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The Effect of Various Inlet Conditions on the Flow Pattern in Ventilated Rooms - Measurements and Computations

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1. Introduction

A test room (figure 1, [1]) which was built at a scale 1:5 to the original one has been used to investigate air-conditioned rooms. The original room was specified by the international project IEA ANNEX 20 ([2],[3]). A lot of experiments were made on different inlet geometries (figures 2, 3) and air change rates. Velocities and turbulent quantities were measured not only in the inlet plane but also in the room itself by means of hot wire anemometry. The ammonia absorption method according to Krückels [4] has been applied to determine the heat transfer coefficients at the walls. Qualitative results were obtained by laser light sheets.
The experimental results serving as boundary conditions and relative values for numerical studies are used to progress the computer code ResCUE developed in Dresden. Further on, the experimental data provide statements on conditions in the occupied zone.

2. Measuring Equipment

The laser light sheet technique used to represent the flow field also visualizes domains which are not appropriate for hot wire measurements.Whereas a 4 Watt Argon-Ion-Laser provides the light, a smoke generator evaporates an alcoholic liquid in order to induce the necessary tracer gas for visualizing the flow. The diameter of the droplets is approximately 1μm. A CCD-camera records the pictures of the flow field to the memory of the computer or to video.
Both flow velocities and turbulence quantities are obtained by hot wire measurements. The voltage given by the DANTEC-55M-system is digitized by an a/d-converter into a 16-bit information and stored in the access memory of a PC. On average, 15 x 60 measuring points were chosen in a plane (x,z-plane=500mm x 600mm) and 10000 values are taken at each point in order to determine the mean velocities and turbulent quantities locally. This equals 3 seconds integration time at each measuring point. The hot wire probes have been locally adjusted with a positioning device of modular-design principle made by ISEL AUTOMATION. This device is computer-controlled and owing to an incremental pitch of 0.0125mm, it makes a rather precizely positioning possible.
As mentioned above heat transfer coefficients are determined by means of the ammonia transfer method [6] using the analogy between heat and mass transfer and a computer aided image processing system [5]. Small quantities of ammonia

are added to the supplied air. That causes a chemical reaction at foils moistened with a reaction substance. The colouring of this foils indicates the intensity of the mass transfer. Using the analogy between heat and mass transfer, the heat transfer coefficients can be calculated by

$$\alpha = \frac{\beta_{NH_3} \cdot \lambda}{D_{NH_3-L}} \cdot \left(\frac{\Pr}{Sc}\right)^n$$

3. Experimental and numerical Investigations

Experiments were carried out for an air change rate of 37,5 h^{-1} and 150 h^{-1} using as well inlet geometry 1 as 2 (figures 2, 3). In all cases the same positions of the probes were chosen. Experimental data have been averaged in time and space. That is

$$\left|\bar{u}_{x,y}\right| = \sqrt{\bar{u}_x^{\,2} + \bar{u}_y^{\,2}}$$

Thus the velocities are given as absolute values. Therefore the velocities close to the outlet device have the same direction like the inlet device velocities.

In correspondence with the experiments numerical investigations were carried out using the code ResCUE, which has been developed at the Dresden University of Technology.

It is based on a finite volume discretization of the Reynolds averaged Navier-Stokes equations. A k-ε model is used for turbulence modelling. The Poisson equation for the pressure is solved by a multigrid method in every time step of the velocity pressure iteration, for details see [7].

The boundary conditions for modelling the various inlets were formulated within the inlet opening. Following a proposal of [8], the HESCO diffuser was modelled by 7 x 4 rectangular slots.

Computations were carried out on a HP workstation 9000/730 and grids of 28^3 and 40^3 discrete cells were used.

