THE INFLUENCE OF FURNITURE ON AIR VELOCITY IN A ROOM - AN ISOTHERMAL CASE

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ABSTRACT

Using isothermal full-scale experiments and 3-dimensional CFD simulations it is investigated how normal office furniture influences the air movements in a mixing ventilated room.

Two different types of inlets are used in the experiments and a set-up with normal office furniture is made. The set-up is simulated with one of the inlets where a volume resistance represents the furniture.

The jet under the ceiling is investigated and it is found that the normal office furniture does not influence the air movements in the upper part of the room. In the lower part of the room the maximum velocity in the occupied zone is studied. This velocity is reduced in the furnished room compared to the empty room and the reduction increases as the total length of the furniture volume in the main flow direction increases.

KEYWORDS

Mixing ventilation, CFD, Office furniture, Air velocity

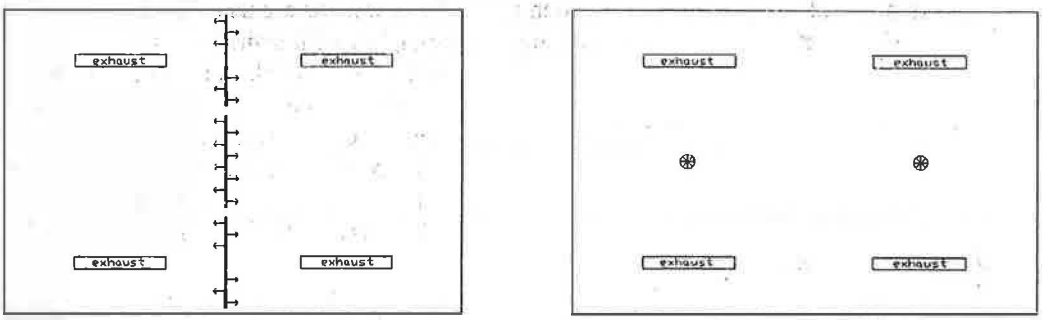
INTRODUCTION

Thermal comfort is of vital importance in a ventilated room, and the air velocity plays an important part because too high air velocity causes discomfort. Therefore, the ventilation system is often designed in such a way that the maximum velocity in the occupied zone does not exceed 0.15 m/s. A number of methods are used to design the ventilation system and they are based on the assumption that the room is empty and this is very seldom the case. Nielsen et al. (1996, 1997) show that normal office furniture has an influence on the air movements in a room with mixing ventilation under isothermal conditions.

This paper describes how normal office furniture influences the air movements under isothermal conditions in two mixing ventilated rooms different from the one used by Nielsen et al. (1996, 1997). The investigations are based on full-scale experiments and CFD (Computational Fluid Dynamics) simulations, and the study is concentrated on the jet under the ceiling and the maximum velocity in the occupied zone.

EXPERIMENTS AND SIMULATIONS

The isothermal experiments are carried out in a full-scale room with the dimensions (L×W×H) 6.0×4.0×2.8 m during the first author's stay at RWTH in Aachen, Germany. It is possible to change the inlet system in the room whereas the exhaust is maintained. Two different inlet systems are used - a slot inlet and two radial jets with swirl - and they both create mixing ventilation. The slot inlet is located in the ceiling in the middle of the room and it injects air into the room in two opposite directions along the ceiling. The two radial jets with swirl are located in the ceiling with one in each half of the room and they create a swirling air movement at the beginning which later is transferred into an almost radial air movement along the ceiling. The two inlets are shown in figure 1.



Slot inlet   Two radial jets with swirl

Figure 1 The experimental rooms with the slot inlet and the two radial jets with swirl.

In the room a set-up with normal office furniture is tested. The furniture consists of two desks, two computers with monitors and two isothermal dummies representing two persons and the furniture is placed symmetrically around the centre line of the room, see figure 2.

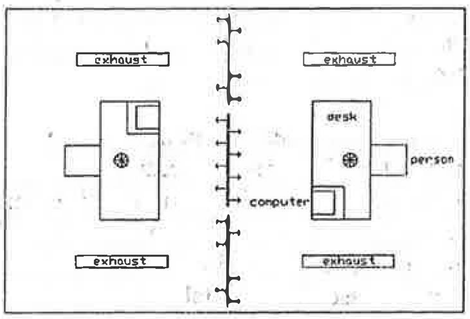


Figure 2 The set-up with normal office furniture. Both types of inlets are shown.

The CFD simulations are 3-dimensional and isothermal. A simulation has been made with the slot inlets and the experimental set-up with normal office furniture. In the simulation the furniture is represented by a volume resistance instead of modelling the detailed geometry. This furniture volume generates a pressure drop which is determined by (Flovent 1994):

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

where $\partial p/\partial x$: Pressure drop per m [Pa/m].
f : Loss coefficient [m^{-1}].
ρ : Air density; 1.19 kg/m^3.
u : Velocity [m/s].

