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International Energy Agency

Annex 20: Air Flow Patterns within Buildings

VALIDATION OF CONCORDIA CODE

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INTRODUCTION

A computer program has been developed for prediction of heat and mass transfer in two-zone enclosure, and been applied to investigate airflow and contaminant dispersion with natural, forced and mixed convection conditions. A validation of this program was performed by comparing the predicted results in natural convection with experimental data obtained by Nansteel and Greif (1984), and by Lieman (1990) in Lyon University. For forced convection studies, since there is no experimental data available, a comparison between velocity distributions predicted by this program and by Chen through PHOENICS code was carried out. The following is the description about Concordia code and the results of comparison.

BRIEF DESCRIPTION OF CONCORDIA CODE

Physical Foundations

This code employs finite-difference method and the k-ε two-equation model of turbulence to obtain the approximate solution of governing equations for the three-dimensional turbulent flow in rectangular enclosures.

The governing equations can be written in a common form as follows:

$$\frac{\partial \rho \phi}{\partial t} + \frac{\partial}{\partial x_i} (\rho u_i \phi) = \frac{\partial}{\partial x_i} \left(\Gamma_{\phi, eff} \frac{\partial \phi}{\partial x_i} \right) + S_\phi \qquad (1)$$

where ϕ denotes the variables u_i, h, c, k, or ε. S_ϕ represents the source term for each of the variables.

At the region near a solid surface, where the viscosity effects become important, the wall function method is adopted to modify the k-ε two-equation model. The principle of the wall function method is using the momentum flux due to shear stress and the heat flux at solid surfaces to modify the source terms in the conservation equations for the grid nodes near the solid surfaces.

Numerical Procedure

(1) The boundaries of the control volume for h, C, k and ε are identical with the physical boundaries. For the velocity components u, v and w, the staggered control volumes are employed.

(2) The Hybrid scheme developed by Spalding (1972) is adopted, which is a combination of the central-difference scheme and the upwind scheme. The upwind scheme is also included in the numerical model as an option.

(3) In order to ensure the mass continuity at the door opening where the flow properties may change rapidly, an overall correction on the velocity component in the direction perpendicular to the partition (the x direction) is added. The overall correction term is derived from the mass continuity over the sections parallel to the partition, and can be expressed as

$$\Delta u = \frac{Q_{up} - Q}{\sum_{j} A_{x,j}} \qquad (2)$$

where Q represents the air volume flow rate across the section before velocity is overall-corrected; Q_{up} denotes the upstream flow rate; and A is the surface area of control volume perpendicular to the x direction.

(4) The SIMPLE algorithm (Patankar and Spalding, 1972) is employed to solve the finite-difference equations. SIMPLE stands for Semi-Implicit Method for Pressure Linked Equations.

(5) The false-time step and the Alternative Direction Implicit (ADI) iterative procedure with under-relaxation are employed.

(6) Convergence of the iteration process is pronounced when the total absolute value of residual sources in the continuity equation is small enough (less than 1% relative error) and when the variation in value of variables between two iterations is small enough (less than 0.1% relative error). The reason for choosing the residual source in continuity equation as a monitor is that the convergence of continuity equation in this study is slower than other variables.

CASE STUDY

The configuration used in computation for comparison is presented in Figure 1. A partition is fixed at the middle of the enclosure dividing it into two equal-sized zone. A ventilation supply opening is located on the western wall in zone A, and an exhaust opening is mounted on the ceiling in zone B. There is a contaminant source placed near the floor in zone A with an unity emission rate. Table 1 lists the dimensions and the locations of the openings of the door, supply, and exhaust.

The contaminant is removed by the ventilation air from zone A, passing through the door opening, and leaves through the exhaust opening in zone B. The air velocity at the supply opening is 1.0 m/s which provides a ventilation rate of 2.5 ach.

TABLE 1 The Dimensions and Locations of Opening

	door	supply	exhaust	source
dimension w/W	0.17	0.083	0.083	-
h/H	0.75	0.083	-	-
l/L	-	-	0.056	-
location x/L	0.5	0.0	0.75	0.25
y/W	0.83	0.13	0.875	0.46
z/H	-	0.042	1.0	0.46

The ceiling, floor and walls are considered to be well insulated, therefore an isothermal airflow could be assumed. The thickness of the partition is negligibly small in comparison with the length of the enclosure. Besides, it is assumed that the contaminant source is a point source, and its emission rate is negligibly small in comparison with the ventilation flow rate.

RESULTS

The velocity distributions at the door opening predicted by Concordia code and PHOENICS code is presented in Figure 2, while the velocity contours computed by Concordia code are demonstrated in Figure 3. The overall contaminant concentrations in zones A and B are shown in

Table 2.

