International Energy Agency
Energy Conservation in Building and Community Systems
Annex 20: Air Flow Patterns within Buildings
Subtask 1: Room Air and Contaminant Flow

RESEARCH ITEM 1.46

SIMULATION OF SIMPLE TEST CASES

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INTRODUCTION

As proposed in IEA Annex 20, a two-dimensional case, for which detailed experimental data are available, has been specified by Nielsen (1990) to test different CFD codes. This report presents the results computed by the PHOENICS-84 code (Rosten and Spalding, 1987) and the comparison between the computed and measured results.

SIMULATION METHOD

In the present study, the PHOENICS-84 has been employed to calculate air flow patterns. The computations involve the solution of two-dimensional equations for the conservation of mass, momentum (u, v), energy (H), contaminant concentration (C), turbulence energy (k), and the dissipation rate of turbulence energy (ε). The turbulence model used is the Lam-Bremhorst low-Reynolds-number k-ε model that has been implemented in the airflow program. The details concerning the model can be found in Chen (1990). This model has been verified to be more suitable for indoor airflow simulations, and a better agreement between computation and experiment has been found with respect to velocity and turbulence energy distributions and heat transfer through solid walls (Chen *et al.* 1990).

RESULTS AND DISCUSSIONS

The computations are carried out for two test cases: (1) an isothermal case and (2) a non-isothermal case as shown in Figure 1. The geometry of the test case is $L/H = 3.0$, $h/H = 0.056$, and $t/H = 0.16$, where $H = 3.0$ m. The inlet conditions are specified by a Reynolds number:

$$Re = \frac{h\, u_o}{\nu} = 5000$$

where kinematic viscosity ν for air is 15.3×10^{-6} m^2/s at 20°C. The inlet velocity can then be determined as

$$u_o = 0.455 \text{ m/s}$$

The inlet conditions for turbulent kinetic energy k and dissipation rate ε are given by:

$$k_o = 1.5\,(0.04\,u_o)^2$$

and

$$\varepsilon_o = k_o^{1.5}/(h/10)$$

For the non-isothermal case, the aim is to predict flow with strong buoyancy effect. A constant heat flux is added along the floor so that the cold jet may deflect from the ceiling before it reaches the end wall. The buoyancy effect is weighted by the Archimedes number defined as:

$$Ar = \frac{\beta\, g\, h\, \Delta T_o}{u_o^2}$$

where β, g and ΔT_o are volume expansion coefficient, gravitational acceleration and temperature difference between return and supply, respectively.

The results for the two test cases are presented in the following sections.

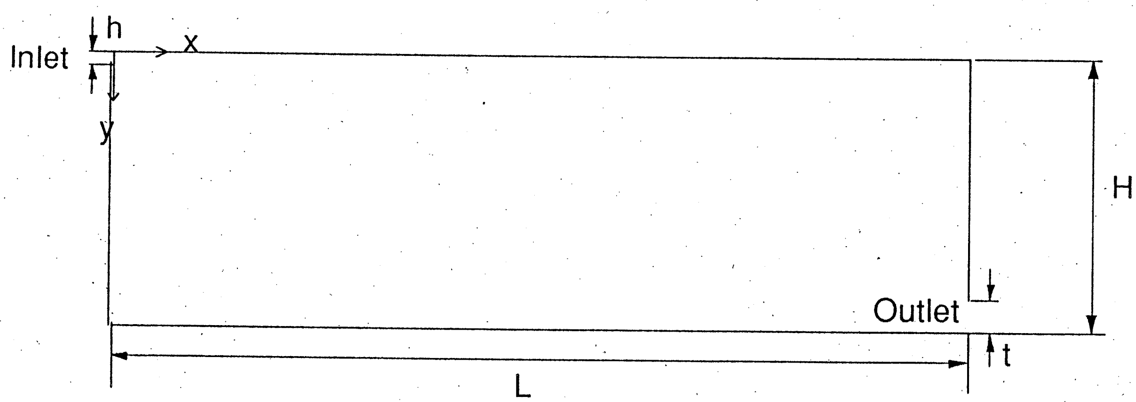

Figure 1. Sketch of the two-dimensional test case.

