PHYSIO-MATHEMATICAL MODELS FOR CALCULATING TEMPERATURE AND VELOCITY FIELDS IN VENTILATED AREAS

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INTRODUCTION

Velocity and temperature fields are formed as a result of the interaction between in-flowing air and convection flows, coming from different heated and cooled sources. That is why the circulation of air flows must generally be characterized as a very complex process.

When solving the engineering problems of ventilation units and systems, however, it is not always necessary to have a detailed description of the motion of air flows. In many cases it is quite sufficient to be sure that, at any point in the inhabited zone, the values of air velocity do exceed preset maximum limits. That is why, alongside the precise mathematical models, which determine the details of the motion of air flows in the space, there is a need for approximate models which provide a more general description of the air motion.

There can be several characteristic circulation zones in a space: stream development zones of air distribution units of ventilation systems; convection stream zones, etc.; and the zones of recirculation flows, ejected with these streams. Mathematical models for calculating the parameters of air flows can be divided into two groups. The first of these groups can be considered to consist of the models which use the Navier-Stokes equations for calculating air velocities in the space. These models are versatile and can be used for calculating air velocities throughout the space. However, they are labour-consuming, both from mathematical and from physical points of view, since their execution requires detailed information concerning turbulent characteristics of air flows, and this information must come from complicated experiments. Also, computations in which Navier-Stokes equations are used are very machine-time consuming. That is why they are only used when the models of the second group can not provide the required accuracy.

The second group includes the models in which the flows are joined by means of the "adhesion" method. The idea of the above mentioned method can be explained in the following way. The given space is divided into characteristics zones, e.g.: an in-flowing streams development zone; the zone of reversed flows, ejected with the streams; etc. The solutions, calculated for each zone, are "adhered" along the boundary of these zones, so that physical parameters could be maintained, e.g., the equality of velocities, temperatures, etc. The "adhesion" method can be applied when we know (at least approximately) the specific nature of the motion of air flows in the space in question.

In this paper the "adhesion" method is applied in the following way. To calculate the parameters of the air flows in a stream field, we used integral equations of the boundary layer, and the current in the reversed flow region is calculated as a potential one. The one-dimensional model is one of the variants of the method of "adhesion" of the currents. In a one-dimensional model, the current in the field of the reversed flow is calculated on the basis of one-dimensional equations of motion. The simplicity of this model makes it quite suitable for solving various engineering problems.

CALCULATION OF TEMPERATURE AND VELOCITY FIELDS IN THE AREA ON THE BASIS OF NAVIER-STOKES (REYNOLDS) EQUATIONS

On the basis of the solutions of Navier-Stokes equations we can calculate temperature and velocity fields throughout the space. Generally speaking, the system of equations is solved for the system including the equation of momentum change, the equation of conservation of mass, the equation of conservation of mass, and the equation of thermal energy change.

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The systems we are investigating are non-closed ones. Thus, additional empirical information is required to solve this problem. In addition to system equations, the equation of the change of turbulent kinetic energy and the equations of turbulent energy dissipation are also used.

At present, several programs, which can be used for calculating the parameters of air in ventilated areas, with the help of computers, are known. [1, 2, 3].

As an example of what has been stated above, in Fig. 1 you can see the calculation of air circulation in a "lengthy" space. The agreement between the calculations and an experiment carried out to investigate its accuracy is really very good. The calculation is a time-consuming one, however, and this makes it difficult to have the model widely applied in design practice.

THE METHOD OF "ADHESION" OF THE CURRENTS

While calculating the parameters of air flows, with the help of the method of "adhesion" of currents, we must separately calculate the field of stream currents and the field of the reversed flows that are ejected by those currents [4]. The method of "adhesion" of currents can be applied if we know the general pattern of the circulation of air flows in the area.

The author has used integral proportions of the boundary layer to work out the analytical model used for computing the parameters of stream currents.

The relationships for calculating axial temperatures and velocities of non-isothermal (both cold and heated) inclined streams, calculated on the basis of these equations, can be as assumed in reference [5].

In ventilated areas, temperature stratification exists beyond the limits of the streams.
This was taken into consideration, when we were writing the system of standard differential equations, based on the integral equations of the boundary layer. This system can be represented for both vertical, flat, non-isothermal streams and for vertical, axially-symmetric, non-isothermic streams.

The presence of temperature stratification in the space substantially changes the parameters of the stream, and must be appropriately modelled.

The calculation of the reversed flows, ejected by the streams, was carried out either on the basis of the equations of non-vortex motion or on the basis of one-dimensional motion.