From Figure 2 and table 2, it is seen that the agreement of both velocity distribution and average contaminant concentration in each zone computed by Concordia code and PHOENICS code is very good.

TABLE 2 Average contaminant concentration in each zone

	zone A	zone B
predicted from our program	10.212	9.929
predicted from PHOENICS code	10.023	9.588

COMPARISON WITH EXPERIMENTAL DATA FROM LYON UNIVERSITY

The two-zone enclosure used in experimental study has a dimension with LxWxH=6.3mx3.1mx2.5m. A partition is placed at the middle of the room length with a centrally located door opening (1.85m height and 0.77m width). There is a step of 0.08m height at the door opening (see Figure 4). The thickness of the partition is 0.07m.

The isothermal boundary conditions for walls, ceiling and floor are:

$T_W = 11.7^\circ C$ $\qquad$ $T_E = 17.93^\circ C$

$T_N = 17.32^\circ C$ $\qquad$ $T_S = 17.20^\circ C$

$T_T = 17.10^\circ C$ $\qquad$ $T_B = 16.71^\circ C$

Figure 5 shows the velocity distribution at the center of the door opening obtained by experimental measurement and numerical computation. Discrepancy is observed in the low region of the door opening. It is because that the 0.08m step on the floor of the door opening is neglected in our computation since it is too small to be considered in a uniform mesh system adopted. In the remaining part of the door opening, the predicted velocity distribution is in very good agreement with the experimental data.

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Spalding, D.B. 1972, "A novel Finite-difference Formulation for Differential Expression Involving Both First and Second Derivatives", Int. J. Num. Methods Eng., vol.4, p.551.