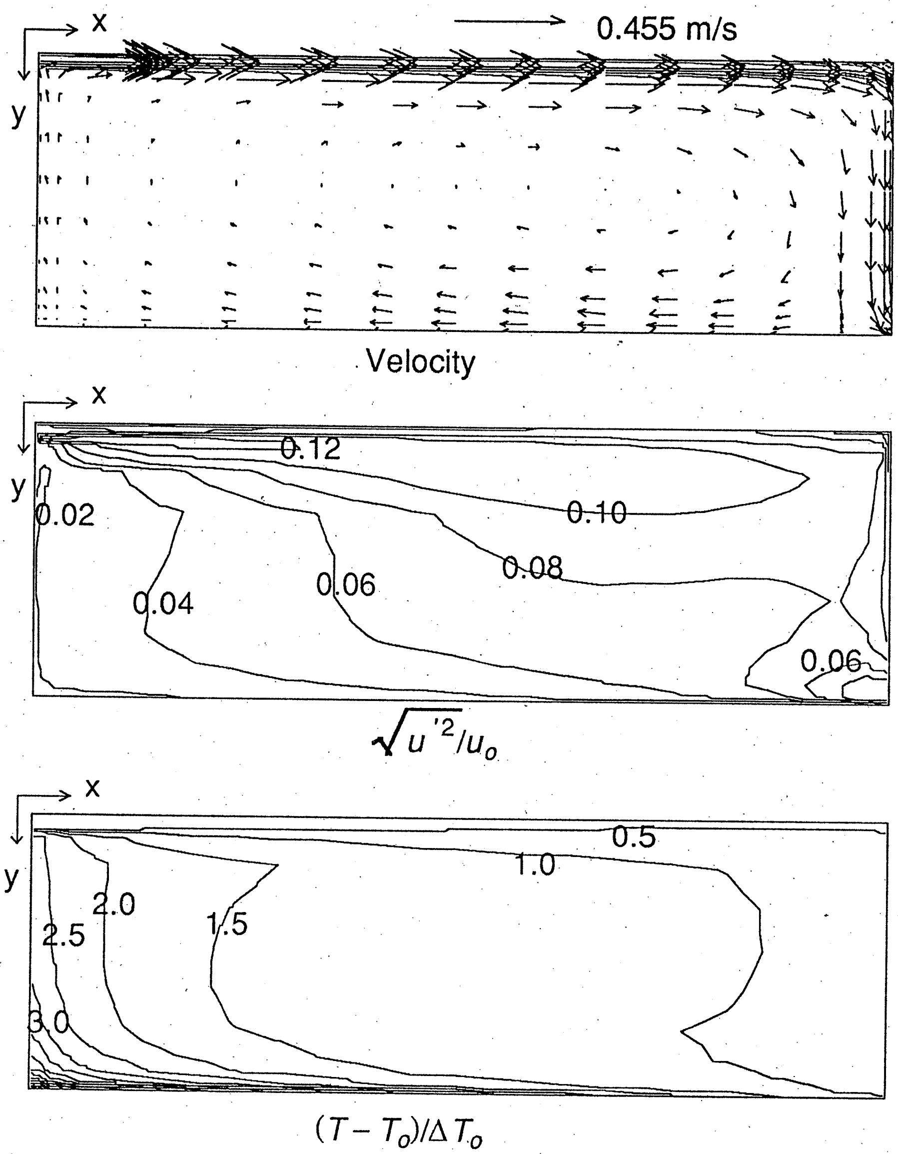

Figure 2. Field distributions of air velocity, turbulent intensity, and contaminant concentration (or temperature at a very small Archimedes number).

Isothermal Test Case

Figure 2 shows the field distributions of air velocity, turbulent intensity, and concentration of contaminant. The contaminant source is uniformly distributed on the floor. Symbol "T " stands for the concentration since it may be regarded as temperature distribution when Ar $\rightarrow$ 0. Then the experimental data with a very small Archimedes number can be used for comparison.