In the first case, the Laplace equation is used for that purpose, as far as the velocity potential is concerned, and the thermal energy equation was developed. In the second case analyzed, the velocities in the reversed flow are assumed to be uniformly distributed along a certain chosen direction.

EXPERIMENTAL INVESTIGATION

Our experimental investigation was on a geometrically scaled-down model of a space with dimensions of 900 x 250 x 200 (H) overall. Electrically heated panels were mounted in the floor of the model. The air was supplied to the model through a flat nozzle, with a feed velocity of 1-2 m/s. We performed the visualization and the photographing of the air flow.

The results of the visualization of the air flow are summarized here.

Along the heated lower panel, a boudary-layer-type motion is developed. At the same time, indications of thermal instability appear near the surface, in the form of longitudinally non- stationary vortices, and "thermals" are torn away from them. These cause active turbulent blending of the flow outside the boundary layers. As a result, there are practically no vertical gradients of temperatures in this zone.

Using the three calculating methods discussed earlier, we calculated the velocities and temperatures for conditions corresponding to the experiment. Comparing the results of the calculations and our experiment, we can come to the following conclusions.

The physical nature of the motion can be fully and adequately described with the help of the calculations, based on Reynolds equations. However, the computing time (using an ES-1030 computer) was 4 hours. The calculations, based on the potential model, also adequately reflect the nature of the vertical shifts of temperature.

The quantitative agreement between the values of the temperatures calculated with the help of the model of the potential currents, and those measured during the experiment, can be considered satisfactory for the better part of the volume of the space. However, closer to the heated panel, within the limits of the boundary layer, the results of the calculations can be interpreted as a smoother change of the temperature than occured in the experiment (Fig. 2).

In Fig. 3, we have shown the temperature shift curves, measured along the heated panel, 45 and 95 mm away from it.

As we can see from these graphs, the values of average temperatures, calculated with the help of the one-dimensional model, are similar to those measured beyond the limits of the boundary layer. Within the field of the stream current, when there is a horizontal temperature gradient, that gradient must be taken into consideration while performing the calculations. The data, calculated without taking the temperature gradient into consideration, differs substantially from the experimental data.

GENERAL CONCLUSIONS

Mathematical models, based on the Navier-Stokes (Reynolds) equations, provide good agreement with observations, but they require a large amount of expensive machine time, so programs based on these equations are very expensive to run. For developing designs, one can use mathematical models based on the "adhesion" mode of flow. They provide adequate accuracy for that purpose, as our experiments have shown.

