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MAXIMUM VELOCITY OF RETURN FLOW CLOSE TO THE FLOOR IN A VENTILATED ROOM - EXPERIMENTAL AND NUMERICAL RESULTS

M T Karimipanah, M Sandberg

Royal Institute of Technology, Centre for Built Environment
Box 88, S 801 02 Gävle, Sweden

Maximum velocity of return flow close to the floor in a ventilated room - experimental and numerical results

M.T. Karimipanah and M. Sandberg
Royal Institute of Technology
Centre for Built Environment
Box 88, S-801 02 Gävle, Sweden

Synopsis

The problem of sensation of draught in ventilated spaces is connected to inappropriate velocities in the occupied zone. In Scandinavia, velocities higher than 0.15 m/s are said to be an indicator of that occupants are likely to feel discomfort. Therefore knowledge of the flow field (both mean velocities and fluctuations) is necessary. Both experimental and numerical analysis of the flow field in a full scale room ventilated by a slot inlet, with two inlet Reynolds numbers 2440 and 7110, have been carried out . Results from both approaches show that the location of the maximum velocity near the floor is nearly independent of the Reynolds number. For a two-dimensional room, the maximum velocity at the floor level occurred at about 2/3 room length from the supply. The distance from the floor level is dependent on the inlet Reynolds number. The velocity profiles far away from the wall opposite to the inlet device have the same character as a wall jet profile. However, close to the corners they are transformed. The relative turbulence intensities measured in the return flow region are questionable, because of a hot wire's inability to record large fluctuations at low mean velocities. These turbulence intensities close to floor level vary from 15 to 80 % and as the authors have pointed out previously hot wires do not indicate the real value of the turbulence intensities beyond 20%. Difficulties appear in numerical predictions of return flow properties. Comparison between predicted values and experimentally obtained values show a reasonable agreement. This is promising for future CFD-predictions. However, there is a need for an appropriate measurement technique that can cope with reversing flow.

1 Introduction

The comfort parameters in a ventilated room are described in terms of appropriate temperatures, and the risk of draught. The latter is related to the velocities in the occupied zone. Existing design procedures require a velocity level below 0.15-0.20 m/s to avoid discomfort of occupants in the region of their activities. According to Fanger et al. (1988), high relative turbulence intensities will increase the sensation of draught. It is not easy to achieve low turbulence levels and low velocity levels at the same time. Measurements are more difficult due to high turbulence intensities which are out of the range of sensitivity of frequently used hot wire anemometers, see Karimipanah & Sandberg (1994a,b). The air movements in a room result in complex processes involving dynamic, thermal, climatic, mechanical and structural parameters, see Jin & Ogilvie (1992a,b). Thus, a general conclusion it is not possible to drawn. But, as mentioned before, one of the important comfort parameters to control is the velocity level and its fluctuations. Usually, the supply air terminal is close to the ceiling level where the velocity profiles are more or less like the traditional wall jet profiles. But the problem occurs when the jet impinges on the opposite wall and deflects to create the return flow above the floor. There, the low velocity levels cause difficulty in measurements.

This report is just one in a long series in this area of fluid mechanics. Hanzawa et al. (1987), Melikov et al. (1988, 1990) and Jin & Ogilvie (1992a,b) investigated air flow patterns in the occupied zone. All these efforts have contributed valuable information in this area but the problem due to its overall complexity still remains unsolved.

2 Experimental set-up

A full-scale test room with dimensions $6\times3\times3$ m $(L\times W\times H)$ is used. The inlet height is 1 cm and spans the whole room width to ensure two-dimensionality. The outlet height is 4 times inlet height and the locations of inlet and outlet are shown in figure 1, see also Karimipanah & Sandberg (1994b) for more details. To measure the velocities at the floor level, 8 stations were chosen. The stations were located at x=2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.3 and 5.6 [m] where x was measured from the supply inlet, see the co-ordinate system in figure 1. For each station, measurements were conducted from the floor up to y=70 cm using a single hot-wire. Both mean velocities and turbulence fluctuations were obtained for each point. The total measuring time for each point was 10 minutes. Two different supply velocities 3.72 m/s (Re=2440) and 10.82 m/s (Re=7110) were used to study to some extent the Reynolds number dependence.