4.Results

The evaluation and intepretation of the experimental data show a clearly different behavior of the flow in all investigated cases. The main reason for that is the very different momentum at the inlet. Figure 7 shows the velocity profiles

in the symmetry plane for the inlet geometry 1 and the high air change rate. For this case measured and simulated values are in a good agreement. But it is seen from figure 10 that even for this simulation the numerical prediction does not meet the typical behaviour of the jet (compare figure 9 and 10).
This tendency is considerably amplified for the low air change rate. In case of inlet geometry 2 (HESCO diffuser), the modelling by a lot of rectangular slots can only be regarded as a trial. Because of the very fine grid, the computer capacity of a workstation is quickly reached. In addition, turbulence modelling by a k-ε model is probably not suitable in the region near the inlet opening. Although the calculated heat transfer coefficients (figure 6) show a similar pattern as the measured ones (figure 5) the results are not satisfying and should be improved in further investigations.

5. Conclusions

Experiments in a scaled test room are very helpful to study the behaviour of the flow under various inlet conditions. It makes the application of some interesting methods, like the amonnia transfer method possible.
Computations show the global situation within the test room, but do not meet the typical behaviour of the flow especially for a low air change rate and complicated inlet devices. Improvement is necessary above all in modelling of turbulence for such situations.

6. Acknowledgement

The authors are grateful to Oliver Hack and Guido Lehmann for carring out numerous measurements and computations.
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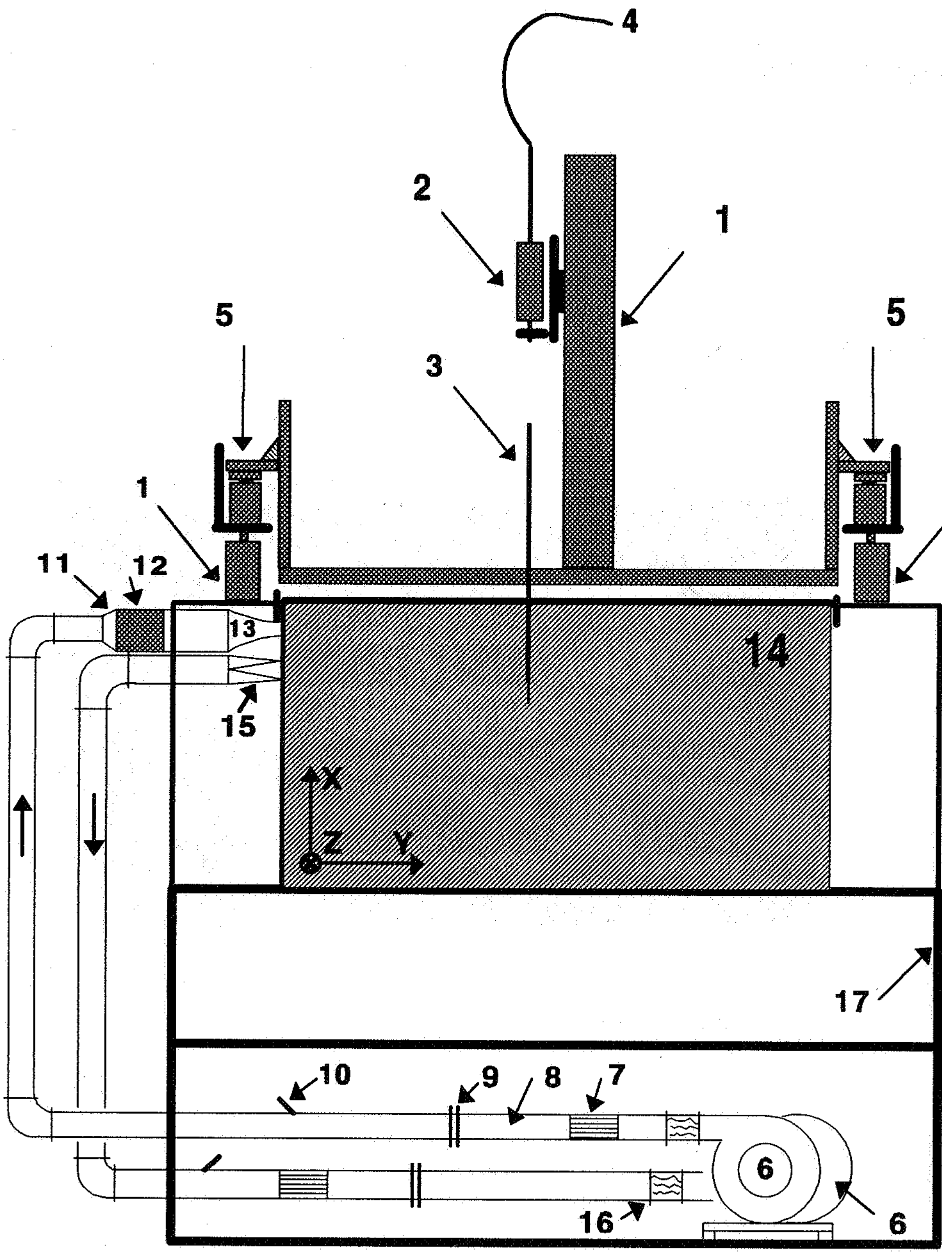
7. Photographs , graphs and diagrams



