CALCULATION OF TURBULENT FLOW FOR BUILDING VENTILATION BY MEANS OF JET PROFILES WITH REGARD TO WALL INFLUENCES

Ch. Heschl[1], M. Fesharaki[1], J. Geyer[1] and A. Kelz[1]

[1] *FH-Pinkafeld (University of Applied Science), Steinamangerstraße 21, 7423 Pinkafeld, Austria (office@fh-pinkafeld.ac.at)*

ABSTRACT

Basis of this work was the question of the formation of air flows in ventilated test rooms with regard to wall influences. In order to determine the effects of the room geometry and the air inlet angle α on the airflow a jet which was placed just below the ceiling was observed in symmetrically designed test rooms. Since there is a correspondence between measurement and CFD simulation, velocity vectors are extrapolated from the CFD simulation and analysed for different geometrical data. It could be shown that due to the equilibrium of the wall shear stresses three-dimensional effects such as cross flows arise. Although two-dimensional inlet and outlet boundary conditions were defined they can produce symmetrical or non-symmetrical room air flows and a varying number of jet centerlines. An influence of the inlet angle α on the distance a and on the number of jet centerlines could be observed. The effect of room width B is small for an inlet angle up to α=30° and a room width greater than B=3H. The influence of the room length L is evident for L<3H. The comparison of the numerical calculation of the velocity profiles with the two dimensional wall jet model showed a considerable agreement in the plane of the jet centerline.

KEYWORDS

Airflow, CFD, Wall jet, Non-symmetrical room airflow.

METHOD OF APPROACH

Introduction

The prediction of the room air flow by empirical and analytical methods leads to reasonable results for strongly simplified flow forms only. For example, non-buoyant and buoyant jets can be calculated by means of the integral method only on condition that there is an unaffected flow field. In practice such flows are never achieved because of wall influences. The calculation of the room air flow by means of numeric solutions of three-dimensional RANS-equations is therefore obvious. The long computing time and arithmetic performance permit no practical and quick interpretation. With the aid of a parameter study about the influence of the room geometry and the air inlet angle, already known wall jet models should be verified and if necessary developed. They allow a rapid but a theoretically founded design of inlets with regard to space geometry.

Geometrical design of the test room

The parameter study was carried out for a test room according to figure 1. The room length L, the room width B, the slot width b and the entry angle between supply air jet and ceiling were determined as changeable parameters. An overview of their order of magnitude is given in table 1. The distance between the sidewalls and the inlet and outlet was in each case s=0.5m. The distance between ceiling and inlet as well as the distance between ceiling and outlet was in each case t=0.2m. The slot height of the inlet and outlet was h=0.05m. The room height was H=3 m.

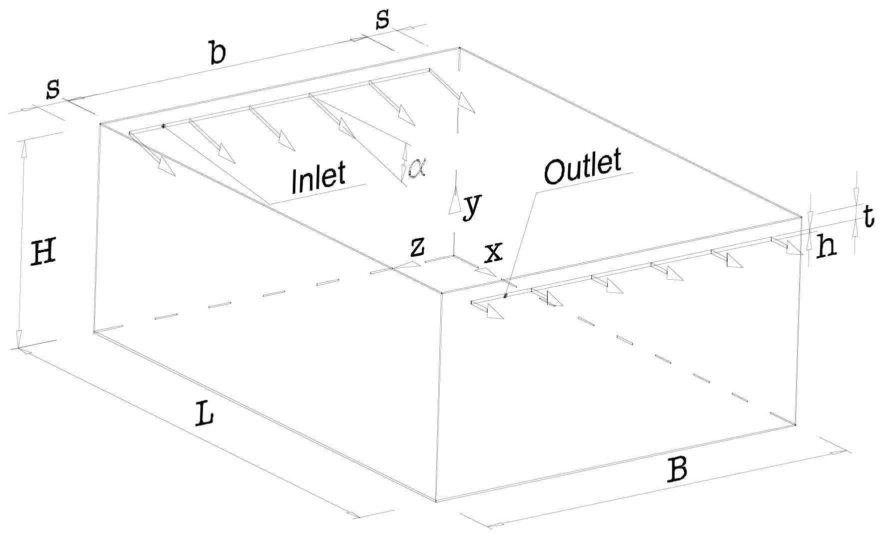

Figure 1: test room

The inlet air was supplied slantingly downward with an entrance angle α from the left. The outlet air was sucked off from the right. In the experiment and in the CFD simulation a constant amount of air was predetermined along the entire slot length.