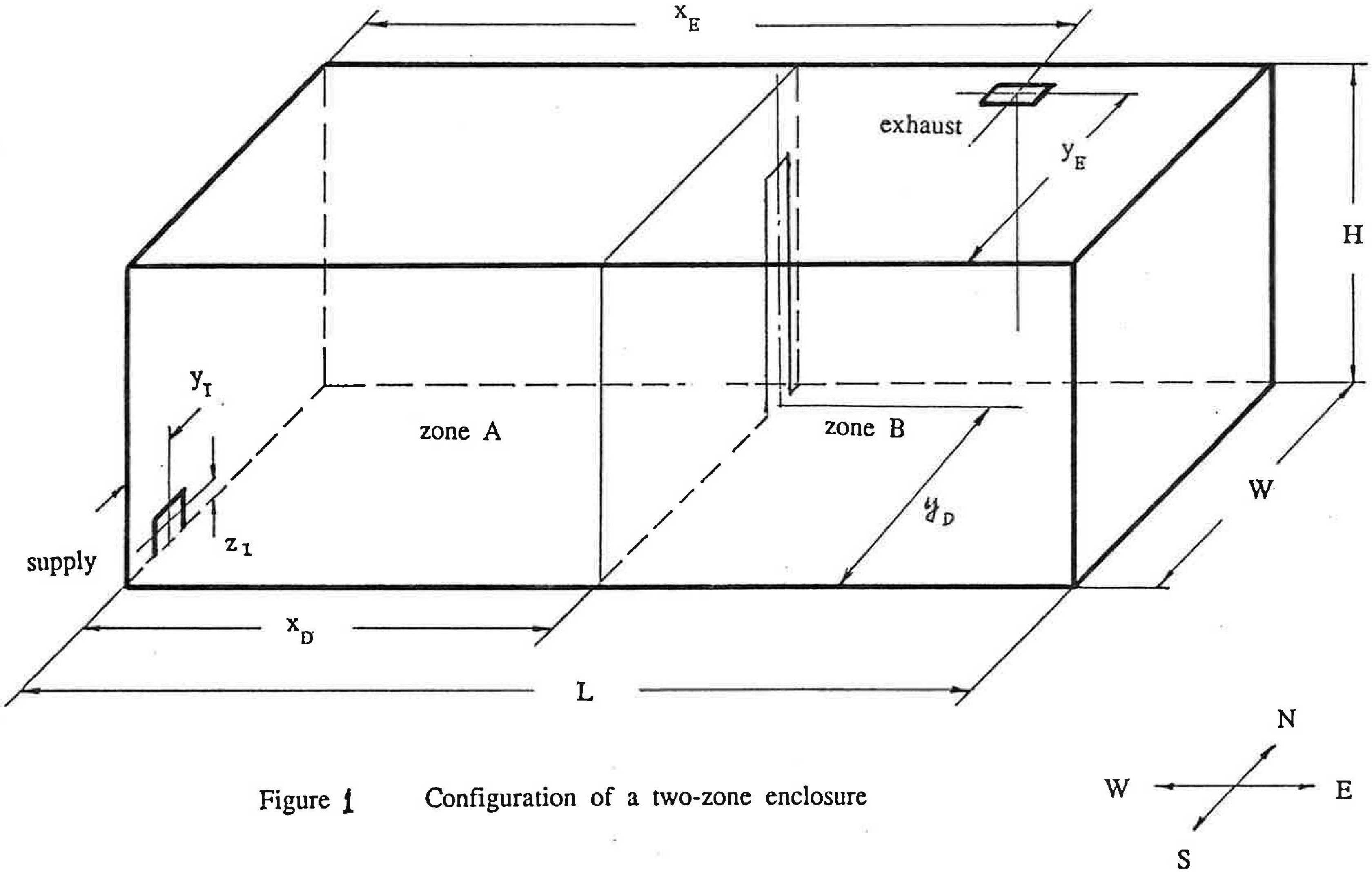


Figure 1 Configuration of a two-zone enclosure