1 isel-motion system with steping motors (360° = 400 steps)
2 mount for the wire probes
3 hot wire probe
4 wire cable
5 isel-stroke system (valve lift=5mm,lifting power=630 N)
6 ventilator
7 rectifier
8,9 air supply pipe with mass measuring equipment
10 temperature measuring point
11 diffuser
12 heat exchanger
13 air supply inlet
14 model room
15 air outlet
16 vibration compensator
17 chassis

Figure 1: The model "post-annex-20-room" with the moving system for the probes

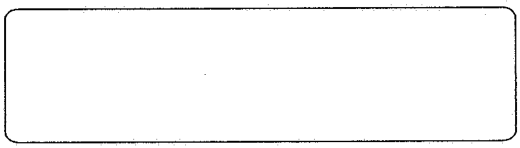


Figure 2 : Inlet geometry 1 (rectangular inlet; width=155mm, height=42mm)

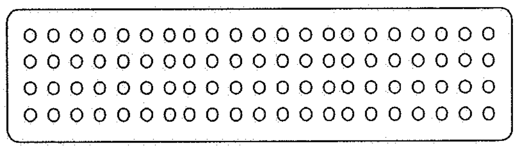


Figure 3 : Inlet geometry 2 (HESCO-diffusor inlet; 4 x 21 round nozzles, ∅ 2.3mm)

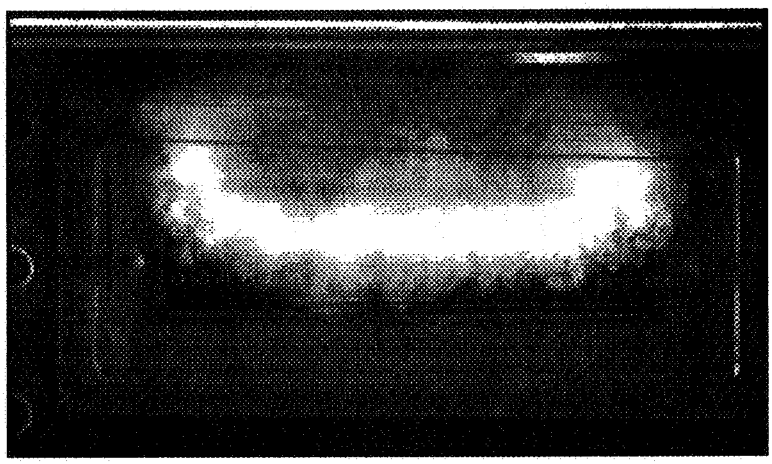


Figure 4 : Flow visualisation of the inlet jets (geometry 2) with 'disco fog' (y=100mm, air change rate=37,5h^{-1}, velocity in the inlet plane=7.52m/s)