Figures 3 - 6 illustrate the comparison between the computed profiles of air velocity and turbulent intensity and the corresponding experimental data provided by Nielsen (1990). The data are those for the symmetry plane. The agreement is rather good. However, there are discrepancies. As indicated in Figure 5, there is a small counter flow near the end wall in the measurement which does not show in the computed results. The measured velocities in the lower part at section $x/H = 2.0$ seems too large to satisfy the overall continuity at the section (see Figure 4). This may be due to the three-dimensional effect in actual measurements.

The turbulent intensity in the computations are calculated from

$$\sqrt{k} = 1.1 \sqrt{u'^2}$$

This is based on the assumption that $v'^2 = 0.6u'^2$ and $w'^2 = 0.8u'^2$. Figure 6 shows that the numerical prediction gives a lower u' near the floor area. It may be partially attributed to the assumption which over estimates v'^2 and w'^2.

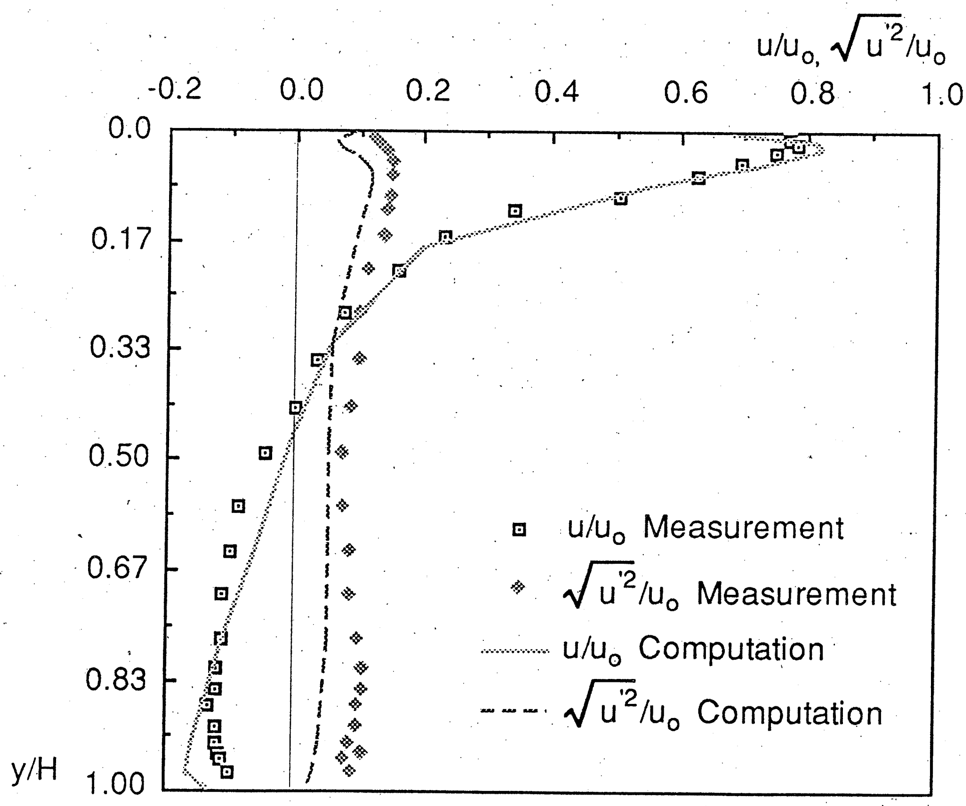

Figure 3. Comparison between the computed and measured mean velocity and turbulent intensity in section x/H = 1.0.

