Modelling

Modelling of Air Flow through a Slatted Floor by CFD

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Modelling of Airflow through a Slatted Floor by CFD

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Summary:

In this paper two different CFD-approaches are investigated to model the airflow through a slatted floor. Experiments are carried out in a full-scale test room . The computer simulations are carried out with the CFD-code FLOVENT, which solves the time-averaged Navier-Stokes equations by use of the k-epsilon turbulence model. The simulations are two-dimensional and the slatted floor has been modelled in two different ways: A *resistance volume* and a *resistance plane*. The resistance volume has been defined as a volume covering the outer dimensions of the slatted floor i.e. 1.17m wide, 5.00 m long and 0.02 m thick. The resistance plane is defined in the same way except that it has no thickness. In both cases two parameters are used to specify the characteristics of the slatted floor: a *free area ratio* and a *resistance coefficient.* At an opening area of 39% the predicted airflow rate is in the range of 6 to 12% less than measured. At lower opening area ratios there is an increasing difference between the two models. The differences are due to different airflow patterns resulting from the models.

slatted floor. Computational Fluid Dynamics (CFD) is a suitable method for a detailed computer prediction of air velocities and temperature distribution in a ventilated space. With a CFD model it is possible to include the effect of room geometry and heat sources in the calculation of air flow in a building.

However, CFD is also a very compute intensive type of calculation, so for practical purposes it will normally be too expensive to model the finest details of the room geometry. The slatted floor normally has a geometry which is too complex to model in details, so it would be preferable to have a suitable coarse-grid representation of the slatted floor. This means that the model should be able to predict how the slatted floor affects the overall airflow field and contaminant distribution even though the local flow field through the slatted floor is not calculated in every detail.

The airflow through the slatted floor is important with regard to air quality and contaminant distribution, since the slurry surface below the slatted floor is a major contaminant source. Figure 1 shows a comparison of the flow in a building with solid floor and a building with a fully slatted floor where the opening area is assumed to be 30% of the total floor area. The calculated flow field shows, that the space below the slatted floor forms an integrated part of the ventilated space. This implies that gaseous contaminants released here may be transported to the occupied zone by the recirculating airflow.

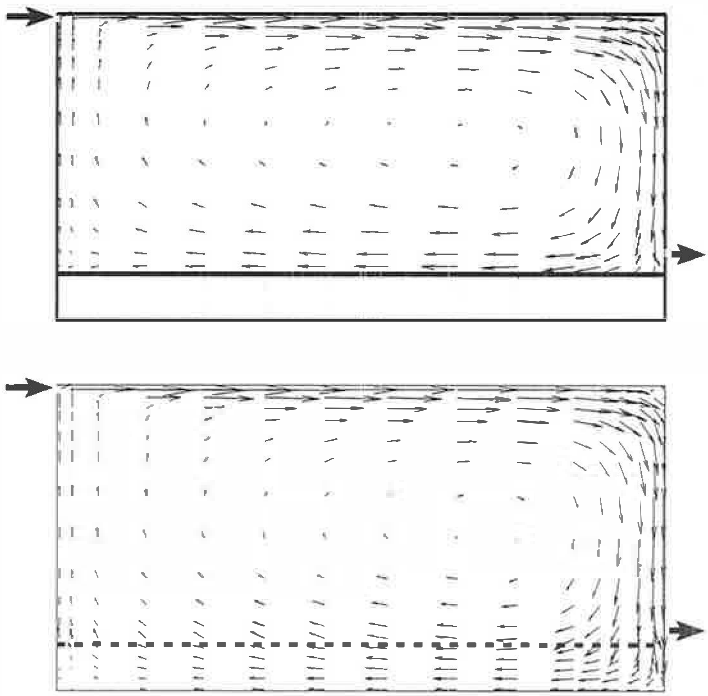

Figure 1 Calculated flow field in case of solid floor and slatted floor. Bold arrows indicate air inlet and exhaust.