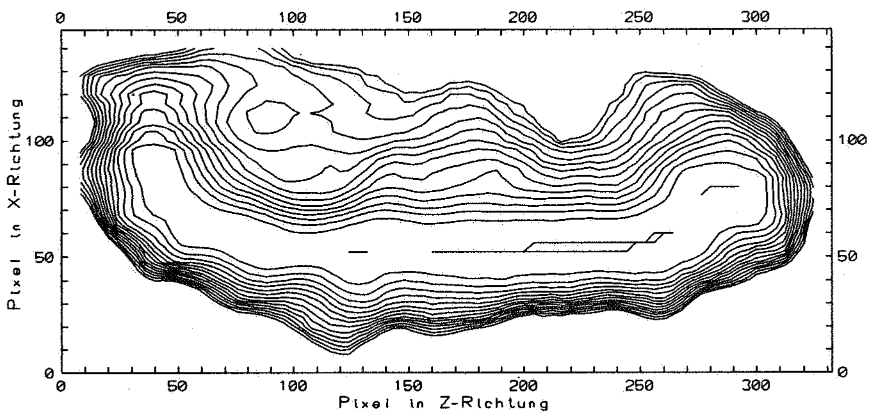


Figure 5 : Lines of equal fog concentration - calculated from the gray levels in picture 4

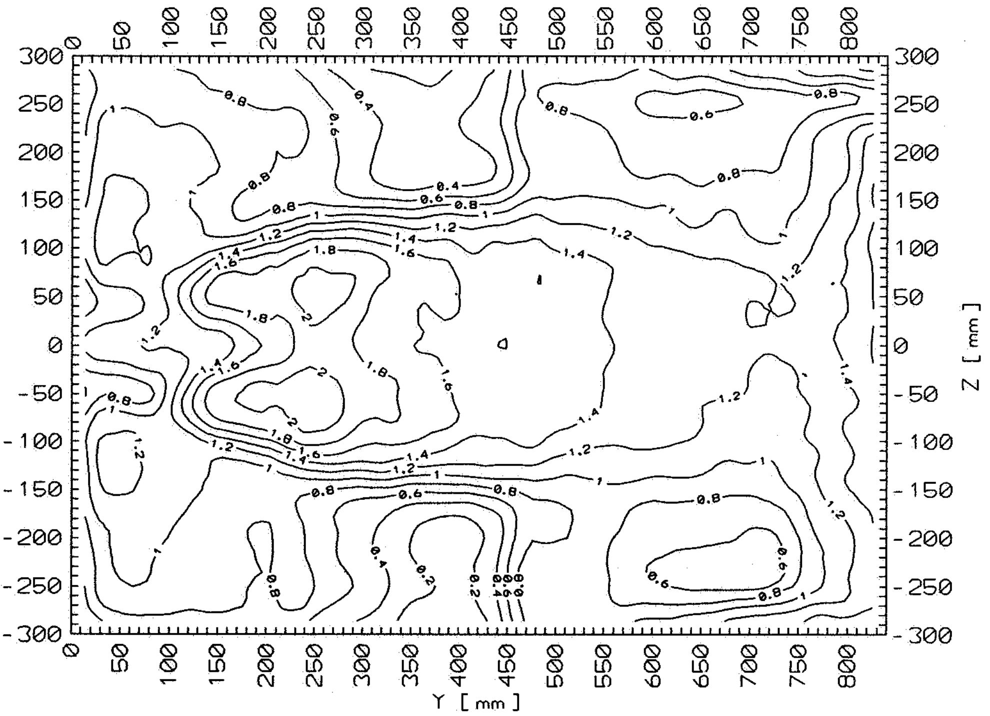


Figure 6 : Normalized heat transfer coefficient $\alpha/\overline{\alpha}$ at the ceiling of the model room (measurements, inlet geometry 2, air change rate=37,5 h^{-1})