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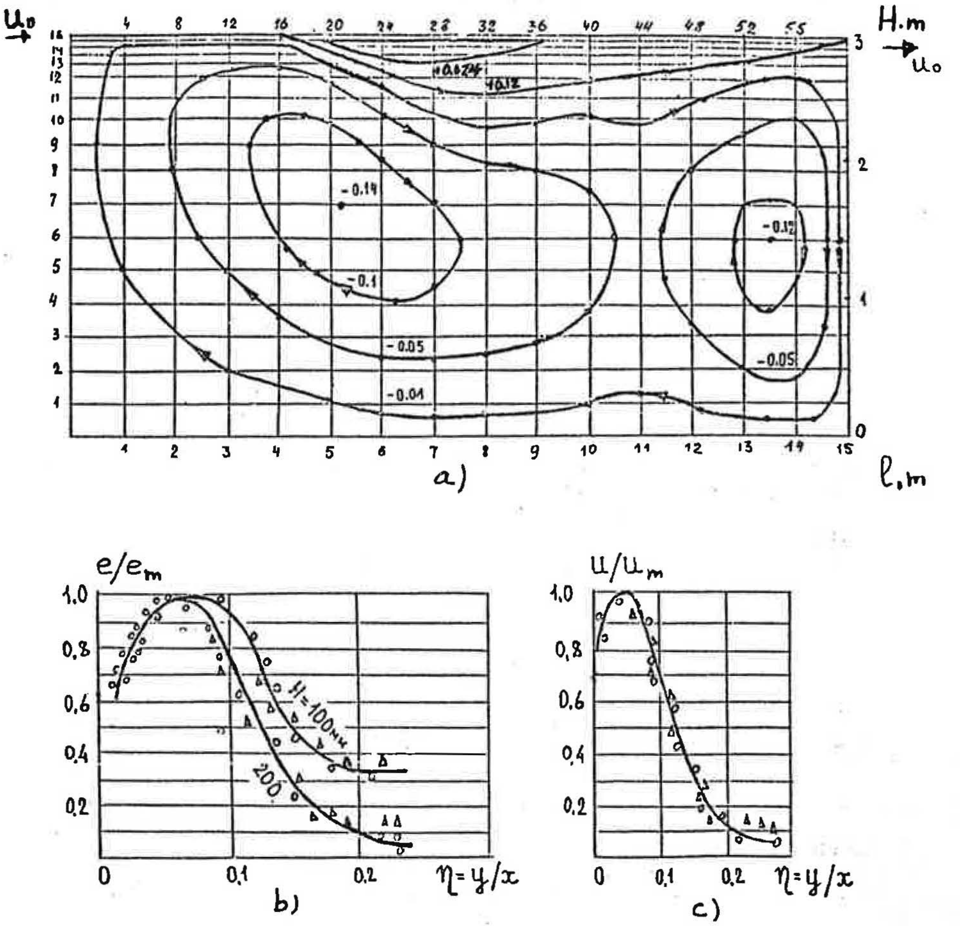
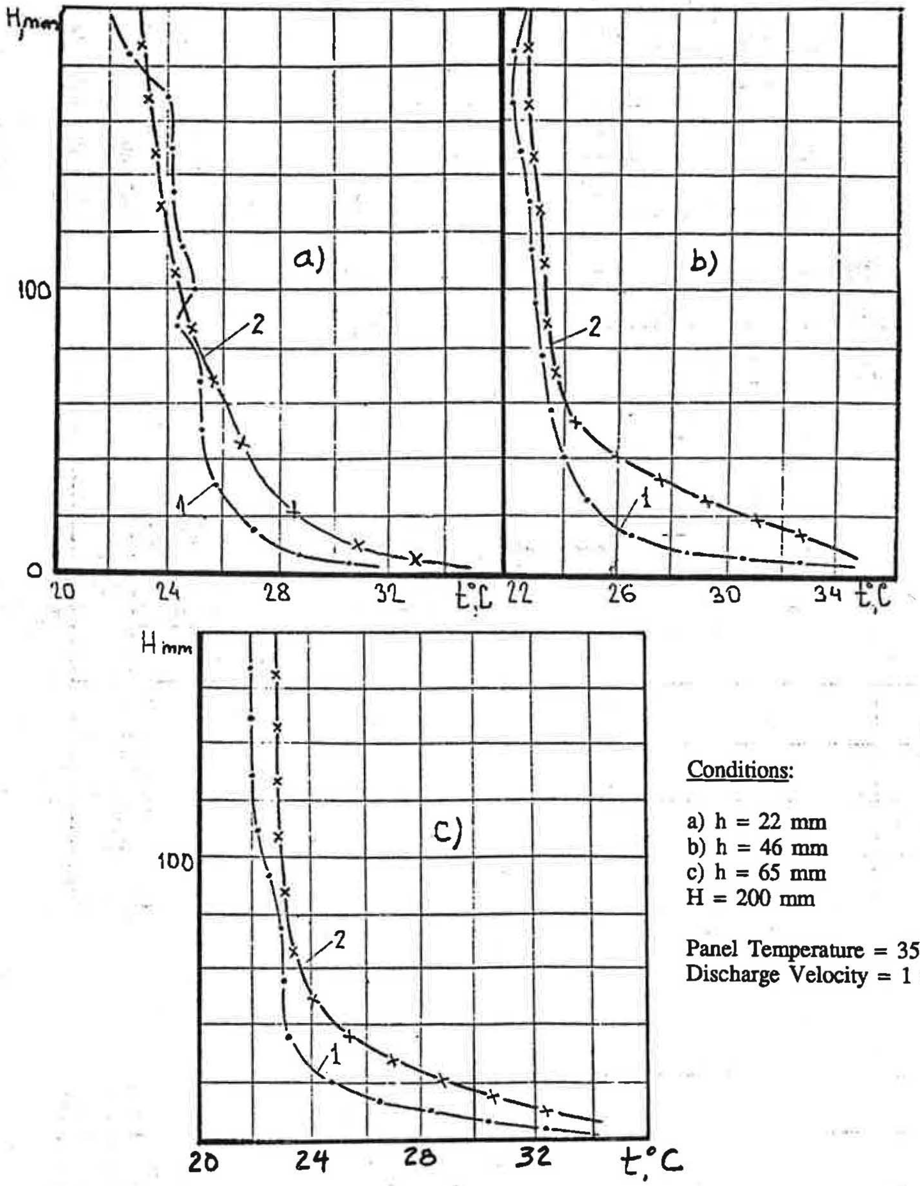


Codes:

a) Flow Velocities
b) Turbulent Kinetic Energy Profiles - near the wall
c) Turbulent Kinetic Energy Profiles - average velocities

Fig.1. Results of the calculation of air flow characteristics on the basis of Reynolds equation in a "lengthy" area