This pressure drop is handled as a additional sink in the Navier-Stokes equations and the loss coefficient, f, is set equal in all three directions. The value of f is determined on the basis of comparison between the velocity profiles in the experimental case and the simulated case. The best results are found with a loss coefficient of 0.5 m^{-1}, which earlier also has been found to be representative for normal office furniture (Nielsen et al. 1997).

The furniture volume is inserted so that its size corresponds to the outer dimensions of the physical furniture, see figure 3.

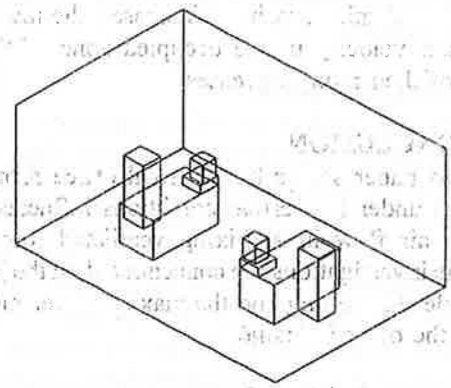


Figure 3 The simulated set-up with normal office furniture.

experimental and simulated results found with the slot inlet and the two radial jets with swirl.

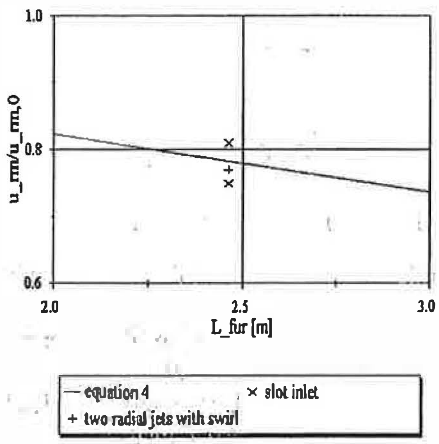


Figure 5 The maximum velocity in the occupied zone of a furnished room, u_{rm}, as a function of the total length of the furniture volume in the main flow direction, L_{fur}.

Figure 5 shows that equation 4 is also valid in a room where normal office furniture is located in both halves of the room. Therefore, the maximum velocity in the occupied zone of a furnished room is determined on the basis of the knowledge of the maximum velocity in the occupied zone of the empty room and the total length of the furniture volume in the main flow direction. The figure also shows that when the total length of the furniture volume increases, the maximum velocity in the occupied zone of the furnished room decreases.

CONCLUSION

This paper shows how normal office furniture under isothermal conditions influences the air flow in a mixing ventilated room. The investigations are concentrated on the jet under the ceiling and the maximum velocity in the occupied zone.

Isothermal full-scale experiments and 3-dimensional CFD simulations form the basis of the investigations. In the experiments two different inlets are used - a slot inlet and two radial jets with swirl but only the slot inlet has been simulated. In the experiments a set-up with normal office furniture is made in order to see the effects on the air movements in the room. In the simulation the physical furniture is replaced by a furniture volume with a loss coefficient equal to 0.5 m^{-1}.

The investigations are concerning the jet under the ceiling and the maximum velocity in the occupied zone of the furnished room. The jet under the ceiling is investigated to see if the flow element theory (throw), which is developed in empty rooms, also is valid when normal office furniture is present in the room. The experiments and the simulations made for this paper show together with Nielsen et al. (1997) that under isothermal conditions the jet under the ceiling in a mixing ventilated room is not influenced by normal office furniture. Therefore, the used theory of throw is still valid in a furnished room.

The maximum velocity in the occupied zone of the furnished room is reduced compared to the empty room. This reduction is connected to the total length of the furniture volume in the main flow direction and the reduction increases as the total length increases.

Hereby, it can be concluded on the basis of the investigations made for this paper and Nielsen et al. (1997) that normal office furniture does not affect the air flow in the upper part of the room whereas the maximum velocity in the occupied zone is reduced compared to the empty room.

ACKNOWLEDGEMENTS

The first author would like to thank Professor Dr. U. Renz and D. Müller for their co-operation with the experiments at the RWTH in Aachen, Germany.

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RESULTS AND DISCUSSION

The investigations described in this paper are concentrated on the jet under the ceiling and the maximum velocity in the occupied zone. It is studied how normal office furniture affects these two parameters under isothermal conditions, and a method for determining the maximum velocity in the occupied zone on the basis of the total length of the furniture volume in the main flow direction is tested.

The jet under the ceiling

The influence of the furniture on the jet under the ceiling is very important because the methods used for design of ventilation systems are based on this flow in empty rooms.