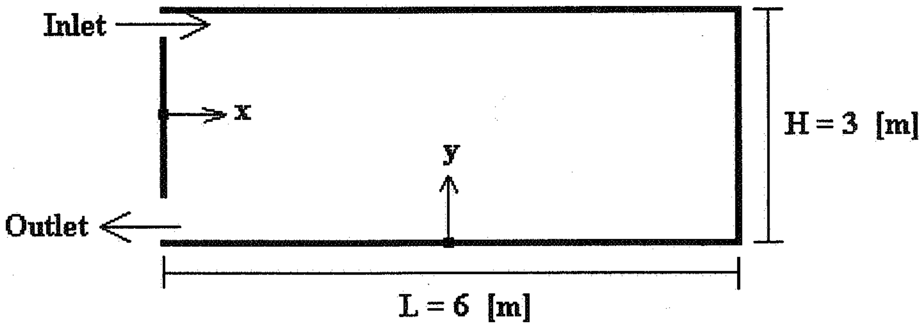

Figure 1 The co-ordinate system and definitions in measurements.

3 Results and discussion

The measured *mean floor velocity* U_r profiles compared to the predicted ones are shown in figure 2. In numerical predictions Launder's (1993) anisotropic version of $k-\varepsilon$ turbulence model, see also Karimipanah & Sandberg (1996), was used. The results show a good agreement indicating the quality of both measured and predicted values. For both inlet velocities the maximum velocity at the floor level lies at x=4.0 m (=0.33L) from the wall opposite to the inlet. Jin & Ogilvie (1992a,b) also found the maximum velocity for a shorter room, L=4.8m, at the location x=0.3L. This is in agreement with the findings of Nielsen (1989). One possible contribution to the small discrepancies between our measurements and those reported by Jin & Ogilvie may be that their outlet location lies a short distance under the supply inlet. Our profiles were almost the same as those of Jin & Ogilvie (1992a,b). Based on these results and other investigations mentioned, one may generalise the findings by concluding that the maximum velocity at the floor level of a two-dimensional ventilated room lies about 2/3 L from the supply. It is worth mentioning that in a three-dimensional room studied by Sandberg et al. (1991) exhibits a different behaviour. They found that the maximum velocity at the floor level occurs at 5/6 L from the supply device.