TABLE 1
Parameters for the test room

Case Number	L/H [1]	B/H [1]	α	a/B [1]
01a, 02a, 03a, 04a	2, 3, 4, 5	2	0°	0.83
05a, 06a, 07a, 08a	2, 3, 4, 5	3	0°	0.80
09a, 10a, 11a, 12a	2, 3, 4, 5	4	0°	0.77
13a, 14a, 15a, 16a	2, 3, 4, 5	5	0°	0.73
01b, 02b, 03b, 04b	2, 3, 4, 5	2	15°	1.00
05b, 06b, 07b, 08b	2, 3, 4, 5	3	15°	0.97
09b, 10b, 11b, 12b	2, 3, 4, 5	4	15°	0.93
13b, 14b, 15b, 16b	2, 3, 4, 5	5	15°	0.95
01c, 02c, 03c, 04c	2, 3, 4, 5	2	30°	1.00
05c, 06c, 07c, 08c	2, 3, 4, 5	3	30°	1.50
09c, 10c, 11c, 12c	2, 3, 4, 5	4	30°	1.30
13c, 14c, 15c, 16c	2, 3, 4, 5	5	30°	1.43

Evaluation of the employed CFD model

In order to be able to check the validity of the CFD model the room air flow was measured in a full scale model room and compared with the calculation results of a commercial software (FLUENT 5.5.14). For a precise description of the experimental setup see Heschl Ch. and Fesharaki M. (2001). The pressure calculation within the CFD analysis was carried out with the pressure correction procedure described in FLUENT (2001). As discretization scheme the first order upwind scheme was used. The standard ke-model with standard wall functions was used for modeling turbulence (Voigt, L. P., 2000). The cell number of the calculation grid was about 1.100.000.

The measurement and the CFD simulation showed an almost identical flow picture. The three-dimensional effects could also be expressed quantitatively correctly. In both cases the jet attached to the ceiling was deflected to one of the side walls. Only a too intensive jet curve in the reattachement zone on the ceiling was calculated. Due to the fact that the reattachement zone is outside the occupied zone an extrapolation of the jet profiles by means of numeric flow simulation can be made.

RESULTS AND DISCUSSION

After the inlet of the air into the room a jet develops. The ambient air is entrained by the turbulent mixing (Fleischhacker, G. and Schneider, W. 1980). Because of the ceiling to little air entrains from above. In order to be able to meet the continuity and the momentum balance, underpressures that press the jet onto the ceiling (Coanda effect) arise. According to this attachment zone a three-dimensional wall jet forms which for the most part is reflected by the back wall. Consequently there is an interaction between the wall jet on the ceiling and the recirculating air.

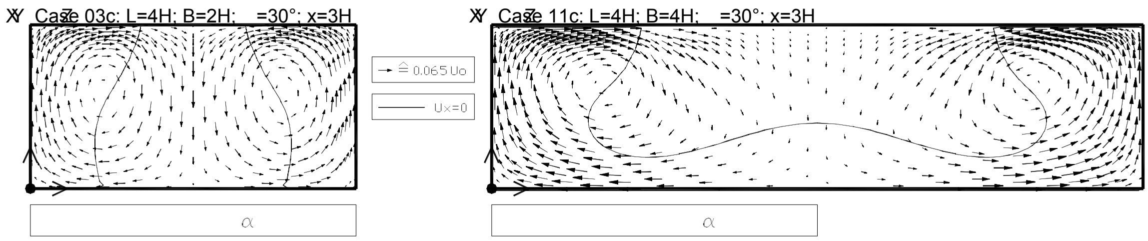

Figure 2: Velocity vectors in yz-plane, case 03c and 11c

The distance s allows a side entrainment of the air which induces cross flows. On the one hand the entrainment occurs due to the turbulent mixing and on the other hand due to pressure differences. For the elucidation of this effect figure 2 represents the velocity vectors in the yz-plane (roomdepth x=3H) for the room geometry L=4H, B=2H and B=4H. The solid line represents the isoline for the x-component of velocity Ux=0. It can be interpreted as a fictitious jet boundary. The recirculation flow field in reference case 03c is located between the sidewalls and the jet center. In reference case 11c the jet boundary doesn't reach the floor. Here the air is forced by continuity to recirculate near floor level.

