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SIMULATION OF DIFFUSERS IN SCALE MODEL EXPERIMENTS OF AIRFLOW DISTRIBUTION IN VENTILATED ROOMS

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ABSTRACT

Scale model experiments make it possible to analyse design concepts of ventilation, especially air distribution in large enclosures. The airflow structure similarity is fulfilled when experiment is carried out according to the principles of the approximate scale modelling. Special attention should also be paid to proper simulation of boundary and initial conditions. In a real ventilated object, the air is supplied with standard diffusers equipped with deflecting vanes. The question is how the supply opening should be constructed in the model in order to ensure the airflow similarity in the whole space modelled. The paper presents the results of experimental tests of supply jets generated by a standard diffuser and circular openings. An eight-channel omnidirectional thermoanemometer was used for the air mean velocity measurements. The jet characteristic parameters (origin distance, velocity distribution coefficient) were determined. Basing on the test results, a method for supply air jet reproduction in models is suggested. Satisfactory similarity of the air mean velocity field in the ventilated room and its models was acquired when real diffusers were simulated in the models by circular openings fitted with turbulizers and when the jet origin was properly positioned.

KEYWORDS

Scale model experiments, airflow similarity, jets, diffusers

AIRFLOW SIMILARITY IN SCALE MODELS OF VENTILATED ROOM

In many complex cases of room ventilation, scale modelling is an effective method for predicting air distribution in the real object. It can also well co-operate with numerical modelling (CFD) of turbulent ventilating flows. The airflow similarity in a real object and its model is fulfilled when experiment is carried out according to the principles of the approximate scale modelling. It is assumed that flows in the real object and in its scale model are fully turbulent and Re-number independent. Then, it is sufficient to maintain the same Ar and Pr numbers in the model (M) and in the prototype (P). Re and Gr- numbers should be over their threshold levels, Heiselberg et al. (1998):

$$Ar_M = Ar_P \qquad Pr_M = Pr_P \quad \text{and} \quad Re_M >> Re_l \quad \text{or} \quad (Gr\,Pr)_M >> (Gr\,Pr)_l$$

Based on the equality of Ar and Pr numbers, the following relation between the scale factors of the representative velocity, length and temperature difference can be derived: $S_U=S_L^{0.5}\,S_{\Delta\Theta}^{0.5}$. Reynolds number in the model Re_M is equal to $S_L^{1.5}\,S_{\Delta\Theta}^{0.5}Re_P$. In practice, Re_M is about 10÷100 times lower than Re_P. Therefore, the previous tests on the improvement in scale modelling, Hurnik et al. (1999) and Popiolek et al. (1998), were focused on determination of threshold Reynolds number, Re_l, in order to characterise the lower limit of the range of mean flow and turbulence spectrum similarity. The tests were carried out in three similar scale models of a sports hall. Satisfactory similarity of the mean velocity distributions in the whole area of the airflow pattern modelling i.e. both in the supply jets and in secondary flows was obtained at the threshold number Re_l about 4000÷2000. The similarity of turbulence spectrum was observed for $Re > Re_{l2}$. Re_{l2} was identified as about 20000÷10000. When doing the tests, high sensitivity of the mean velocity distribution to the way in which the boundary conditions were generated was found by Hurnik et al. (1999). When the boundary conditions were not reproduced properly, considerable distortions in the mean velocity field were found, e.g.: non-isothermal jet occurrence (the supply air warming in the fan), imprecise velocity reproduction in the supply openings (different types of supply system were used). However, if the boundary conditions were simulated properly, satisfactory similarity was observed. In the previous tests circular openings were used in all the models. In the real ventilated object, the air is supplied from standard diffusers fitted with deflecting vanes. The question is how the supply opening should be constructed in a model so that the airflow similarity will be ensured. In order to explain this problem, experimental tests of supply jets formed by various supply openings and mean velocity fields in the whole space modelled were carried out.

TESTS OF JETS FROM CIRCULAR OPENINGS AND STANDARD DIFFUSERS

The experiments included tests of jets from standard diffuser 80×180 mm and circular openings in scale 1:3 with equivalent diameter d=35 mm without and with turbulizers.

Description of the measurement stand

In the tests, basing on the mean velocity distribution measurements in the jet, its characteristic parameters (origin distance, velocity distribution coefficient) were determined. A scheme of the measurement stand is shown in Fig1a. Velocity distributions were measured in four cross-sections of the jet, at the beginning of the jet fully developed region. The distances between the measurement sections were assumed as multiplicity of the supply opening equivalent diameter, i.e.: 10d, 15d, 20d and 25d. The scheme of the grid used in the tests is shown in Fig.1b. An eight-channel omnidirectional thermoanemometer was used for the air velocity measurements. The averaging time was 5min. Movable systems for simultaneous measurement in eight points of the grid were constructed.