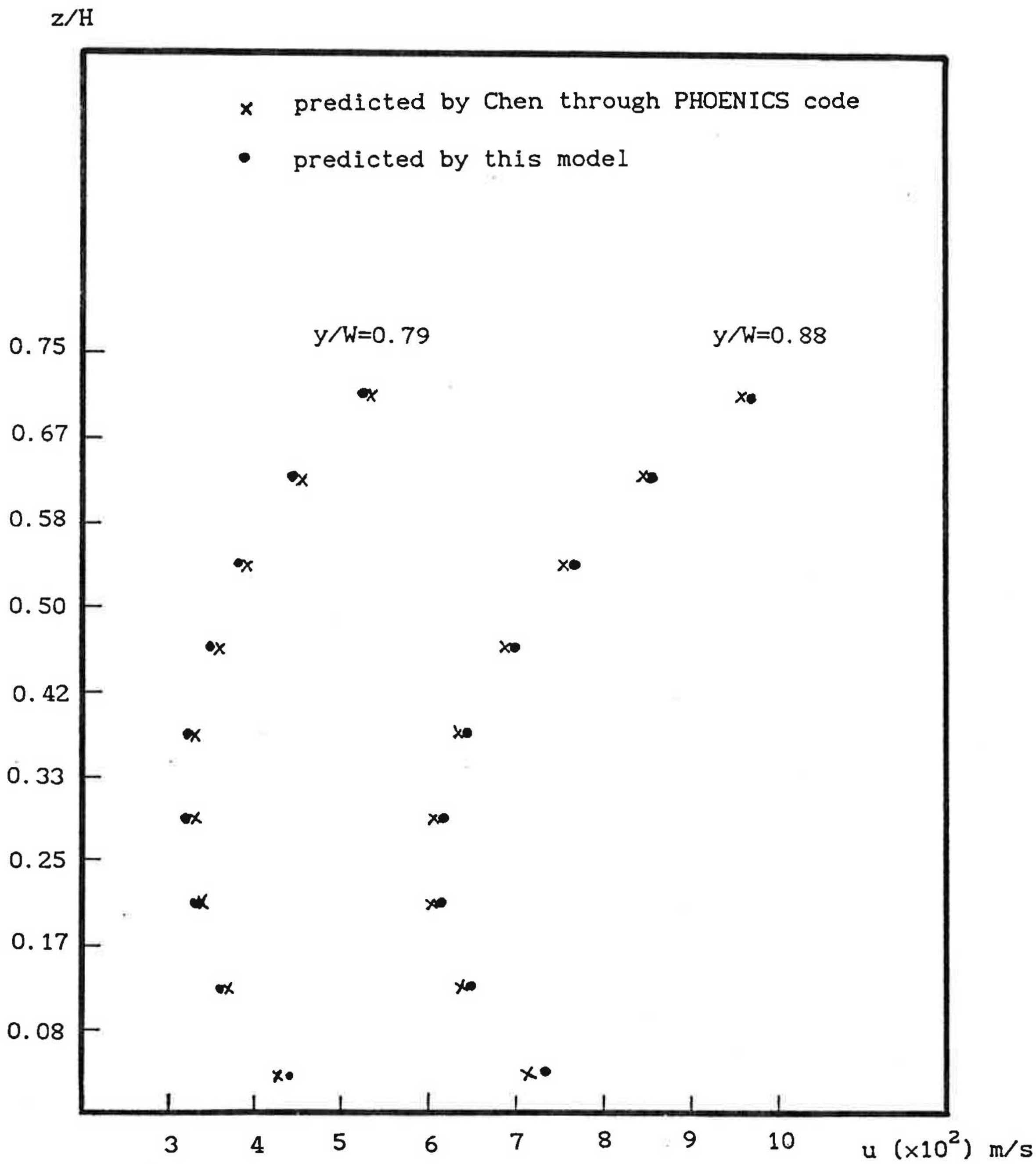
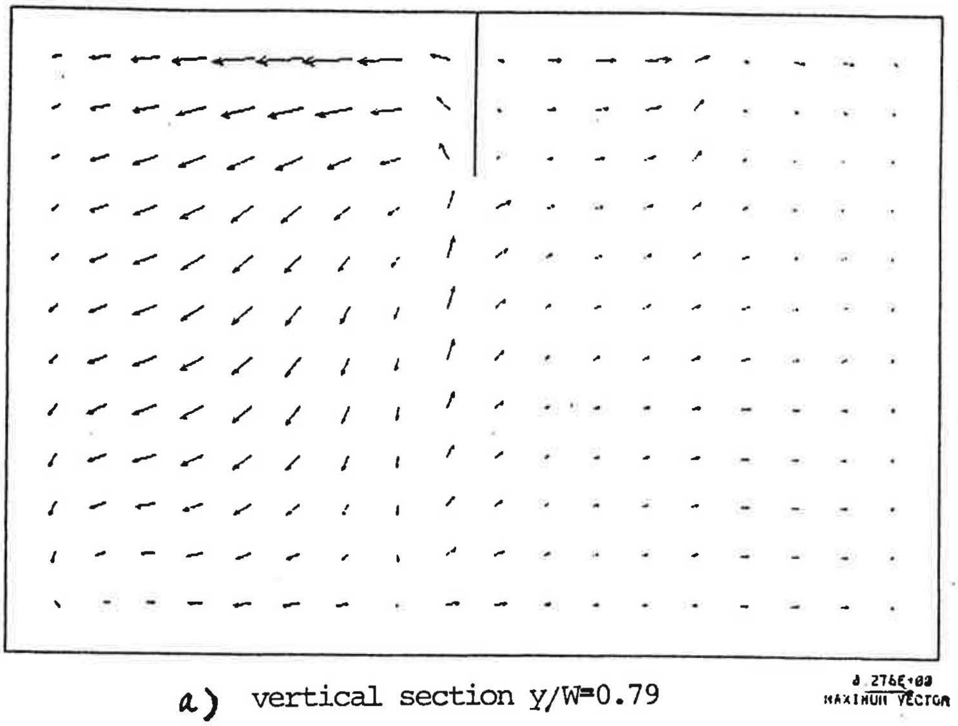
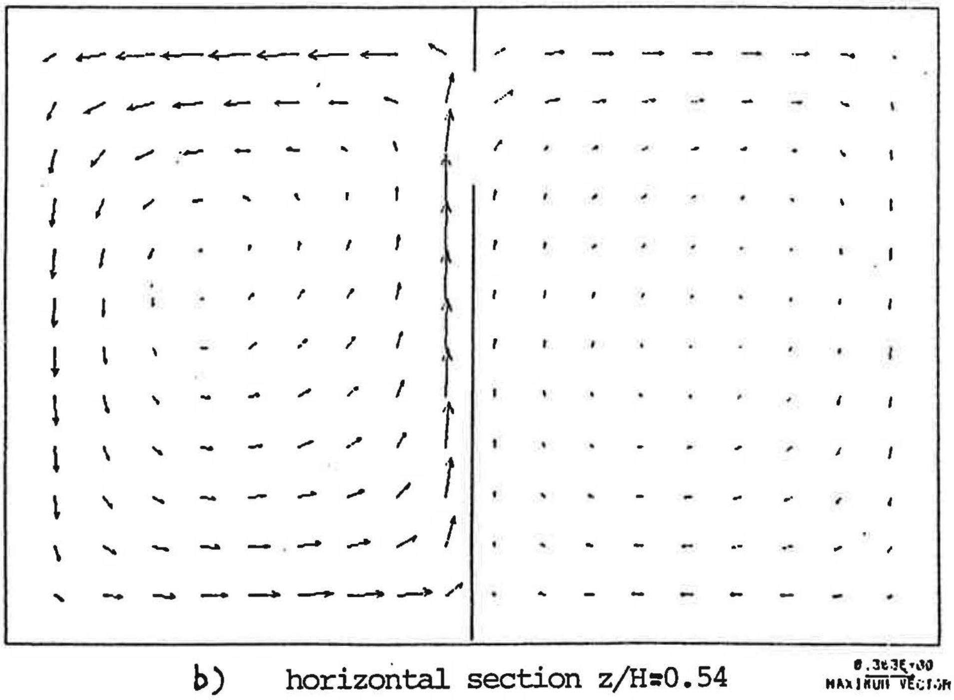