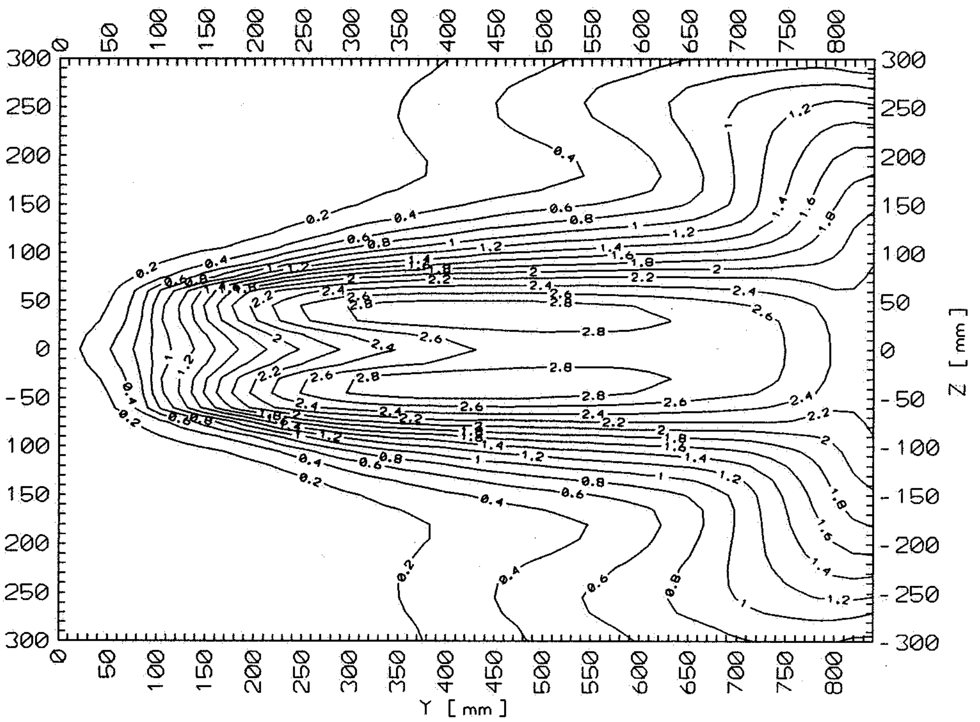


Figure 7 : Normalized heat transfer coefficient $\alpha/\overline{\alpha}$ at the ceiling of the model room (calculation, inlet geometry 2, air change rate=37,5 h^{-1})

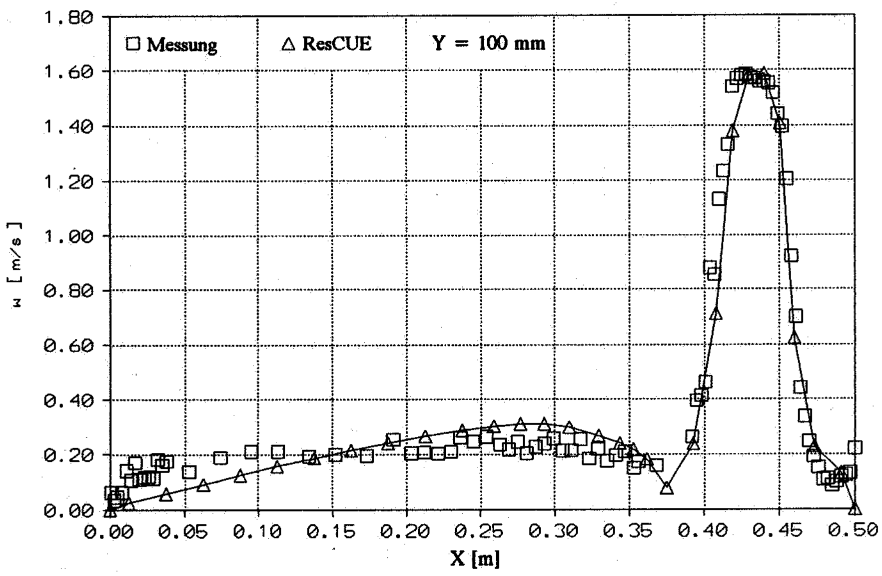


Figure 8 : Comparison of experimental and numerical results in the symmetry plane (y=100mm, inlet geometry 1, air change rate=150,0 h^{-1})