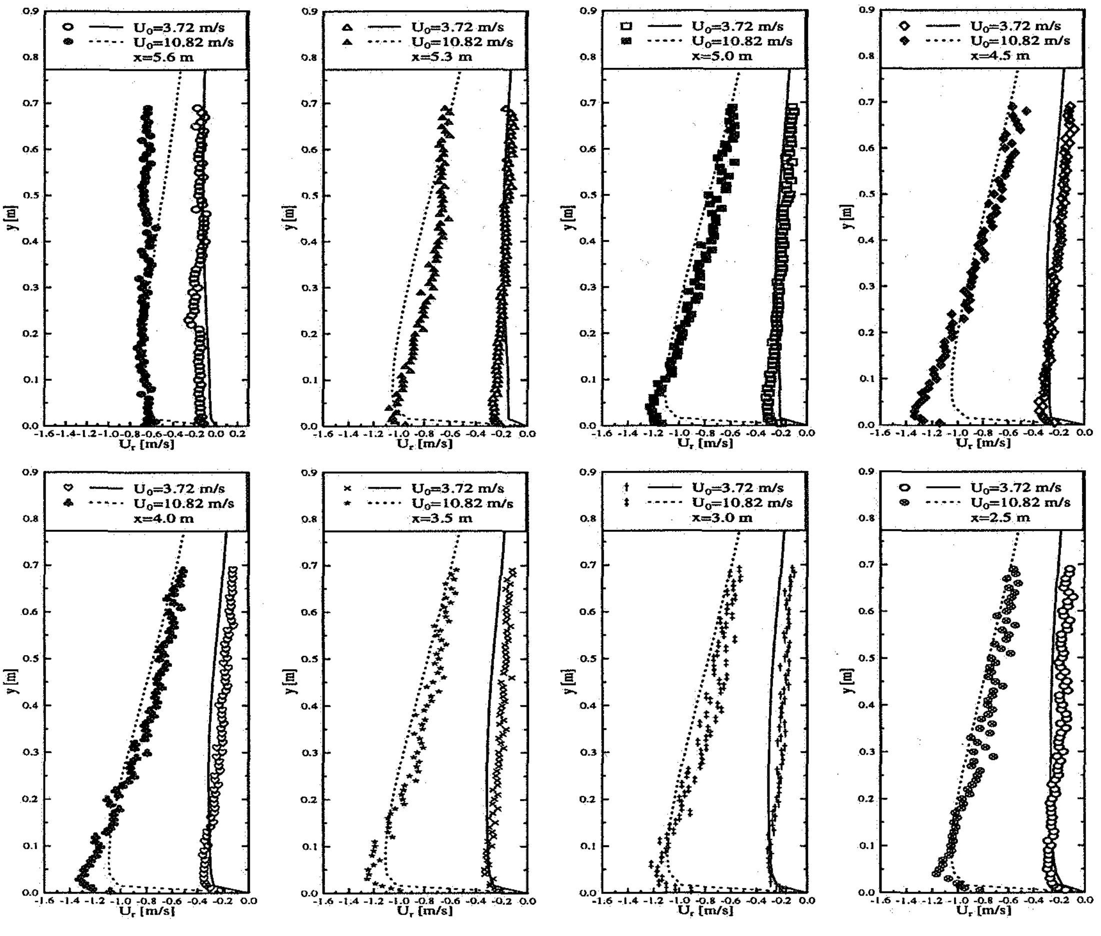

Figure 2 Measured (symbols) and predicted (lines) velocity profiles above floor level for different sections.

From figure 2 it is evident that the velocity profile close to the wall opposite to the supply (x=5.6 m) is unlike the wall jet profile, while the profiles at the other distances are almost similar to wall jet profiles. According to Nielsen (1989), the maximum velocity at the floor level, return flow velocity U_{rm}, in normal cases is assumed to be the maximum velocity in the occupied zone. This maximum velocity in the occupied zone is proportional to the inlet velocity, inlet height, and the room length L. Nielsen used a relation between the maximum floor velocity and the velocity, U_L, extrapolated to the distance L from the supply for a wall jet in an "infinite" space as

$$\frac{U_{rm}}{U_L} = K_{rm} \tag{1}$$

where K_{rm} was roughly estimated to be about 0.7.
In this paper we extrapolated U_L to room length based on two different situations (see table 1):

a) A jet in an open room (only ceiling) of the same length as in Fig. 1.
b) A jet in a closed room as in Fig. 1.

For case (a) we obtained a K_{rm} of 0.7 and 0.92 respectively. For case (b) we obtained a K_{rm} of 0.58 and 0.76 respectively. As Nielsen indicates this might be due to the geometry effect and based on these results also due to the Reynolds number effect. Nielsen (1989) uses a model room and here a full-scale room is used. The quotient (1) in case (b) are about 83% of that in case (a) for both Reynolds numbers. This is due to that the rate of decay of the velocity in the wall jet is less rapid in case (b), see Karimipanah (1996) and figure 3. It is worth mentioning that although the location of the maximum floor velocity shows very small Reynolds number dependence, see figure 3, the distance above the floor level is decreasing by increasing the Reynolds number. These distances were y=3 cm and 5 cm for Re=7110 and 2440 respectively. The following relation of Nielsen (1989) may be used with acceptable accuracy to calculate the maximum floor velocity

$$U_{rm} = K_p K_{rm} U_0 \sqrt{\frac{h}{L + x_0}} \quad [\mathrm{m/s}] \tag{2}$$

where h is slot height, L is room length, x_0 is the jet virtual origin , U_0 is the supply inlet velocity and K_p and K_{rm} are decay constants for ceiling level velocities and floor level velocities respectively.
To illustrate the turbulence characteristics the recorded rms values of the fluctuating velocities and the relative turbulence intensities, $I = \frac{U_r}{\sqrt{u'^2}} \times 100$, are shown in figures 4 and 5 where.