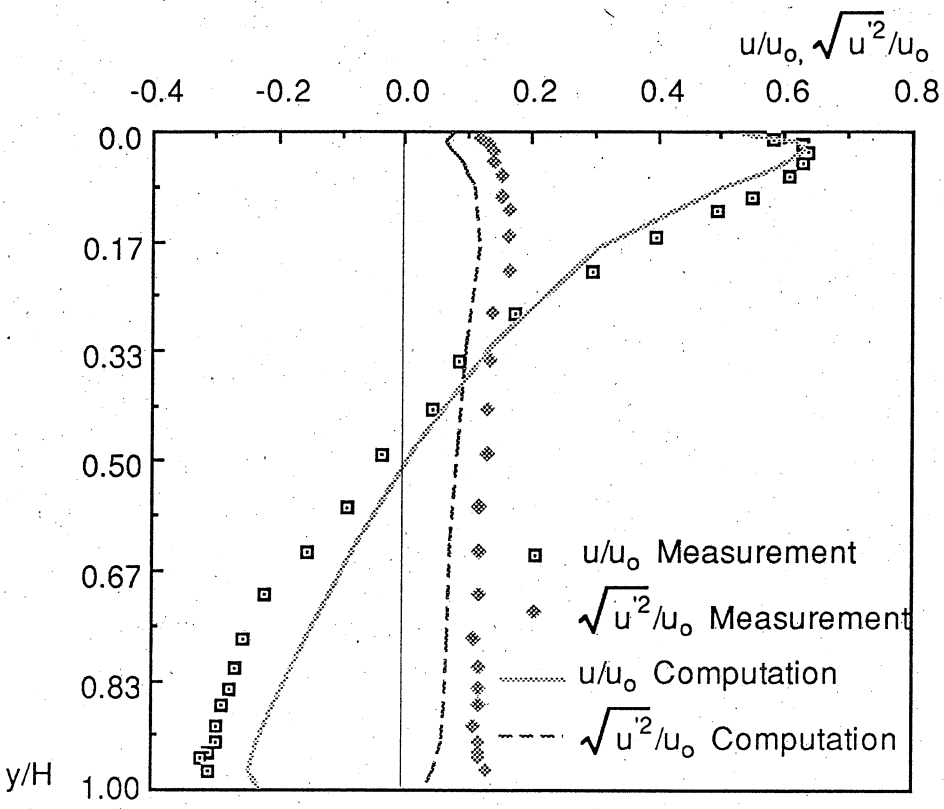

Figure 4. Comparison between the computed and measured mean velocity and turbulent intensity in section x/H = 2.0.

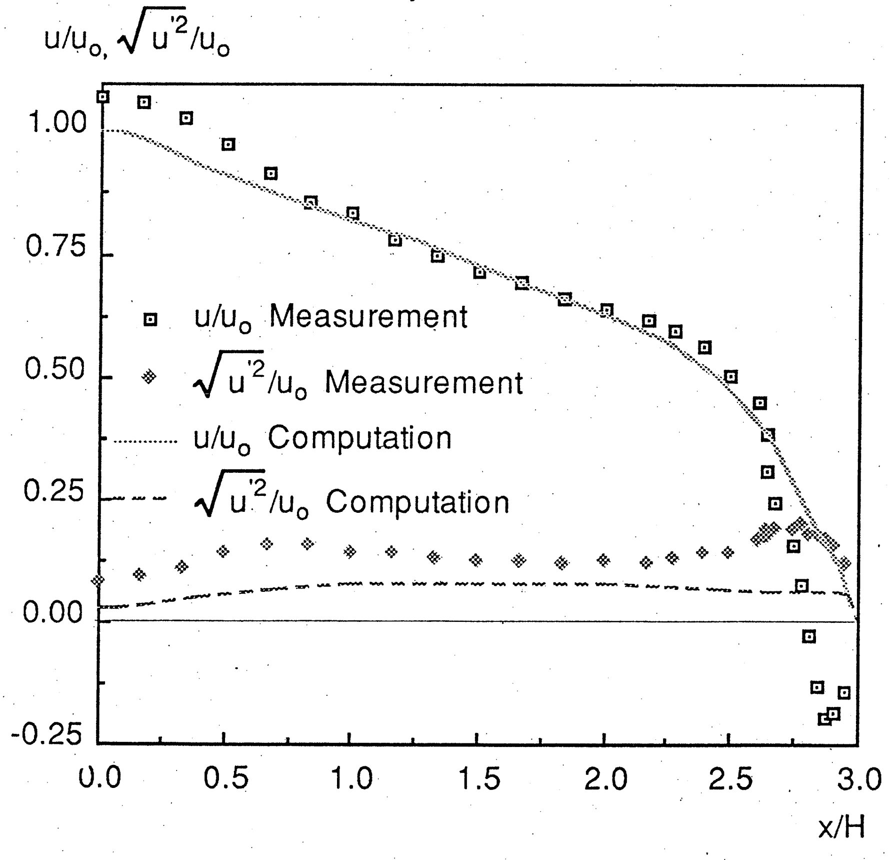

Figure 5. Comparison between the computed and measured mean velocity and turbulent intensity in section y = h/2.