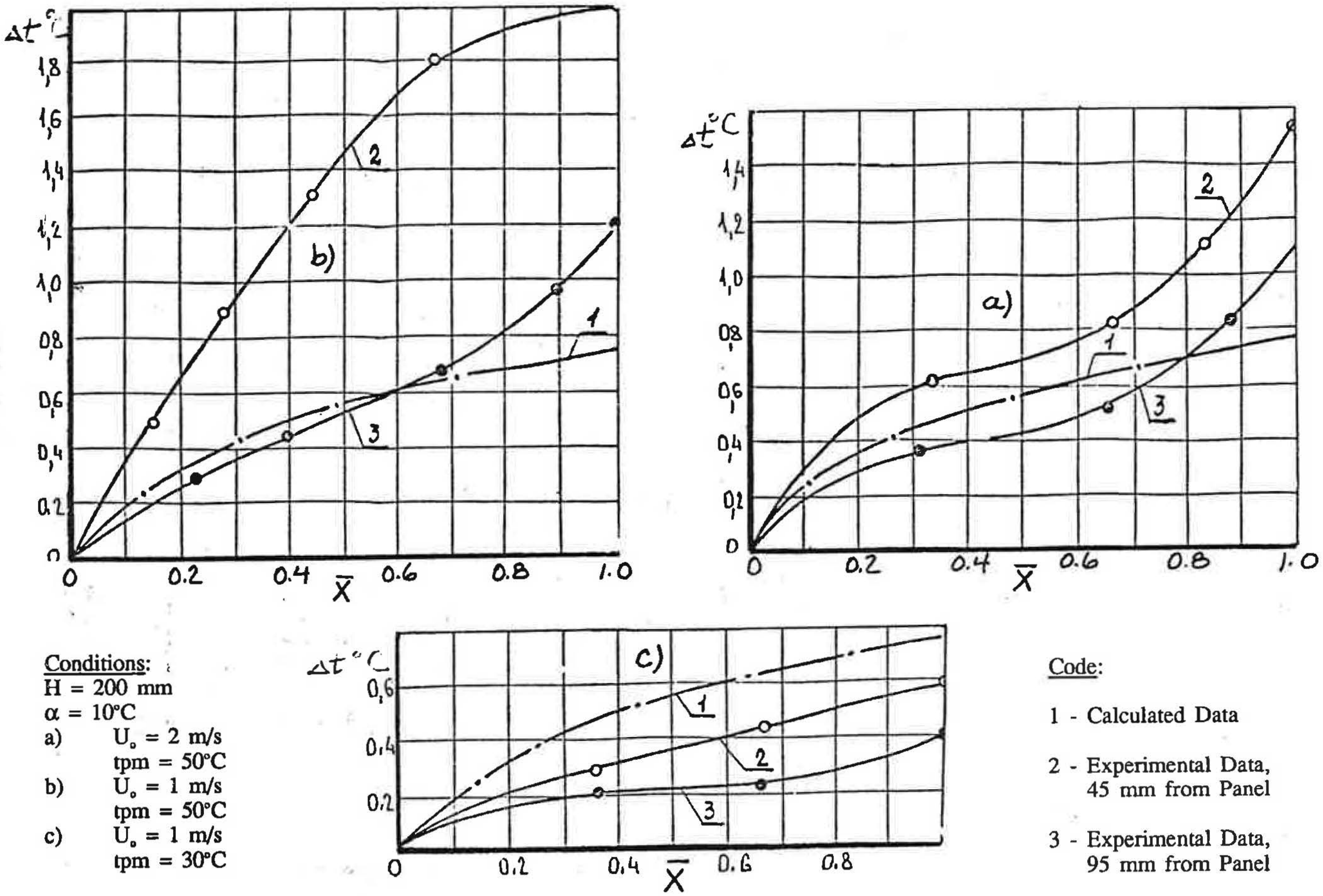
Conditions:

a) h = 22 mm
b) h = 46 mm
c) h = 65 mm
H = 200 mm

Panel Temperature = 35°C
Discharge Velocity = 1 m/s

1 - Experimental Data
2 - Potential Model Predictions

Fig.2. Changes in Air Temperature



Conditions:
H = 200 mm
α = 10°C
a) U_o = 2 m/s
tpm = 50°C
b) U_o = 1 m/s
tpm = 50°C
c) U_o = 1 m/s
tpm = 30°C

Code:

1 - Calculated Data

2 - Experimental Data, 45 mm from Panel

3 - Experimental Data, 95 mm from Panel

Fig.3. Comparison of Calculations of ID Model and Experiment