Analytical procedure for identification of the jet model characteristic parameters

The test results were approximated by a model of a free jet generated by a point source of momentum:

$$\overline{V}_x=\left(\frac{2\,m\,\dot{\text{I}}}{\text{ð ñ}}\right)^{0.5}\frac{1}{x+x_o}\cdot e^{-m\left(\frac{r}{x+x_o}\right)^2} \qquad (1)$$

where: $\overline{V}_x$ - mean axial velocity component, • – momentum flux, ρ – density, x – distance from the opening, x_o –position of the jet origin (virtual point source of momentum), m - velocity distribution coefficient.

In order to identify the jet characteristic parameters: momentum flux • , velocity distribution coefficient m and origin position x_o, the computer optimisation was applied. At first the real actual position of the jet axis was identified.

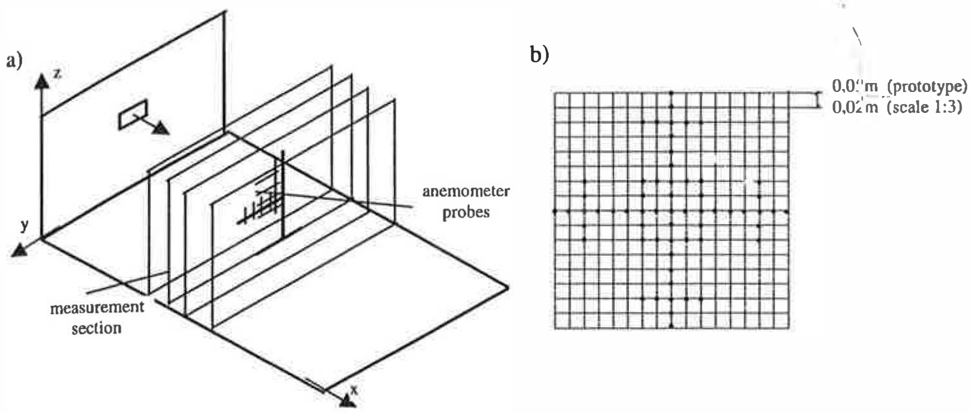

Fig.1.a) The measurement stand
b) The grid used in the tests of jets

Velocity distributions in two central axes of the measurement grid were approximated by Gaussian curves to find the co-ordinates of the jet axis y_a, z_a. Then real distances from the jet axis to the measurement points were calculated:

$$r_i = \sqrt{(y_i - y_a)^2 + (z_i - z_a)^2} \tag{2}$$

where: y_a, z_a – co-ordinates of the jet axis, evaluated separately at each cross-section. Measured velocity values were approximated by the model of jet from point source of momentum using least square method. The value of the approximation error was calculated as:

$$\Delta = \sum_{i=1}^{n} \delta_i^2 = \sum_{i=1}^{n} \left[\frac{\overline{V}_{x,i}}{\overline{V}_{x\max,cal}} - \frac{\overline{V}_{x,cal}}{\overline{V}_{x\max,cal}} \right]^2 = \sum_{i=1}^{n} \left[\frac{\overline{V}_{x,i}}{\left(\frac{2\, m\, \dot{I}}{\pi \rho}\right)^{0.5} \frac{1}{x + x_o}} - e^{-m\left(\frac{r}{x+x_o}\right)^2} \right]^2 \tag{3}$$

Then, the approximation error minimal value was sought by proper selection of $\dot{I}$, x_0 and m values. An example of the calculations is presented in Table1. An example of the normalised velocity distribution is shown in Fig.2. Velocity values lower then 10% of the axial velocity value were neglected in the approximation.

Next, the approximation error was minimised in another way: m and x_o values were assumed and only $\dot{I}$ value was sought. The optimisation was carried out for all the combinations of the following m and x_o values: $(m_{\Delta\min} - 10) \leq m \leq (m_{\Delta\min} + 10)$, $(x_{o,\Delta\min} - 1.5 \cdot d) \leq x_o \leq (x_{o,\Delta\min} + 1.5 \cdot d)$, with the step equal 2 and 0.5d, respectively. Basing on those results, a map of approximation errors as a function of m and x_o was generated by using a graphic computer programme. All the tested cases are shown as one map of approximation error fields limited by a line of equal error $(\Delta - \Delta_{min}) / \Delta_{min} = 1\%$, see Fig.3. The map gives information about m and x_o values, which describe the jets with high accuracy. It represents sensitivity of approximation to velocity distribution coefficient m and position of the origin x_o.