The origin of the secondary flows can be put down to the fact that air always tries to take on a form which causes as little resistance as possible. Consequently air is carried into the room interior at places of greater wall shear stresses while air is carried to places of smaller shear stresses from the inner to the outer zone (floor). Therefore the velocity decreases at places of greater wall shear stresses and increases at places of smaller wall shear stresses. At the room corners and within the wall jet overpressures cause a double vortex across the main flow direction.

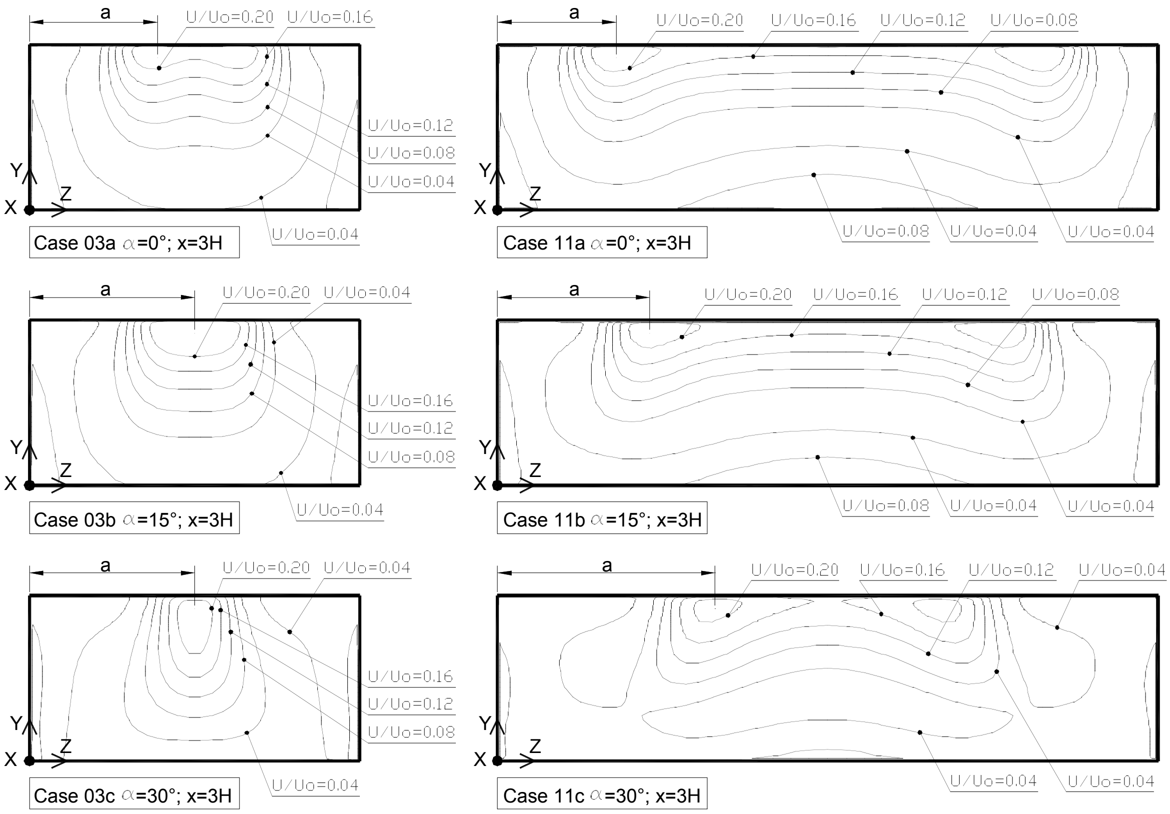

Figure 3: Isolines for velocity magnitude case 07 and 11 (FLUENT 6.0.14, SKE)

The calculation of the room air flow requires a complete three-dimensional viewing (Zhang G. et al 2000). Hence, the empirical equation for the prospective two-dimensional wall jet according to Verhoff (1963) is limited.

