PROBLEM OF AIR FLOW PATTERN REPRODUCTION IN SCALE MODELS OF VENTILATED ROOMS

M Hurnik, S Mierzwinski, Z Popiołek

Department of Heating, Ventilation and Dust Removal Technology
of the Silesian Technical University in Gliwice, Poland

ABSTRACT

Scale model experiments give possibilities for analyses of the design conceptions of ventilation especially of air distribution in large enclosures. When simulating aerodynamic and thermal processes in scale models of room ventilation, the flow patterns are visualised and the air flow temperature and velocity are measured. The paper presents the results of experimental tests of the air mean velocity field in three different size models of the same ventilated room. The field maps of the air velocity mean value were analysed. The measurements proved that the mean velocity distribution depended on how the boundary conditions were generated.

INTRODUCTION

Scale model experiments create possibilities for analyses of the design conceptions by reproduction and observation of dynamic and thermal processes in models of ventilated rooms. In many complicated cases of room ventilation, scale modelling is a useful research tool. It can also profitably co-operate with numerical modelling (CFD) of turbulent ventilating flows. Similarity for the air mean velocity field can be fulfilled when flows in the real object and in its scale model are fully turbulent and Re-number independent. Besides, correctness of a scale model experiment is a result of carefully chosen methods of measurement and identification of the air flow parameters. In the present tests on the improvement in scale modelling, methods of mean air velocity measurement were tested and a graphical way of presentation was suggested. Maps of normalised mean velocities obtained in the experiments are a convenient source of information for ventilation processes analysing. Basing on those results, high sensitivity of the mean velocity distribution as a function of different ways of boundary conditions generation was observed.

DESCRIPTION OF THE MEASUREMENT STAND

The tests were carried out in three similar scale models of a sports hall: 1:10, 1:5 and 1:1.75 (Fig.1). The models were provided with supply and exhaust systems. The comparative analyses were based on the circular openings supply in all the models. The flow rate and the supply mean velocity were established on the basis of the static pressure measurement before the supply opening. Supply and exhaust flows were balanced by setting differential static pressure in the model and its surroundings: $\Delta p=0.0$ Pa. Velocity distributions were measured in the vertical plane including the axis of the middle supply opening, in the points according to the grid as shown on Fig.2. An eight-channel omnidirectional thermoanemometer was used for the air velocity measurements. The models were provided with mechanisms traversing the probes of the thermoanemometer.