One can see from figure 4 that the values of the rms velocities are nearly constant in all locations, except for the distances x=5.6 m and 5.3 m. But the low mean velocities result in a high turbulence intensity of more than 70% which is outside the capability of hot wires. Jin & Ogilvie (1992a,b) argued that the maximum averaged turbulence intensity in their study was less than 50% but they never commented on the quality of their measured mean velocities and the rms values some distances above the floor level.

With respect to the above mentioned difficulties one may accept that new measuring techniques are needed for the occupied zone in a ventilated room and until these have been found the problem of draught will be unsolved.

Table 1 Test conditions and U_L for open and closed room.

Conditions				Open room (a) Extrapolation to L		Closed room (b) Extrapolation to L	
U_0 [m/s]	Re	U_{rm} [m/s]	$\frac{U_{rm}}{U_0}$	U_L [m/s]	$\frac{U_{rm}}{U_L} = K_{rm}$	U_L [m/s]	$\frac{U_{rm}}{U_L} = K_{rm}$
10.82	7110	1.320	0.12	1.43	0.92	1.73	0.76
3.72	2440	0.345	0.092	0.49	0.70	0.59	0.58

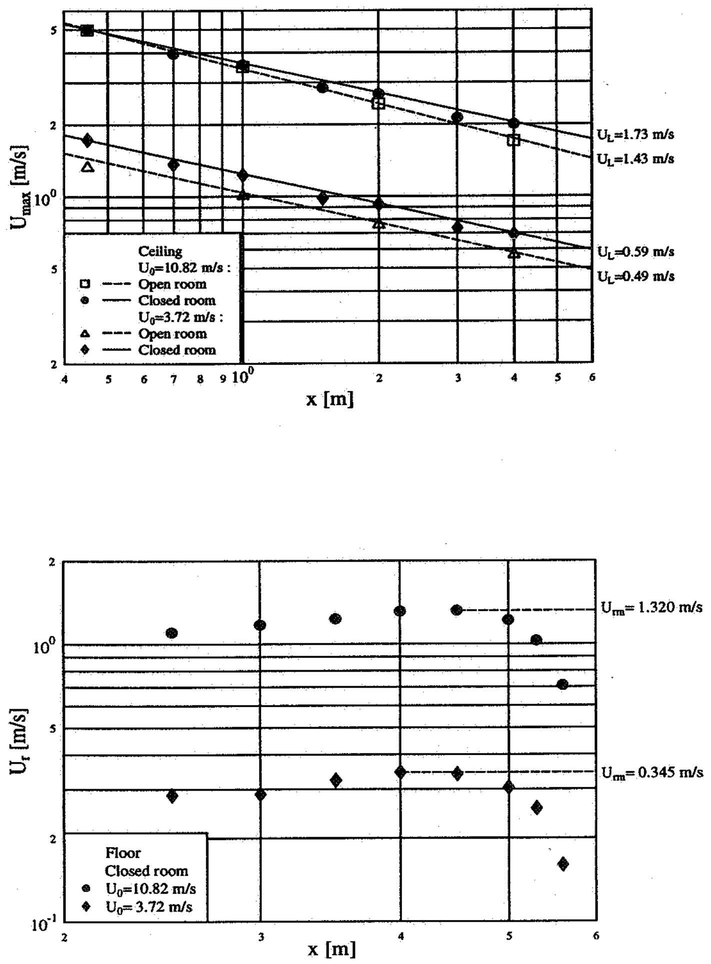

Figure 3 Maximum velocity for ceiling level (upper graph) and floor level (lower graph) respectively.

4 Concluding remarks

Regarding air movements in the occupied zone the following conclusions may be drawn:

1. According to these results and previous investigations, the location of the maximum floor velocity for a two-dimensional flow is at about $\frac{2}{3}L$ measured from the supply air terminal and is almost independent of the Reynolds number and room size.
2. The value of maximum velocities at the floor level, U_{rm}, is proportional to the velocity in the wall jet, U_L, at the end of the room. The proportionality constant is approximately 0.67 (but higher for higher inlet Reynolds numbers and lower for lower ones).
3. The effect of degree of room's confinement is shown by that the extrapolated jet velocity at the end of a closed room U_L is reduced by 83% compared to a wall jet in an open room.
4. Although the location of the maximum floor velocity shows some Reynolds number dependence, the distance above the floor level is decreasing with increasing Reynolds number.
5. By using a hot wire anemometer, the relative turbulence intensities vary from 15% up to more than 80%. This points out the difficulty of measuring the turbulence in the occupied zone with a hot wire. Thus, there is a need for a new measuring technique capable of measuring in the occupied zone.