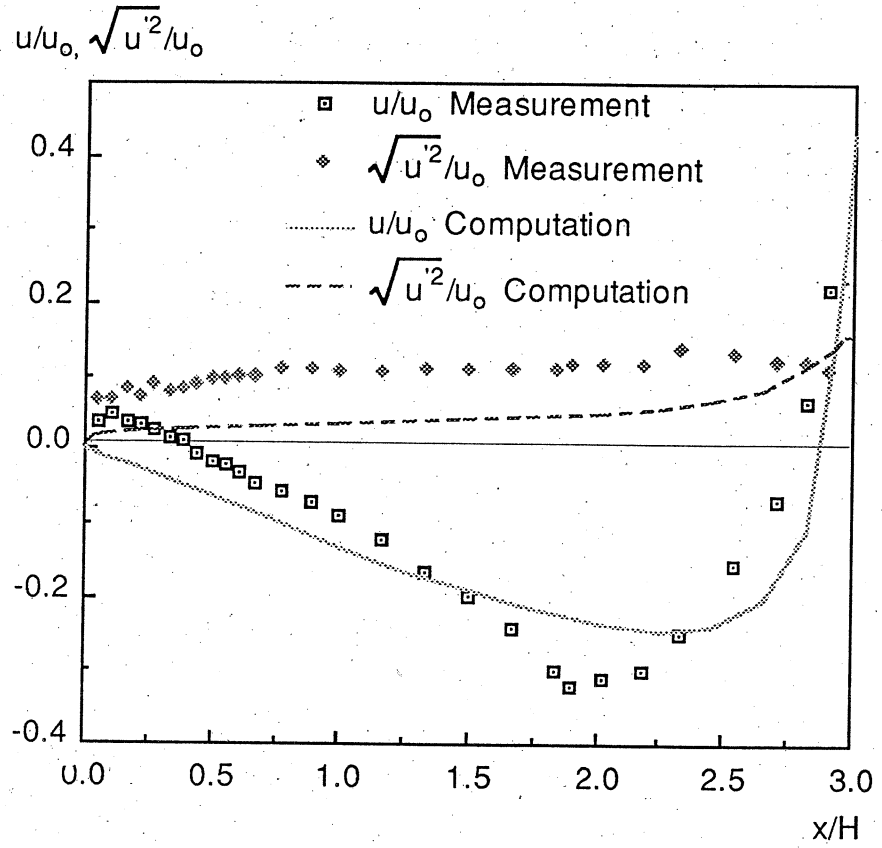

Figure 6. Comparison between the computed and measured mean velocity and turbulent intensity in section y = H-h/2.

Figure 7 illustrates the comparison between the computed and measured contaminant concentration (or temperature at very small Archimedes numbers) for the test case. The computed results are close to the measured ones. The small difference may be due to the difference in Reynolds numbers.

Non-isothermal Test Case

According to the suggestion by Nielsen (1990), the Archimedes number is increased until a reduced penetration depth takes place. All the computations are carried out with uniform initial conditions, i.e. zero values for air velocities and 20°C for air temperature. From Figures 8 and 9, the jet can still reach to the end wall when $Ar = 0.142$. It falls down immediately to the room when $Ar = 0.143$. There is no intermediate status. The turning Archimedes number ($Ar = 0.143$) is higher than measured by Schwenke ($Ar = 0.02$) (Nielsen 1990). We have noted that h/H and Reynolds number used in the experiment are different.