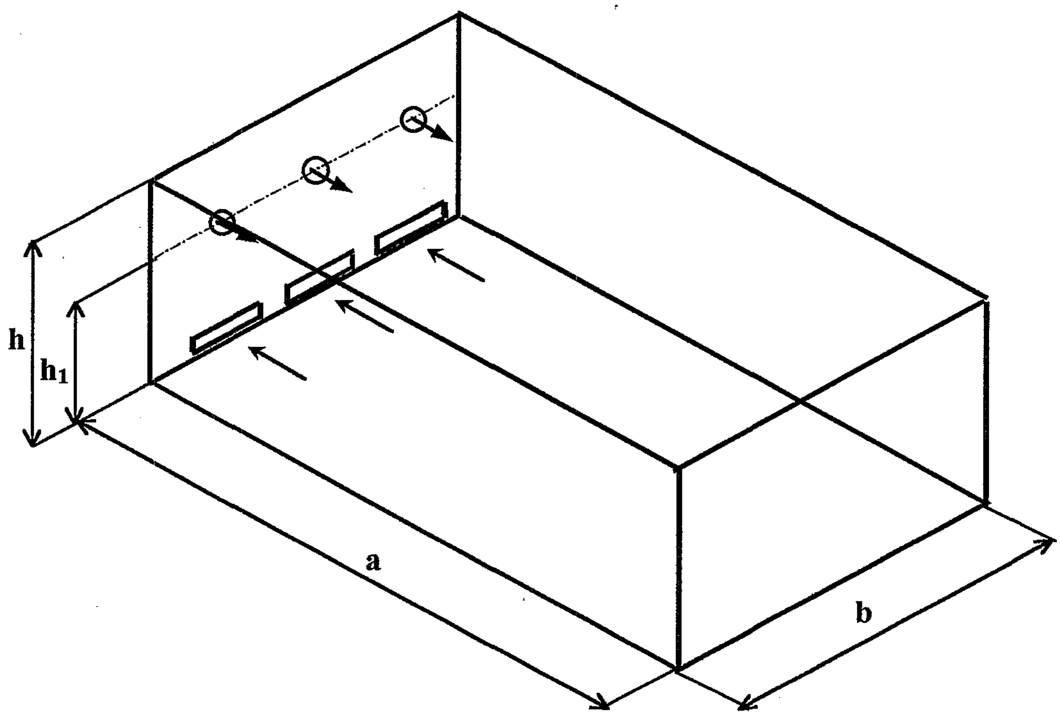

Figure 1. The view and the basic dimensions of the model

Table 1. Models dimensions

Dimensions according to Fig.1. [mm]	Model A scale 1:10	Model B scale 1:5	Model C scale 1:1.75
Length a	1500	3000	8570
Width b	900	1800	5140
Height h	550	1100	3150
Height of supply openings placing h_1	298,5	597	1720
Circular opening diameter ϕ	18,5	37	105.8
Exhaust slot dimensions	254x5,0	508x10	1450x28.5

RESEARCH METHOD

For the purpose of anemometric measurement of the turbulent air flow mean velocity in the model, the uncertainty of the mean velocity value estimation and averaging time necessary to get the required repeatability of the results were analysed. In the measurements 10 min averaging time was applied with 5% estimation uncertainty. The test results are shown as normalised mean velocities isolines maps (isotachs W/W_O). The maps, resulting from the measurements at various boundary conditions, can be compared with one another and with numerical calculation results. Application of the multichannel anemometer made a dense grid use possible in the mean velocity measurements. Movable systems for simultaneous measurement at various heights were constructed. The mean velocities were measured by eight probes in two runs at 14 heights. At the height of 2.33 m and 3 m (jet axis) the measurement was repeated. Fig.2. shows the grid used in the tests of the mean velocities fields.

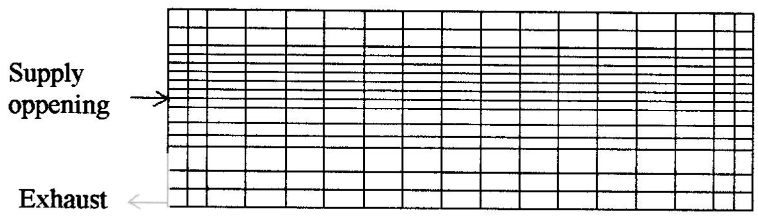

Figure 2. Scheme of the grid used in the tests of mean velocity field

In order to present the mean velocity fields a graphical computer programme was used. In that programme irregular spatial data XYZ were located in a regular spatial grid. Basing on the grid, planar or spatial maps were created. Although the dense grid was used, a distorted picture was formed. Those distortions were caused by the too small number of the measurement points in the field of large velocity gradients. In order to smooth the pictures and to avoid distortions, the experiment results were approximated. The system of equations (the background –polynomials of two variables, 5x3x8 order; the jet – Gaussian type distributions), prepared in a calculation sheet, described the normalised velocity field with good accuracy. New spatial data included the computed velocity values in a dense, uniform grid. The maps created on this basis were legible and without distortions (Fig.3.)

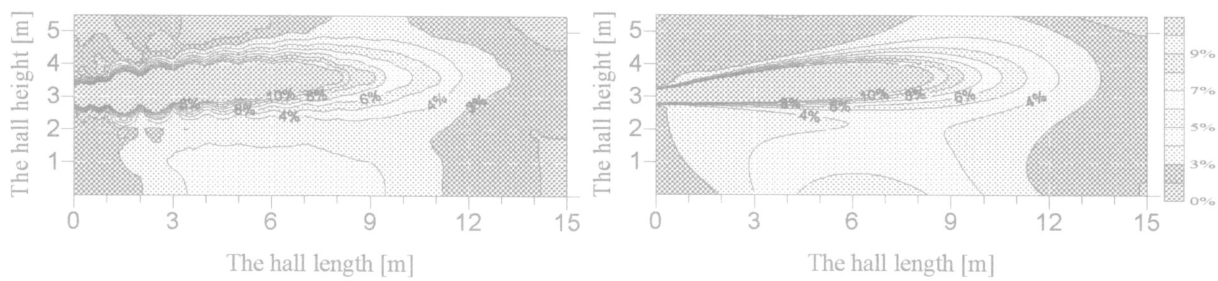

Figure 3. Maps of normalised mean velocity isolines with approximation and without approximation (model B, W_0=12 m/s)