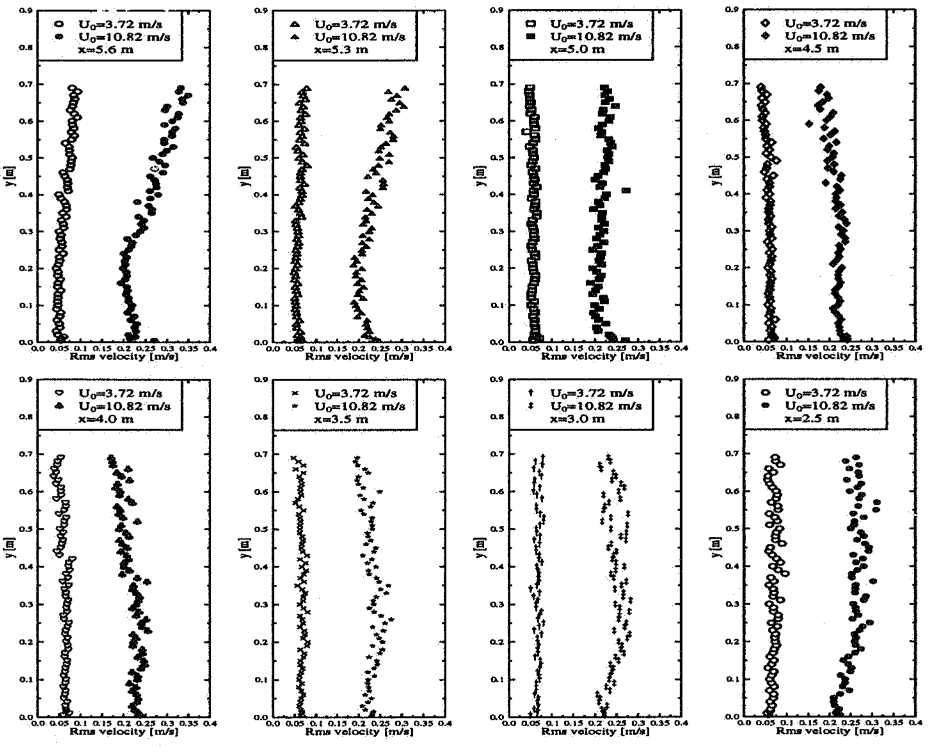

Figure 4 Measured rms velocity profiles above floor level for different sections.