Influence of the room width

In order to be able to analyze the effect of the wall faces the jet center line, the contour of velocity for different entry angles and room widths were evaluated. In figure 3 the reference calculations of case 03 and case 11 are represented. Except for the reference case 09 all numerically examined case studies showed a symmetrical room air flow. With an inlet angle of $\alpha = 0°$ a three-dimensional symmetrical wall jet with two spatially separate jet peaks formed. In figure 3 this is shown by isolines U/Uo=0.20. The distance a between the sidewalls and the jet centerlines is constant in x-direction and can be extracted from table 1 in dependence of the room geometry. Accordingly, the room length L and the room width B do not have any influence on a. On the other hand the inlet angle α represents an essential actuating variable. If the inlet angle α gets larger distance a increases too. With the inlet angles $\alpha = 15°$ or $\alpha = 30°$ and the room widths B=2H or B=2H and B=3H a symmetrical three-dimensional wall jet with one jet centerline arises.

For the analysis of more simple jet sections which are, however, theoretically founded, it is reasonable to reduce the room dimensions. Since little influence of the room width B on the jet distance a could be shown the obvious thing to do is to evaluate the jet profiles in the z = a plane.

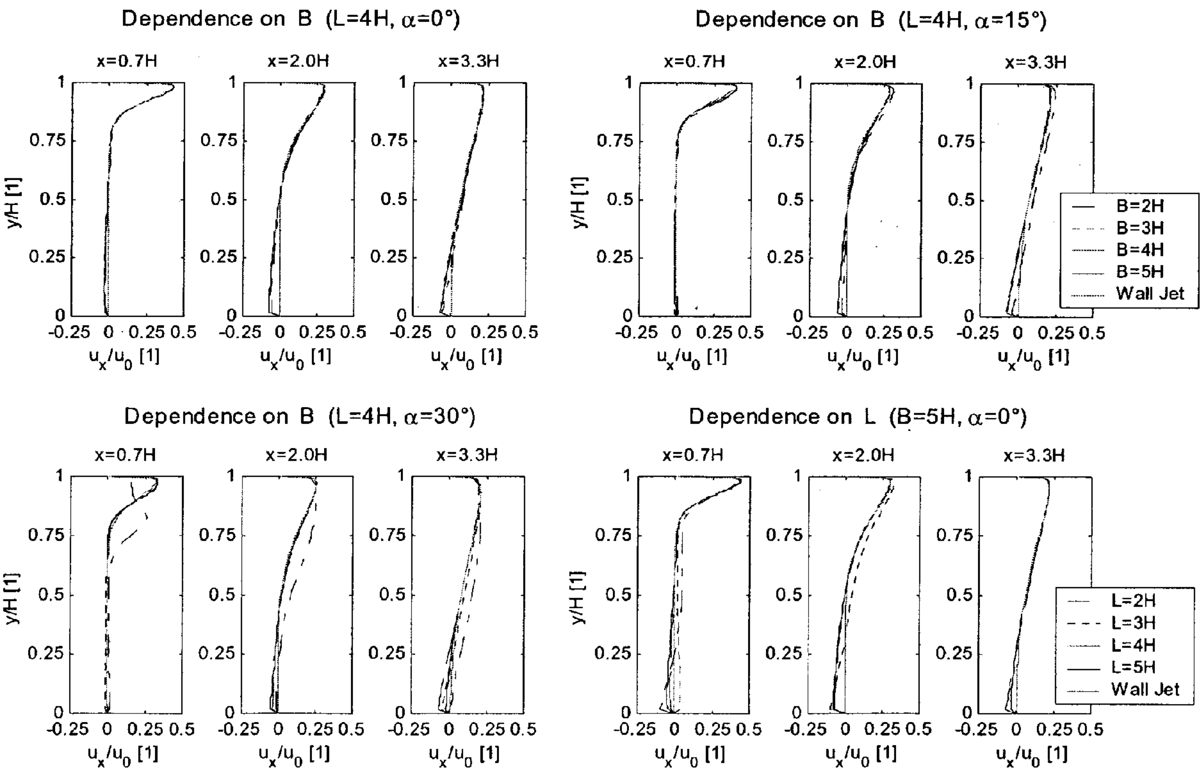

Figure 4: Velocity profiles for different room geometries B and L

In figure 4 the jet profiles are represented for different room widths B at a room length L = 4H and the distance z = a. With an inlet angle $\alpha = 0°$ the profiles are almost identical. Even the single calculation model for the velocity profiles of two-dimensional wall jets according to Verhoff (1963) agrees very well with numeric results for velocities Ux/Uo>0. But the velocity profiles for an inlet angle $\alpha = 15°$ at a room width B=2H deviate from the other profiles.

At a inlet angle $\alpha = 30°$ and a room width B=2H the pressure caused by the Coanda effect isn't sufficient anymore to completely deflect the jet to the ceiling within a length x=0.7H. For the investigated room width B>2H the jet section can be calculated according to Verhoff (1963) with sufficient accuracy.

Influence of the room length

Furthermore, the velocity profiles are represented for different room lengths at a room width B=5H and an inlet angle $\alpha = 0°$ in figure 4. It is obvious that the room length L has a considerably greater influence on the velocity profile formation (in the plane z = a) than the room width. Only at a room length of at least L=3H the dependence is smaller and the velocity profile according to Verhoff (1963) gains validity.