ANALYSIS OF THE BOUNDARY CONDITIONS EFFECT ON THE MEAN VELOCITY DISTRIBUTION

The comparative analysis of the maps of the mean velocity fields showed high sensitivity of the mean velocity distribution to the way in which the boundary conditions were generated.
In the model A (1:10) in spite of the isothermal, horizontal air supply application, the falling jet was created. It suggested the wrong construction of the supply system. An elbow placed close to the supply oppening caused imprecise equalising of the velocity profile in the supply jet (Fig.4-type A, Fig.5a) After structural modification of the supply system (using a longer supply duct with the filter cloth and the confusor outlet), the jet propagated in horizontal direction (Fig.4-typeB, Fig.5b)

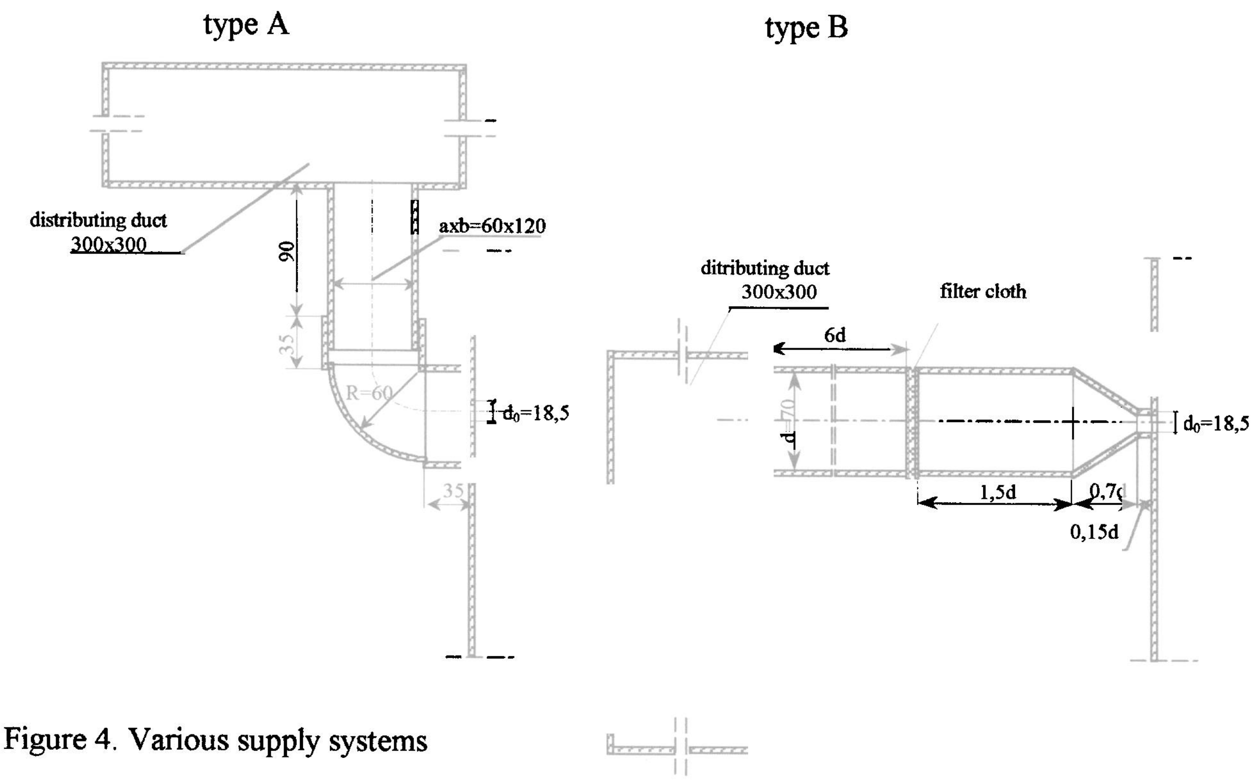

Figure 4. Various supply systems

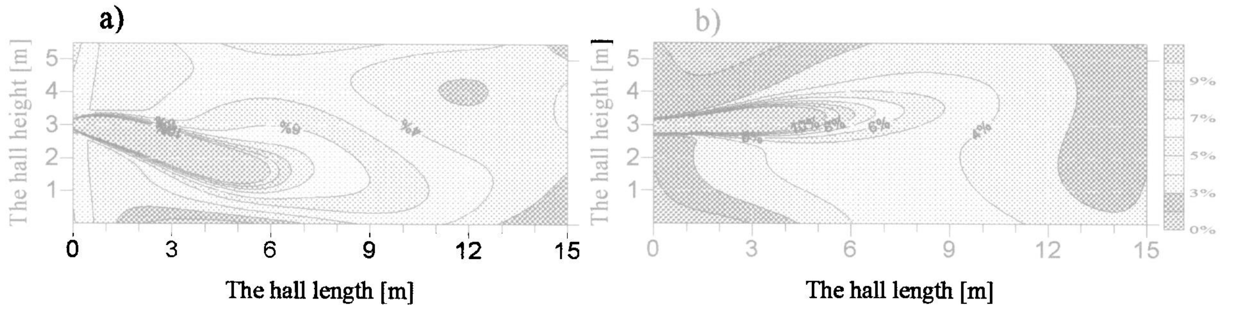

Figure 5. Comparison of maps of the mean velocity fields with various supply systems:
a) – the supply system – type A, b) – the supply system – type B
(model A, W_0=3m/s)