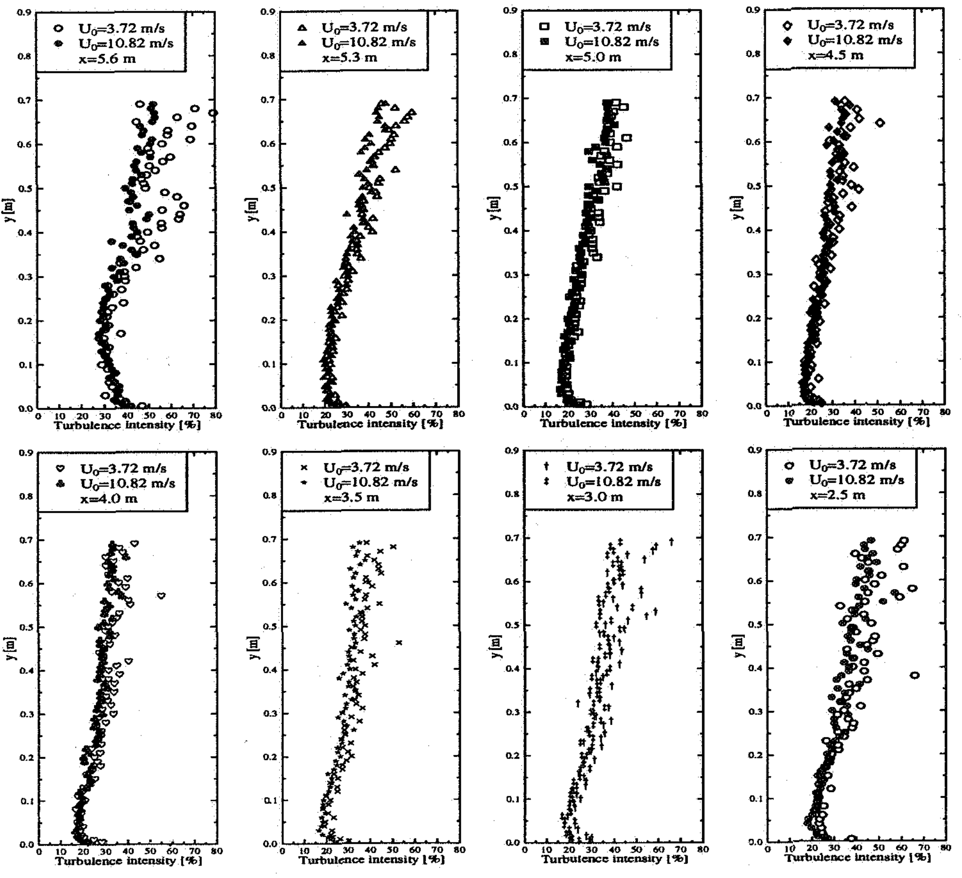

Figure 5 Measured relative turbulence intensities above floor level for different sections.

Acknowledgements

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References

Fanger, P.O., Melikov, A.K., Hanzawa, H., and Ring, J., 1988 , "Air Turbulence and Sensation of Draught," Energy and Buildings, Vol. 12, No. 1, pp. 21-39.

Hanzawa, H., Melikow, A.K., and Fanger, P.O., 1987 , " Air Flow Characteristics in the Occupied Zone of Ventilated Spaces, " ASHRAE Transactions, Vol. 93, No. 1, pp. 524-539.

Jin, Y., and Ogilvie, J.R., 1992a, "Isothermal Airflow Characteristics in a Ventilated Room with a Slot Inlet openning". ASHRAE T ransactions: Symposia, BA-92-2-2, pp. 296-306.

Jin, Y., and Ogilvie, J.R., 1992b, "Near Floor Air Movement in an Enclosure with Mixing type Ventilation". Proceedings of ROOMVENT'92, Vol. 3, pp. 247-261, Aalborg, Denmark.

Karimipanah, T., 1996, "Behaviour of Jets in ventilated Enclosures," Submitted to the Fifth International Conference on Air Distribution in Rooms, ROOMVENT '96, Yokohama,Japan.

Karimipanah, T. and Sandberg, M., 1994a, "Decay of Momentum and Velocity in an Axisymmetric Impinging Jet," Proc. of the Fourth International Conference on Air Distribution in Rooms, ROOMVENT '94, Karakow,Poland.

Karimipanah, T. and Sandberg, M., 1994b, "Deflection and Influence of Room Size of a Two-Dimensional Wall Jet in a Ventilated Room," Proc. of the Fourth International Conference on Air Distribution in Rooms, ROOMVENT '94, Karakow,Poland.

Karimipanah, T. and Sandberg, M., 1996, "Momentum balance of a round jet and its impingement on a flat plate- Part I : model development," Submitted to the ASME Journal of Fluids Engineering.

Launder, B., 1993, "Lectures in turbulence models for industrial applications," Summer school in Germany.

Melikow, A.K., Hanzawa, H., and Fanger, P.O., 1988 , "Airflow Characteristics in the Occupied Zone of Heated Spaces without Mechanical Ventilation," ASHRAE Transactions, Vol. 94, No.1, pp. 52-70.

Melikow, A.K., Langkilde, G., and Derbiszewski, B., 1990 , "Airflow Characteristics in the Occupied Zone of Rooms with Displacement Ventilation," ASHRAE Transactions, Vol. 96, No.1, pp. 555-563.

Nielsen, P.V., 1989, "Numerical Prediction of Air Distribution in Rooms--Status and Potentials". ASHRAE Transactions, pp. 31-38.

Sandberg, M., Blomqvist, B., and Mattsson, M., 1991, "Turbulence Characteristics in Rooms Ventilated with a high Velocity Jet," 12th AIVC Conference, 24-27 September, Ottawa, Canada.