening, h. A line with the slope -0.5, corresponding to the velocity decay in the wall jet, is also plotted in the Figure. To determine the velocity decay in the two-dimensional wall jet the following equation is used (Nielsen 1995 p.6):

$$\frac{u_{max}}{u_0} = K_p \sqrt{\frac{h}{x}} \qquad (2)$$

where

u_{max}	= maximum velocity of the jet at the distance x from the supply opening [m/s].
u_0	= inlet velocity [m/s]
K_p	= individual constant of the diffuser
h	= height of the supply opening [m]
x	= distance from the supply opening [m]

The individual constant of the diffuser is found to be 3.16.

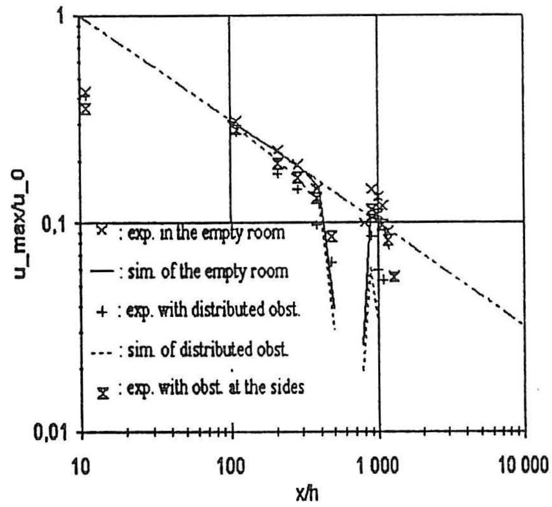

FIGURE 4 Velocity decay through the room.

Figure 4 shows that the individual constant of the diffuser, and thereby the velocity decay in the entire room, both are lowered at sidewall location and, especially, when the obstacles are distributed in the occupied zone. The simulations show the same tendency. It can be concluded that the obstacles influence the maximum velocity in the entire room including a disturbance of the wall jet.

Momentum flow

The previous sections showed that the obstacles influence the air flow in the entire room, and that the velocity level is reduced. The momentum flow through the room is studied in order to see if the decrease in the velocity is due to a reduction of the momentum flow, a redistribution of the velocity profile or a combination. This is made with simulations in the normal room and in a room twice the length. The volume resistance used in the two cases has the same geometrical size and loss coefficient, f (see page 3, Equation 1 and Figure 2).

The momentum flow is determined from the velocity and the area. To determine the momentum flow at the ceiling the upper part of the profile is used, and at the floor the lower part is used. The momentum flow is calculated by (Rajaratnam 1976 p.6):

$$I = \rho \int u^2 dA \qquad (3)$$

where

I	= the momentum flow [N]
ρ	= the air density; 1.19 kg/m^3
A	= area [m^2]
u	= velocity [m/s]

In Figure 5 the simulated momentum flow non-dimensionalized with the initial momentum flow (0.143 N), is given as a function of the distance from the supply opening non-dimensionalized with the length from the supply opening to the opposite wall.

In the short room, Figure 5.a, it can be seen that the momentum flow in the entire room is reduced when obstacles

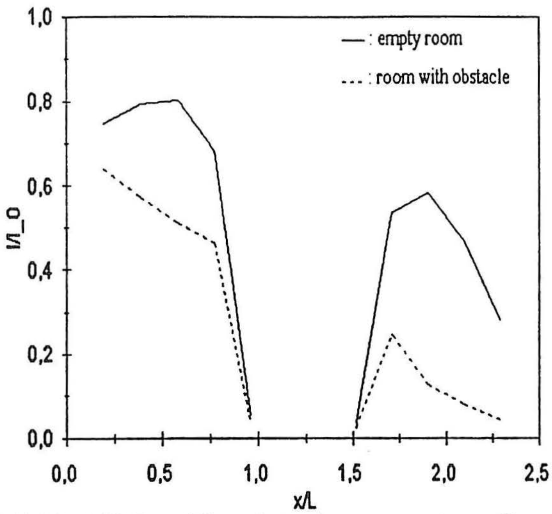

FIGURE 5.a Simulated momentum flow in the short room. L is the distance between the inlet and the opposite wall.

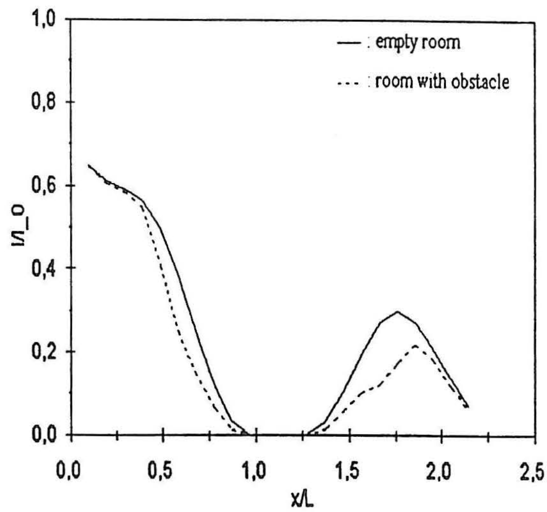

FIGURE 5.b Simulated momentum flow in the long room. L is the distance between the inlet and the opposite wall.

are placed in the occupied zone. Even at the beginning of the jet a difference in momentum flow can be seen. The difference is largest where the obstacles physically are placed - both at the ceiling and at the floor. In the end of the room opposite to the supply opening no difference appears.

In the long room, Figure 5.b, the difference between the empty and the occupied room is smaller than in the short room. Here, the difference at the supply opening and at the opposite end of the room is negligible. Also in this case the biggest difference is found where the obstacles physically are placed - both at the ceiling and at the floor.

CONCLUSION

This paper discusses how obstacles placed in the occupied zone of a room with mixing ventilation influence the air movements in the room. The investigations are based on full-scale experiments and CFD-simulations made under two-dimensional, isothermal conditions. The obstacles are placed on the floor in the area where the maximum velocity in the empty room is expected. The investigations are made with two different experimental set-ups, and one of the set-ups is also simulated. Simulation in a room with twice the length as the room used in the experimental cases is made.

It is found that the maximum velocity in the occupied zone, and the velocity level in the entire room decrease when obstacles are present in the room. The velocity profile changes shape and the maximum velocity in the lower part of the room is located higher above the floor than in the empty room. It is found that the obstacles influence the flow in the entire room, and because the obstacles not only redistribute the velocity profile but also decrease the overall velocity level in the room the momentum flow is reduced.

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