In the model B (1:5), in experiments with small supply velocities, a non-isothermal jet was observed. Its occurrence was caused by warming of the air in the fan, in which the small flow rate was obtained by strong throttling. The Archimedes number, calculated on the basis of the jet axis deviation was Ar=0.001. It corresponded to the temperature excess in the supply opening ΔT=8K. When the fan was changed and the flow rate was controlled by changing the rotational speed of the engine, the deflection of the jet was eliminated (Fig.6.).

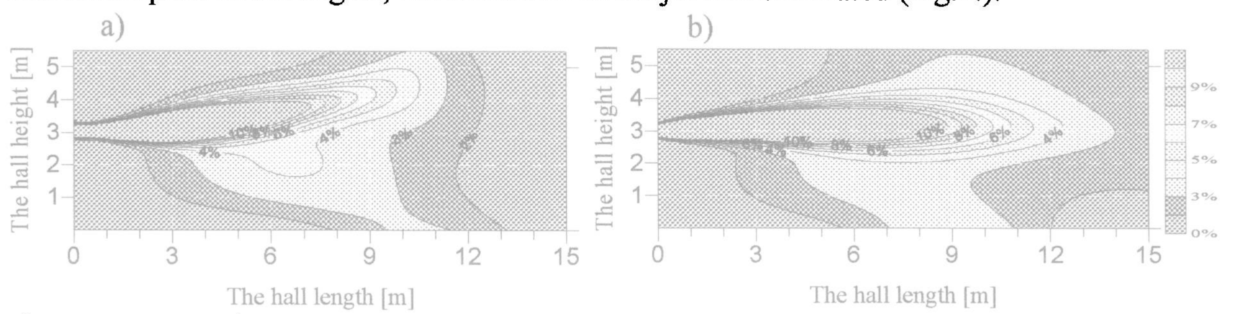

Figure 6. Comparison of maps of the mean velocity fields with: a) - non-isothermal supply,
b) - isothermal supply (model B, W_0=1.5m/s).

According to the principles of the approximate scale modelling [1] the tests of the mean velocity fields were carried out at Re numbers range from 2000 to 100000. In all the models the same constructions of the supply systems were used and non-isothermal supply was eliminated. Maps of the normalised mean velocity fields, obtained in the tests in models of different sizes and at different Re numbers, show similarity of mean velocity distributions in the whole area of the ventilating air flow pattern modelling (Fig.7).