CONCLUSION

The comparison of measurement results and the three-dimensional CFD simulation showed very good agreements. Hence, a parameter study for the determination of the basic effects of global room air flow and its interactions with walls is possible.

It could be shown that due to the equilibrium of the wall shear stresses three-dimensional effects arise. Although two-dimensional inlet and outlet boundary conditions were defined they can produce symmetrical or non-symmetrical room air flows and a varying number of jet centerlines. An influence of the inlet angle α on the distance a and on the number of jet centerlines could be observed.

The evaluation of the velocity profiles for symmetrical room air flow in the plane of jet centerline allows the following conclusions:

- Directly on the fictitious jet centerline cross flows are negligibly low.
- The influence of room width B is small for an inlet angle up to $\alpha = 30°$ and a room width greater than B=3H.
- The influence of room length L is evident for $L \leq 3H$.
- The calculation of the room airflow according to the wall jet model by Verhoff (1963) is possible for a testroom complying with the following parameters:
  - $\alpha = 0°$; $B \geq 2H$; $L \geq 3H$
  - $\alpha = 15°$; $B \geq 2H$; $L \geq 3H$
  - $\alpha = 30°$; $B \geq 3H$; $L \geq 3H$

The calculation of the room airflow with two-dimensional wall jet models is always possible although distinct three-dimensional effects could be found. But it must be pointed out that a consideration of the backflow area is impossible and that large deviations can appear there.

References

Fleischhacker, G. and Schneider, W. (1980). Experimentelle und theoretische Untersuchungen über den Einfluss der Schwerkraft auf isotherme turbulente Freistrahlen. *Gesundheitsingenieur* **101-5**, **129-140**.

FLUENT (2001). FLUENT 6.0 User's Guide. *Fluent Inc. Centerra Resource Park, Lebanon.*

Heschl, Ch. and Fesharaki, M. (2001). Raumluftströmungssimulation. *Internationaler Kongress e.nova.2001, Pinkafeld Austria,* **259-275**.

Voigt, L. P. (2000). Comparison of Turbulence Models for Numerical Calculation of Airflow in an annex 20 Room. *International Centre for Indoor Environment and Energy Engineering Technical University of Denmark*, ISBN 87-7475-225-1.

Verhoff, A. (1963). The Two-Dimensional Turbulent Wall Jet without an External Free Stream. *Princeton University Report,* No. **626**.

Zhang, G., Morsing, S., Bjerg, B. and Svidt, K. (2000). A Study on the characteristics of airflow in a full scale room with a slot wall inlet beneath the ceiling. *Proceedings if RoomVent'2000,* **199-204**.