Table 1.Example of measurement and calculation results

	r_i	$r_i/(x+x_o)$	$\bar{V}_{x,i}$ measured	$\frac{\bar{V}_{x,i}}{\bar{V}_{x\,max,cal}}$	$e^{-m\left(\frac{r}{x+x_o}\right)^2}$	δ_i^2	
-	m	-	m/s	-	-	-	
1	0.006	0.01793	2.319	0.98324	0.97952	1.4E-05	$\Delta_{min} = \sum_{i=1}^{233} \delta_i^2 =$
2	0.014	0.04241	2.159	0.9154	0.8907	0.00061	= 0.9494
3	0.020	0.05985	1.917	0.81287	0.79413	0.00035	
4	0.022	0.06531	1.760	0.74624	0.75997	0.00019	
5	0.026	0.07777	1.364	0.57847	0.67757	0.00982	$\dot{I}\|_{\Delta min} =$
6	0.050	0.14913	1.144	0.48510	0.23901	0.06056	$= 0.018\ kg{\cdot}m{\cdot}s^{-2}$
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232	0.132	0.18713	0.122	0.11017	0.10418	3.6E-05	$m\|_{\Delta min} = 64.35$
233	0.137	0.19476	0.116	0.10434	0.10504	4.9E-07	
234	0.148	0.20933	0.098	0.08827	0.09372	3E-05	$x_o\|_{\Delta min} = -0.042\ m$
235	0.152	0.21485	0.096	0.08639	0.05021	0.00131	
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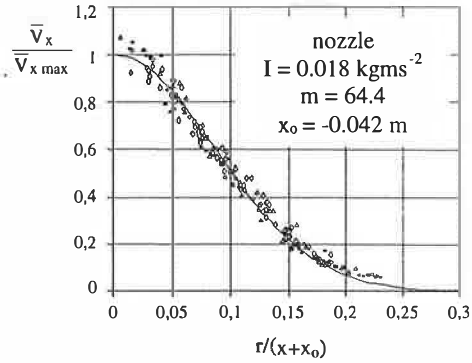

Fig.2. Normalised velocity distribution

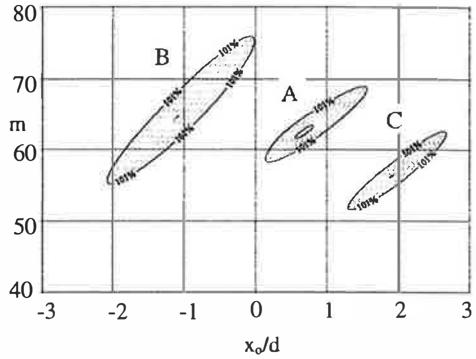

Fig.3. A map of approximation errors

Test results

Jets from the following openings were tested: standard diffuser 80×180 mm, see Fig.4a, V_o= 6 m/s, case A, circular opening in scale 1:3 d=35 mm, see Fig.4b, V_o= 3.6m/s, case B.

The test results are shown in Fig.3 as the areas A and B. The ranges of the origin distance x_o and the velocity distribution coefficient m are different for the standard diffuser and circular opening. However, when assuming the mean value of the velocity distribution coefficient as m=60, the difference in the jet origin position is about 2d, i.e.: x_o=+0,5d for the standard diffuser and x_o=-1,5d for the circular opening. It suggests that similarity of jets may be acquired when the position of the jet origin in room is the same. In order to simulate the jet from the standard diffuser, circular openings with various turbulizers were tested. Basing on the velocity distributions at the distance 20d from the outlet plane, the velocity profiles widths were determined, see Table 2. The toothed ring turbulizer, placed inside the cylindrical extension of the nozzle at the distance of 2d from the outlet plane, generated the turbulent jet at the widest spreading angle.

Table 2. Velocity profiles widths in jets generated by a nozzle fitted with various turbulizers

Type of turbulizer	Relative width of the velocity profile R/d
nozzle without turbulizer	1.83
grid 5x5 mm in the outlet plane of the nozzle	1.80
toothed ring placed in the outlet plane of the nozzle	1.63
toothed ring placed inside the cylindrical extension of the nozzle at the distance of 2d from the outlet plane	2.14

The nozzle was used in further tests. The result of the tests is shown in Fig.3 as area C. For m=60 the origin position is x_o=2.5d .
The test results show that it is possible to generate jets in which the origin position is the same as in the case of jets generated by diffusers when nozzles with turbulizers are placed at the right position in reference to the wall. The nozzles should be put at the distance of 2d before the wall (Fig.4c).