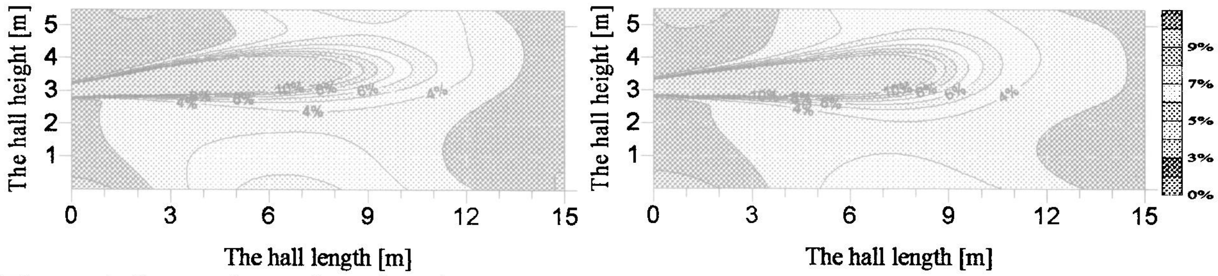

Figure 7. Comparison of results of two measurement series carried out in different models (models: B and C, W_0=6m/s)

For the cases compared, quantitative correlations of normalised velocities were determined. Regression and correlation coefficients were calculated (Fig.8). Fields of large velocity gradients close to the supply openings were neglected in the analysis.

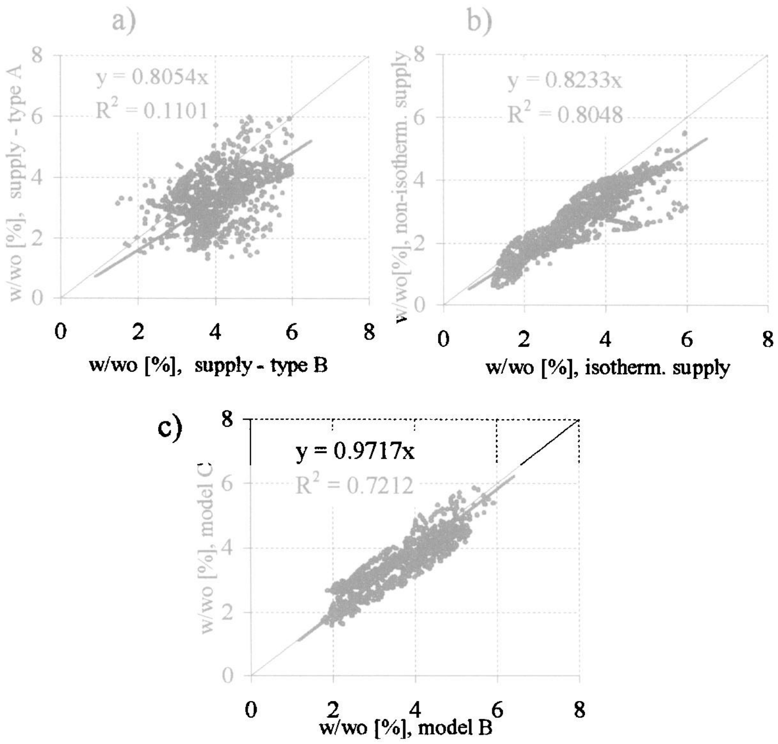

Figure 8. Convergence diagrams of the measurement series compared:

a) - different supply systems (model A, w_o= 3m/s)

b) - isothermal and non-isothermal supplies (model B, w_o=1.5m/s)

c) - series with boundary conditions similarity provided (models B and C, w_o=6m/s)

CONCLUSIONS

1. The analysis of the test results suggests the correctness of the measurement method, the data processing and the mean velocity fields presentation.
2. An improper boundary conditions reproduction causes considerable mean velocity fields distortions i.e.:
   - non-isothermal jet occurrence (the supply air warming in the fan)
   - imprecise velocity profiles equalising in the supply openings (using different types of supply system)
3. Satisfactory similarity of the mean velocity distributions in the whole area of the air flow pattern modelling is obtained if experiments are carried out according to the principles of the approximate scale modelling with boundary conditions proper simulation.

KEYWORDS

Ventilation, modeling

REFERENCES

1. Mierzwinski, S.; Popiolek, Z. and Lipska, B. (1998): Experimental Verification and Improvement of Mathematical and Physical Methods of Ventilation Flows Modelling in Large Enclosures. *KBN research report No 7 T07G 001 09,* Silesian Technical University, Gliwice (in Polish)

2. Zhang J.S.,Christianson L.L.,Zhang B.: Predicting Room Ventilation Flow with Reduced Scale Models. *Proc. Roomvent '92*, vol.1, p.p.502-522 Aalborg

3 Heiselberg, P. and Murakami, S. (editors), (1996) Ventilation of Large Spaces in Buildings. *Final report IEA-ECB&CS Annex 26.* Chapter 2.5