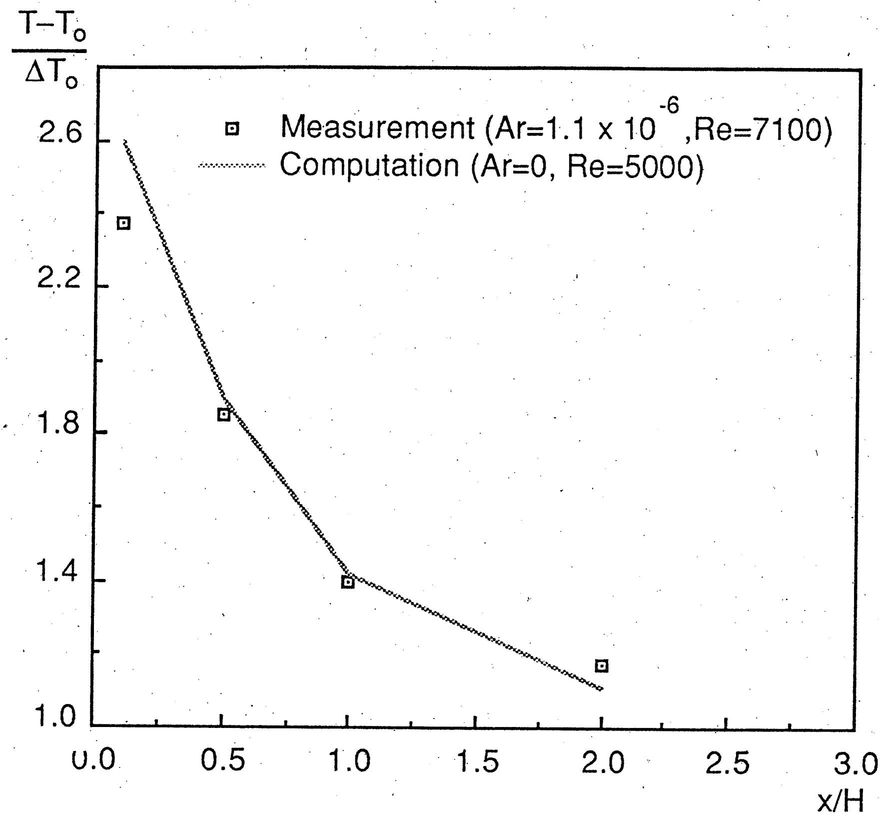

Figure 7: Comparison between the computed and measured contaminant concentration (or temperature) in section y/H = 0.75.

Borth (1990) recently has compared the computed results by PHOENICS-84 and the experimental data for the airflow in a full-scale room with natural convection (floor heating). The air velocities and turbulence intensities were measured by an LDA system. The agreement is very good. This seems to be in contradiction to the conclusions from the non-isothermal test case. Therefore, more detailed measurements for the non-isothermal test case are needed to extract solid conclusions.