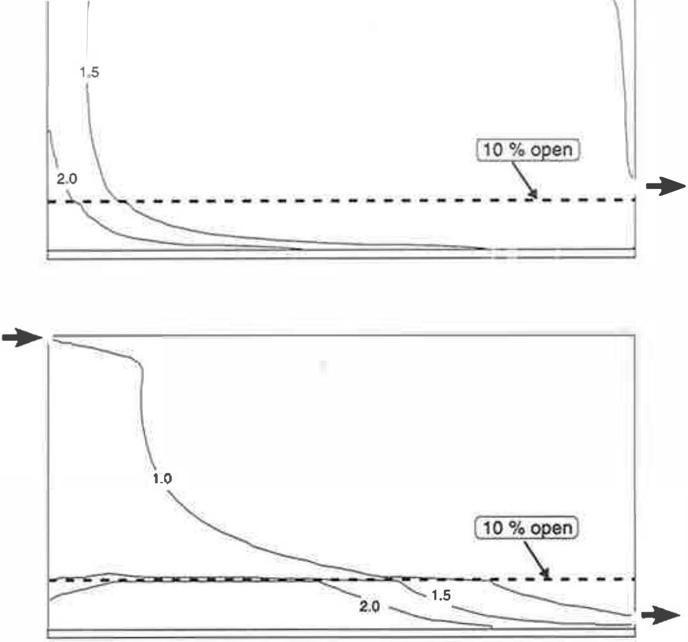

Figure 2 Calculated contaminant concentrations in a room with the air exhaust above the slatted floor and below the slatted floor, respectively. The free area ratio of the slatted floor is 10%.

Contaminant concentrations are studied in figure 2. It is assumed that a contaminant is released at a constant rate from a surface 0.4 m below the slatted floor. Concentration levels are normalised with the exhaust concentration, i.e. a concentration level of 1.0 is the concentration that would be in a situation with completely mixed air. The contaminant distribution has been calculated with the exhaust opening above the slatted floor and below the slatted floor respectively. The figure shows that in this case with a free area ratio of 10 %, the exhaust position clearly affects the air quality in the occupied zone.

2. Methods

Two different CFD-approaches to model the airflow rate through a slatted floor are compared with a full-scale laboratory measurement. Experiments are carried out in a full-scale test room as shown in figure 3. The room dimensions are 3.00 x 8.50 x 5.00 m. An inlet slot in the end wall covers the full width of the room. The inlet is located immediately below the ceiling and the inlet height is 19 mm. The air flow rate is 1300 m3/h. For the CFD-calculations an effective height of 15 mm was specified. An exhaust slot is located in the floor near the inlet-wall. The room is equipped with guiding plates below the ceiling to ensure a two-dimensional flow field (see Bjerg et al 1998). A channel covered by a slatted floor is located from 4.76 m to 5.93 m from the inlet-wall. The bottom of the channel is 0.42 m below floor level. The slatted floor is a 2 cm thick plastic type with 39% open area.

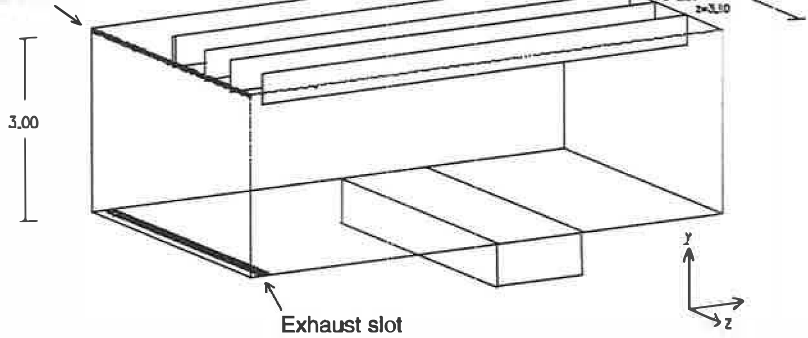

Figure 3 The full-scale test room has a slot inlet and exhaust, guiding plates below the ceiling and a channel covered with slatted floor.

The airflow rate through the slatted floor is measured by a tracer gas method with CO_2 as tracer gas. The measuring procedure is as follows: 1. An airtight cover is placed on the slatted floor. 2. While the ventilation system is running, CO_2 is supplied to the room above the slatted floor. The exhaust air is reused as inlet air to maintain a constant CO_2 concentration. 3. When the concentration is stable the cover is removed and concentration history is recorded in the channel (0.29 m below floor level) as well as in the room (0.20 m above floor level).