Fig. 2 Velocity distributions at door opening (x/L=0.5) in comparison with PHOENICS code



a) vertical section y/W=0.79



b) horizontal section z/H=0.54

Fig. 3 Airflow pattern predicted by Concordia code

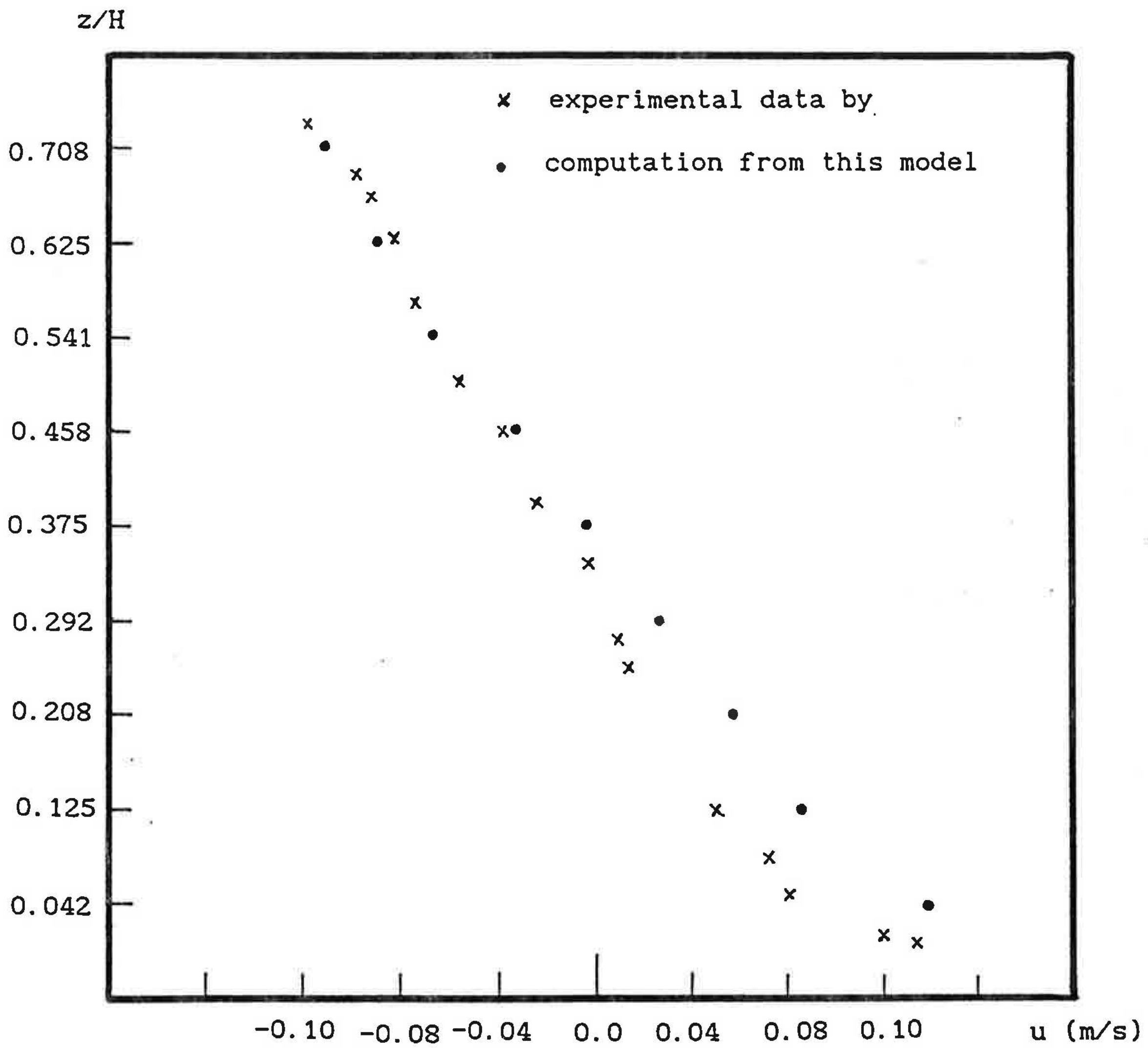


Fig. 5 Velocity distribution at the center of door opening in comparison with measurements