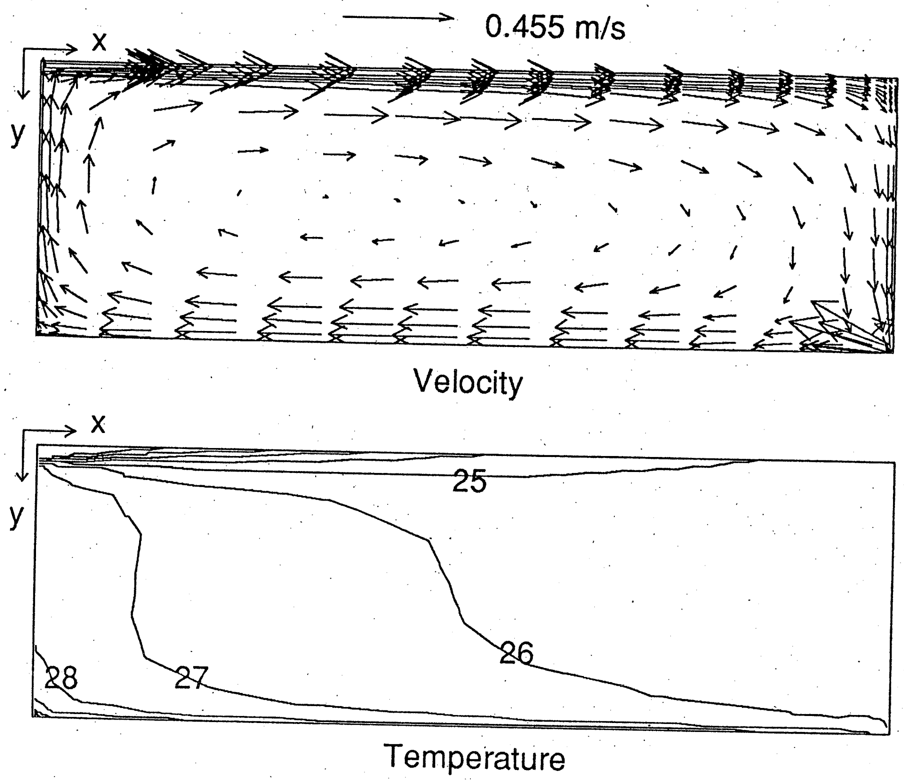

Figure 8. Velocity and temperature distributions when Ar = 0.142.

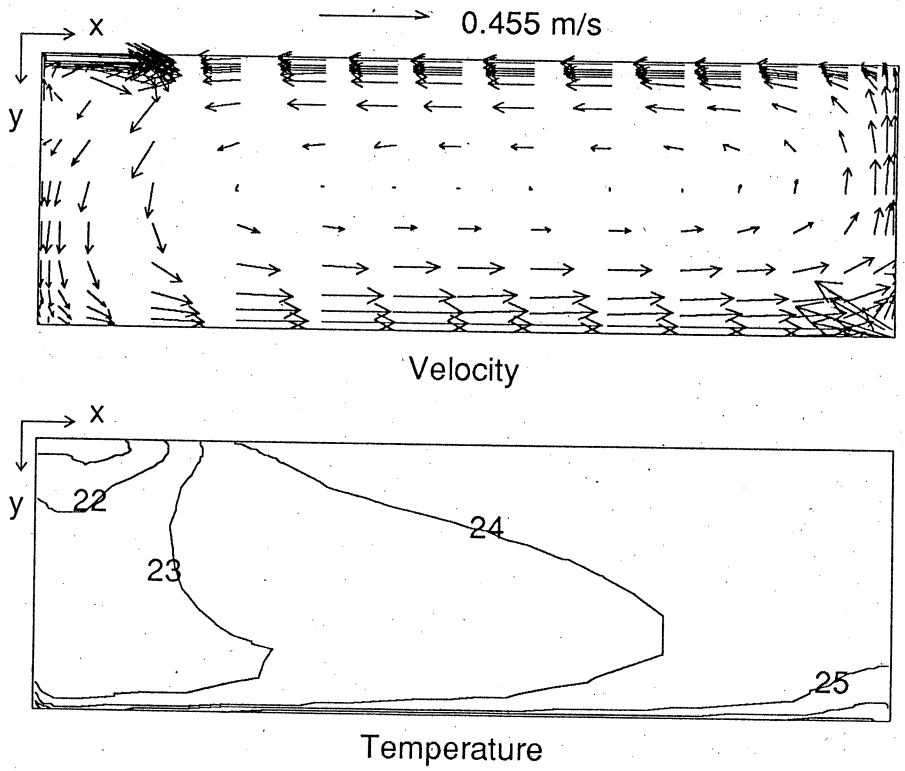

Figure 9. Velocity and temperature distributions when Ar = 0.143.

CONCLUSIONS

Following conclusions may be drawn from the present report:

- The computed velocity profiles for the two-dimensional test case are in good agreement with the available experimental data.

- The computed turbulent intensity is lower than the measured one. Probably the velocity fluctuations in *y* and *z* directions are over estimated.

- The computed and measured concentration distributions (or temperature distributions at a very small Archimedes number) are close.

- A cold supply jet deflects from the ceiling before it reaches the end wall when the computed Archimedes number is equal to 0.143 for Re = 5000 and $h/H = 0.056$. More detailed measurements are required for comparison.

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