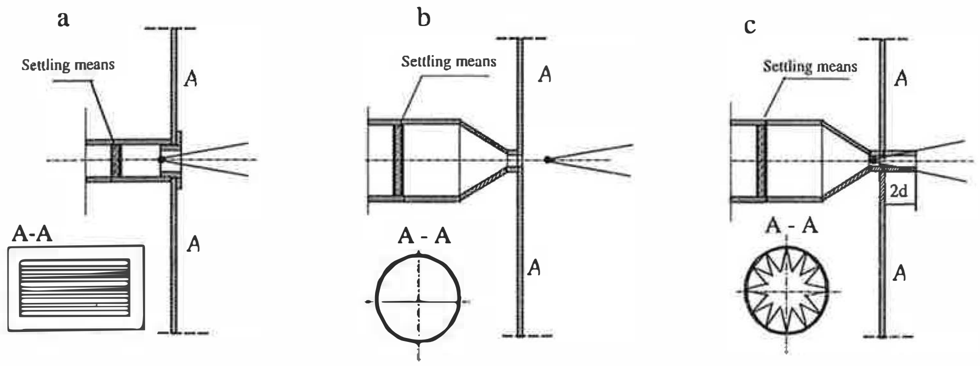

Figure 4. Various supply systems

THE EFFECT OF SUPPLY OPPENING FITTING ON THE MEAN VELOCITY FIELD IN SCALE MODELS

In order to determine the effect of the supply opening fittings on the mean velocity field in the whole region of the flow modelled, air velocity measurement was carried out in the cross-sections of the models according to the method described by Hurnik (1999). The measurement series data are as follows:

1. Prototype, room dimensions - 9×3.3×5.4 m (length, height, width), with three standard diffusers (Fig.4a), V_o=6 m/s
2. model 1:3, supply from circular, nozzle openings (Fig.4b), V_o=3.6 m/s
3. model 1:3, supply from circular opening with turbulizer (Fig.4c), V_o=3.6 m/s

The airflow was tested in isothermal conditions to avoid difficulties in the simulation of thermal boundary conditions and air velocity measurement. Although practical situations are all non-isothermal such the simplification was possible since the aim of the tests was not to provide information on the velocity field for a particular existing ventilated room but only to find out how the supply opening should be constructed in the model. The test results are shown as normalised mean velocities isolines maps - V/V_o (Fig.5). For the cases compared, quantitative correlation of normalised velocities was determined. Regression and correlation coefficients were calculated (Fig.6). Fields of large velocity gradients close to the supply openings were neglected in the analysis.

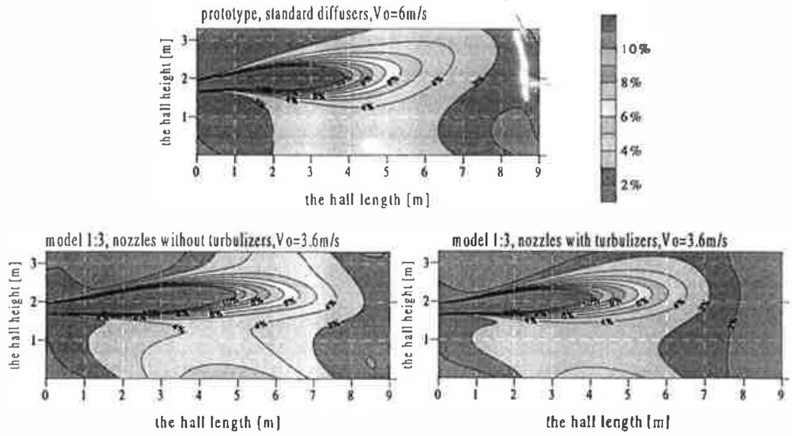

Figure 5. Comparison of results of three measurement series

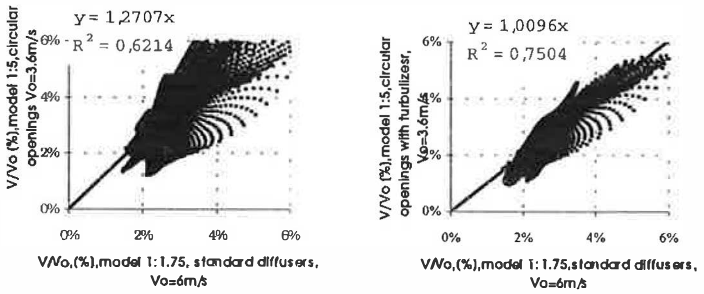

Figure 6. Convergence diagrams of the measurement series compared

CONCLUSION

Satisfactory similarity of the air mean velocity field in the ventilated room and its models was acquired when real diffusers were simulated in the models by circular openings fitted with turbulizers and when the jet origin position was adjusted to be the same in the prototype and its model.

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REFERENCES

Heiselberg P., Murakami S., Roulet C., - editors (1998). Ventilation of Large Spaces in Buildings – Analysis and Prediction Techniques, chapter 2.5 Scale model Experiments, IEA Annex 26, Aalborg University, Denmark

Hurnik M., Mierzwinski S., Popiolek Z. (1999). Problem of air flow pattern reproduction in scale models of ventilated rooms. *Proc. Indoor Air '99*, Edinburgh

Popiolek Z., Mierzwinski S., Hurnik M., Wojciechowski J. (1998). Air flow characteristic in scale models of room ventilation. Proc. Roomvent '98, Stockholm