By this procedure the concentration progress is expected to follow equation 1:

$$\frac{C_b - C_0}{C_a - C_0} = 1 - e^{-nt} \qquad (1)$$

where C_a is the concentration above the floor

C_b is the concentration below the slatted the floor

C_0 is the background concentration

t is elapsed time in hours

n is the number of air changes per hour

The computer simulations are carried out with the CFD-code FLOVENT, which solves the time-averaged Navier-Stokes equations by use of the k-epsilon turbulence model. The simulations are two-dimensional. The slatted floor has been modelled in two different ways: A *resistance volume* and a *resistance plane*. The resistance volume has been defined as a volume covering the outer dimensions of the slatted floor i.e. 1.17m wide, 5.00 m long and 0.02 m thick. The resistance plane is defined in the same way except that it has no thickness. In both cases two parameters are used to specify the characteristics of the slatted floor: a *free area ratio* and a *resistance coefficient*. The slatted floor affects the air flow by a pressure drop as used by Nielsen et al (1996,1998), Svidt et al (1998):

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

where $\partial p/\partial x$ is the pressure drop [Pa/m]

f is the loss coefficient

ρ is the air density [kg/m^3]

v is the local air velocity taking into account the free area ratio[m/s]

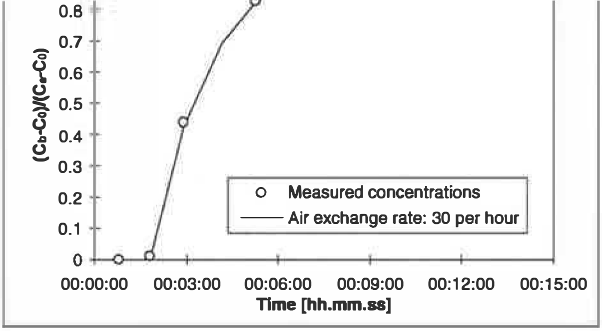

Figure 4 The air exchange rate below the slatted floor is determined from the concentration history.

3. Results and discussion

Figure 4 shows the normalised concentration history for the full-scale measurement. A theoretical curve based on equation (1) with n = 30 is shown together with the measured values. From this figure it is concluded that the air change rate below the slatted floor is 30 times per hour. This corresponds to 88.6 m^3/h for the simulated channel.

The simulated air flow pattern using a volume resistance with a free area ratio of 0.39 and resistance coefficient f = 1 is shown in figure 5. The calculated airflow through a horizontal plane 0.02 m below ceiling level (i.e. the lower side of the slatted floor) is 83.2 m^3/h for this case, which is 6% lower than the measured airflow rate.

To illustrate the sensitivity to the value of free area ratio and resistance coefficient, a number of simulations have been performed. Figure 6 and 7 show the calculated air change as a function of the two parameters. The two methods (resistance volume and the resistance plane) perform surprisingly different when the free area ratio is varied between 0.1 and 0.5. The difference may be explained by figure 8 which shows that the flow near the slatted floor is different for the two models with a free area ratio of 0.1. The *resistance volume* causes a local airflow immediately below the slatted floor which does not penetrate to the bottom of the channel, while the *resistance plane* results in a recirculating flow in the channel.

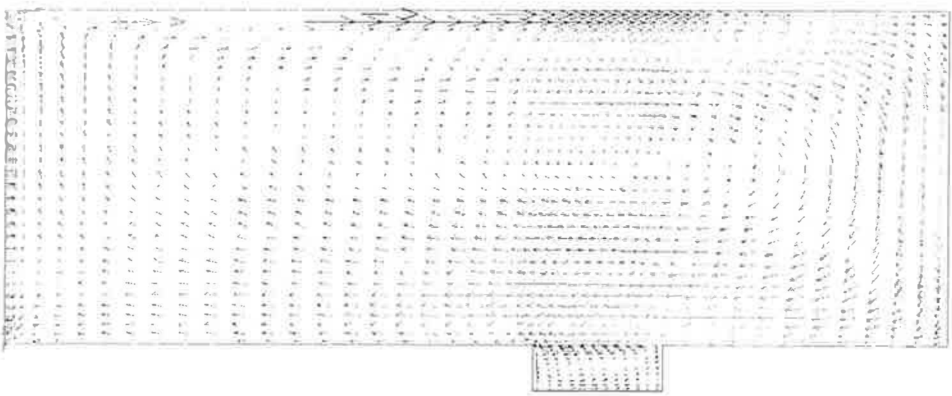

Figure 5 An example of the simulated airflow pattern.