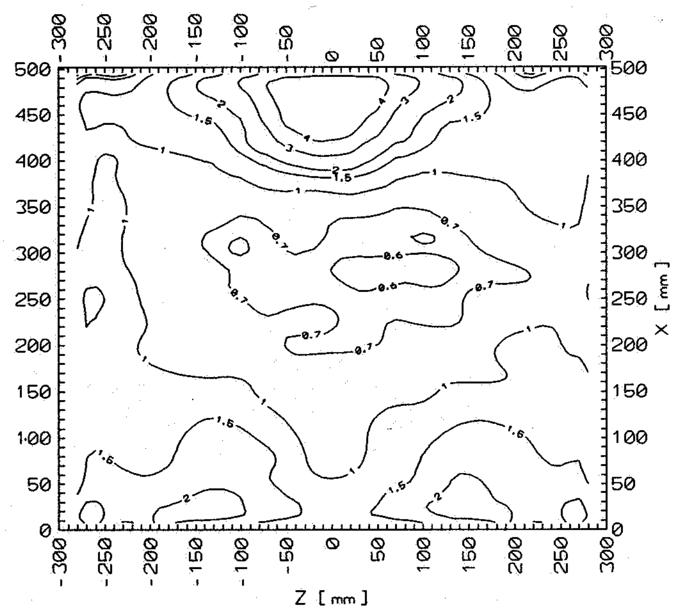


Figure 9 : Measured lines of equal velocity (y=400mm, inlet geometry 2, air change rate=150,0 h^{-1})

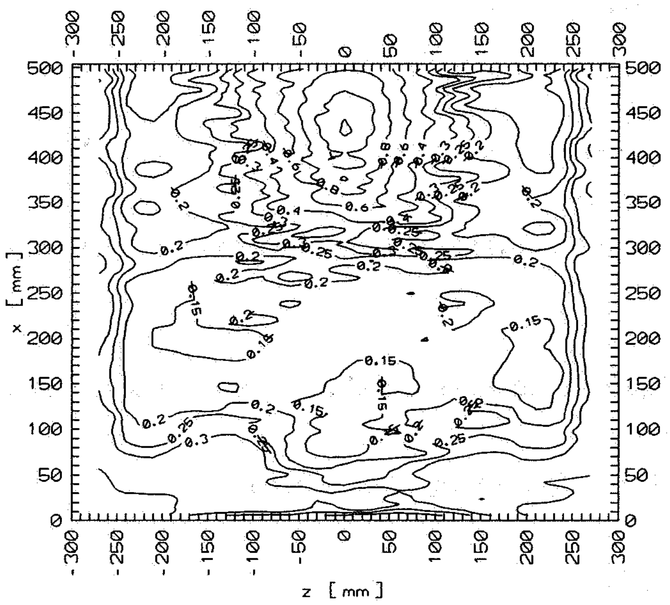


Figure 10 : Measured lines of equal velocity (y=400mm, inlet geometry 1, air change rate=150,0 h^{-1})

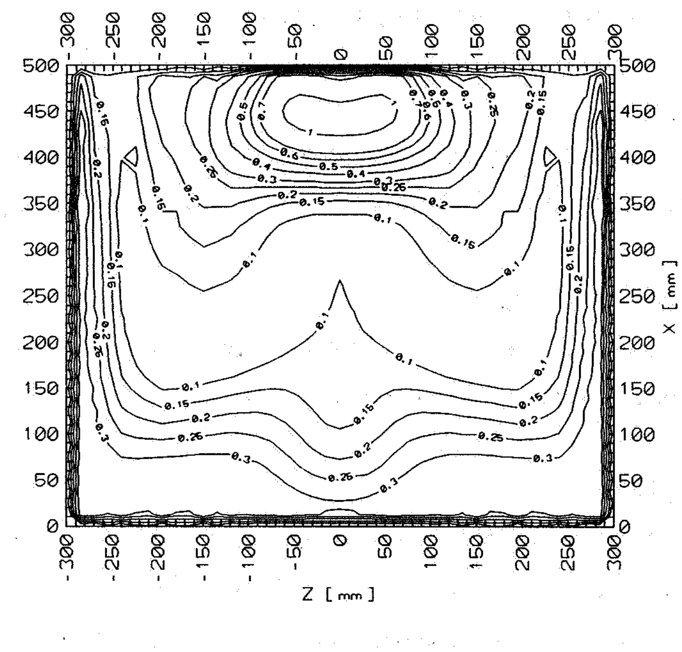


Figure 11 : Calculated lines of equal velocity (y=400mm, inlet geometry 1, air change rate=150,0 h^{-1})

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