The jet under the ceiling is investigated by studying the velocity decay at the ceiling. The velocity decay, when the slot inlet is used, is determined by (Rajaratnam 1976):

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

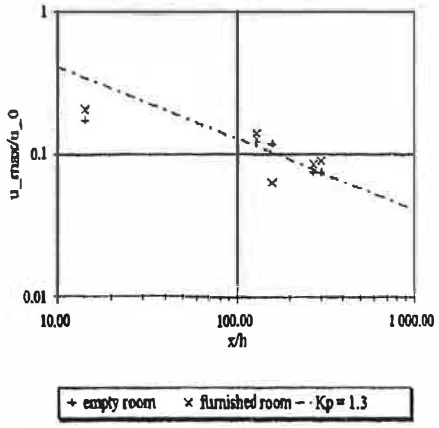
where u_{max} : Maximum velocity of the jet at the distance x from the supply opening [m/s].
u_0 : Inlet velocity [m/s].
K_p : Individual constant of the diffuser.
h : Height of the supply opening [m].
x : Distance from the supply opening [m].
x_0 : The distance to the virtual origin of the jet [m].

When the inlet type is two radial jets with swirl the velocity decay is assumed to follow the equation for a radial jet (Rajaratnam 1976):

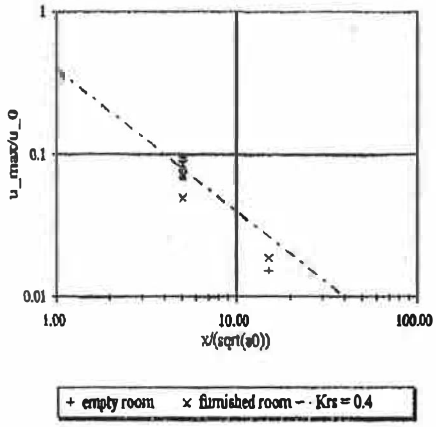
$$\frac{u_{max}}{u_o} = K_{rs} \frac{\sqrt{a_0}}{x} \qquad (3)$$

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_{rs} : Individual constant of the diffuser.
a_0 : Area of the supply opening [m²].
x : Distance from the supply opening [m].
x_0 : The distance to the virtual origin of the jet [m].

The two equations above are used to find the individual constant of the diffuser (K_p and K_{rs}) from the knowledge of the velocity decay. If the individual constant of the diffuser is identical in the empty room and in the furnished room, then the jet under the ceiling is not influenced by the furniture. Figure 4 shows the velocity decay in the room with the slot inlet and in the room with two radial jets with swirl.



Determination of K_p in the room with slot inlet



Determination of K_{rs} in the room with two radial jets with swirl

Figure 4 The velocity decay in the room with slot inlet and two radial jets with swirl, respectively.

In the experiments and the simulations made with the slot inlet K_p is found to be 1.3 in both the empty room and in the furnished room. K_{rs} is found to be 0.4 in both the empty room and the furnished room when the inlet type is two jets with swirl. The low K_{rs} value is very typical for flow with swirl, see also Balandina and Lovtsov (1979) and Nielsen et al. (1988) for axial jets with swirl. Hereby it is found that the jet under the ceiling is not disturbed by the furniture as was the case with the investigations made by Nielsen et al. (1997). On the basis of these experiments and simulations together with Nielsen et al. (1997) it is concluded that the jet theory is valid in furnished rooms under isothermal conditions.

Maximum velocity in the occupied zone

The maximum velocity in the occupied zone in a room is normally determined on the basis of methods developed in empty rooms. Therefore, it is of interest to study the effects of furniture in the room. In the isothermal experiments and simulations described in this paper it is found that the normal office furniture reduces the maximum velocity in the occupied zone of a mixing ventilated room. This has also been found by Nielsen et al. 1996, 1997) and this reduction is dependent on the total length of the furniture volume in the main flow direction (Nielsen et al. 1997) and can be determined by (Nielsen et al. 1997):

$$\frac{u_{rm}}{u_{rm,0}} = 1 - C \cdot L_{fur} \qquad (4)$$

where u_{rm} : Maximum velocity in the occupied zone in the furnished room [m/s].

$u_{rm,0}$: Maximum velocity in the occupied zone in the empty room [m/s].

C : A constant of 0.088 [m^{-1}].

L_{fur} : Total length of the furniture volume in the main flow direction [m].

The equation above is only valid under isothermal conditions in a mixing ventilated room and only when the furniture is located in one end of the room (Nielsen et al. 1997). The results found in this paper are compared with the equation in order to examine if the location of the furniture in the room is unimportant. If that is the case it will be possible to use equation 4 in most situations. Figure 5 shows equation 4 together with the