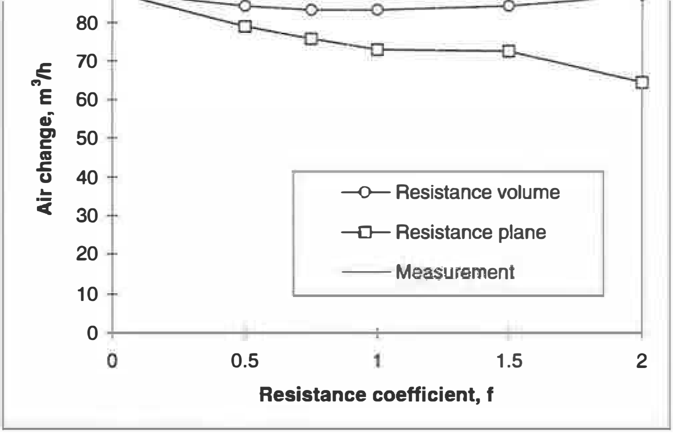

Figure 6 Calculated air change rate or the two models at a free area ratio of 0.39.

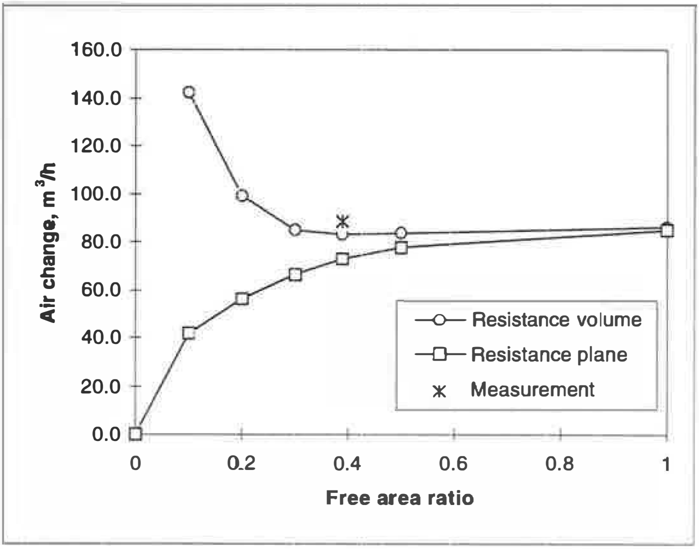

Figure 7 Calculated air change rate or the two models with the resistance coefficient $f = 1.0$

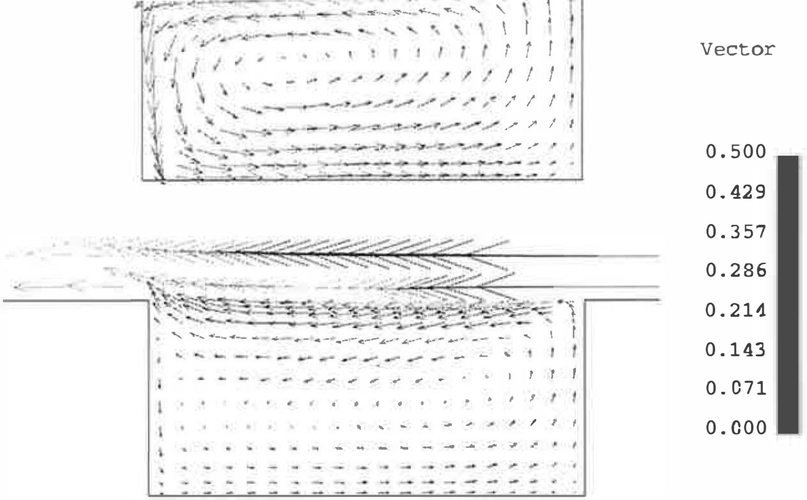

Figure 8 Flow field below the slatted floor with a free area ratio of 0.1. Top: Resistance *plane* model. Bottom: Resistance *volume* model.

4. Conclusions

A volume resistance model and a plane resistance model to simulate the airflow through a slatted floor have been compared. At an opening area of 39% the predicted airflow rate is in the range of 6 to 12% less than measured. At lower opening area ratios there is an increasing difference between the two models. The differences are due to different airflow patterns resulting from the models. Further experiments with different types of slatted floor, including different opening area ratios, are necessary to determine the possibilities of the models.

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