DYNAMIC ANALYSIS OF A REFRIGERATED ROOM

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ABSTRACT

The prediction of velocity and temperature distributions in a refrigerated room generally requires the simultâneous three-dimensional solution of the equations governing the flow pattern (Navier-Stokes equations for buoyant flows) and the energy equation.

This paper presents numerical predictions and experimental validation of the three-dimensional turbulent flow inside two different three-dimensional refrigeration chambers with forced convection.

The refrigerated rooms are a 26 m^3 living produce storage room and a 10 m^3 yogurt truck refrigerated chamber.

Agreement between measured and predicted values was very satisfactory for engineering purposes.

The model is very useful in chamber´s design since an important tool to predict food storage in order to allow energy savings.

KEYWORDS

Numerical simulation; Refrigerated room; Velocity distribution; Temperature distribution; Ventilation.

INTRODUCTION

In the past the design of refrigerated rooms and the choice of operating conditions has largely been arrived at by trial and error. In the last decades, however, the need of soaring costs of energy has developed a new performance and design concepts.

The model, providing an adequate design, contributes to energy savings decreasing the power needs to assure good conditioning and the correct conservation conditions all over the chamber. By using the same machine we can assure the project conditions to all goods since we can predict the ideal storage conditions.

Much can be learned from the careful instrumentation and monitoring of the daily operation of existing refrigerated rooms. Experimental data on refrigerated rooms are extremely scarce. However for the study of the aerodynamics of the rooms, some guidance may be sought from the air conditionning studies in domestic and office buildings. Experimental studies in this area may be grouped in reduced models usually isothermal (1), (2) and in rare occasions non isothermal real scale models (3), (4).

Decreasing costs allied to computer development made a place to numerical methods in this field of investigations.Two-dimensional calculations of the flow and heat transfer in a room have been presented by e.g. (5), (6) while (7) has performed similar studies in three-dimensional situations. Marshall and James (8) modelled a quick freezing tunnel.

GOVERNING EQUATIONS

The equations describing the steady, turbulent, bouyant three-dimensional flow in a refrigerated room can be written in a common form assuming that the eddy viscosity concept is valid for estimating the Reynolds stresses:

$$\frac{\partial}{\partial x}(\rho U \emptyset)+\frac{\partial}{\partial y}(\rho V \emptyset)+\frac{\partial}{\partial z}(\rho W \emptyset)-$$
$$-\frac{\partial}{\partial x}\left(\Gamma_{\emptyset eff}\frac{\partial \emptyset}{\partial x}\right)-\frac{\partial}{\partial y}\left(\Gamma_{\emptyset eff}\frac{\partial \emptyset}{\partial y}\right)-\frac{\partial}{\partial z}\left(\Gamma_{\emptyset eff}\frac{\partial \emptyset}{\partial z}\right)=S_{\emptyset}$$

where $\emptyset$ = the dependent variable (=1 for the continuity, U,V,W,T for momentum and energy equations); $\Gamma_{\emptyset}$ = diffusion coefficient and $S_{\emptyset}$ = source term.

The characteristics of turbulence k & ε are calculated through the k-ε turbulence model (9)

The conservative finite volume method was used to discretize the flow and the turbulence model equations (10). The solution algoritm was embodied in the TEACH programme for three-dimensional recirculating flows (11). The convection terms were discretised by the hybrid central/upwind method (12).

DESCRIPTION OF THE RESEARCH CASES

Case 1: Forced convection living produce storage room

The research storage room (13) consists of a 3,6*2,6*2,7 m. The air flows into the room through two sides of convection box and leaves the room in the vertical direction through a circular hole in the center of the box (Figure 1).

The velocity componentes were measured using a hot wire anemometer and the sign of the velocity component was verified through the use of a turbinemeter anemometer. Measurements were carried out in a mesh at several y constant planes of the room.

A numerical grid of 37*25*27 grid nodes was used. Convergence was achieved when the normalized residuals for the three momentum equations and mass conservation were less than $5*10^{-3}$. This was achived after 600 iterations, that corresponds to 30 CPU hours in a VAX 8700.

Figure 1a) shows the calculated velocity field in vertical planes (z = constante). The figure clearly indicates the strong inflow through the opening in the one side of the convection box driving the flow inside the room. Figure 1b) shows the calculated velocity field in horizontal planes. The air spreading due to the supply in the room is clearly showed in all the planes while the suction effect of the outlet can be seen in the plane y = 2.4 m. The predictions were validated against experimental data acquired in the room. The discrepancy between predictions and measurements is considered satisfactory for engineering purposes.

Case 2: Forced convection yogurt truck refrigerated chamber

The chamber (14) presented in Figure 2 consists of a 1.8*1.5*3.4 m . The air flows into the room through a square hole of a convection box and leaves the chamber in the vertical direction through a square hole in the center of the box.

The code was applied to calculate the non-isothermal flow in a full scale forced convection yogurt truck chamber above stated. A numerical grid of 15*13*21 nodes was used with a concentration of points near the walls. The inlet velocity was imposed and the outlet velocity was given a value determined from overall continuity. The computations were performed in a IBMRT-PC and the convergence was achieved after 18 CPU hours.

The numerical results of velocity and temperature fields can be visualized at figures 2a) and 2b), respectively. The velocity field allows to know the flow patterns and the vortices formation. The temperature contours indicate the temperature remains high near the ceilling in the two sides of the convection box, which suggest an improvement to obtain a low uniform temperature.

CONCLUSIONS

A three-dimensional turbulent computer model for the simulation of the aerodynamics and heat transfer of forced convection refrigerated rooms is presented in this paper. The model was applied to two cases: a 26 m^3 living produce room and a 10 m^3 yogurt storage truck.

According to the results of the simulation and experiment, conclusions can be drawn:

a) Predictions of the fluid motion inside the rooms are useful tools in order to get a better storage of food products allowing energy savings without decreasing food quality.

b) The complicated air flow in a refrigerated room can be solved, although it needs a lot of computation time.

c) Agreement between measured and predicted values was very satisfactory for engineering purposes.

d) Because of the lower costs, the code for refrigerated rooms mentioned before can be conveniently used in practice.

e) Improvements or developments of new designs of refrigerated rooms can be supported by numerical prediction procedures that allow the fluid motion inside the room to be numerically predicted.

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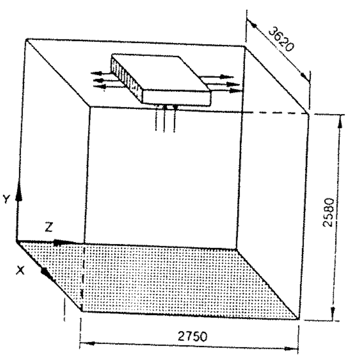

Fig. 1 - Sketch of the geometry of the experimental storage room (case 1)

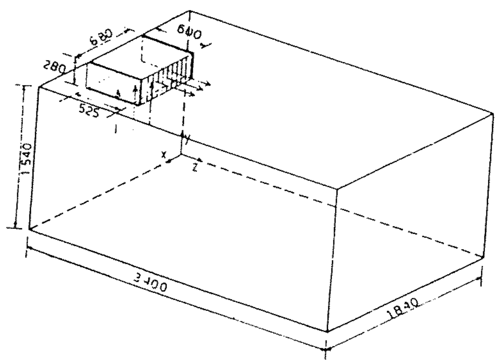

Fig. 2 - Schematic diagram of the experimental yogurt truck refrigerated chamber (case 2)

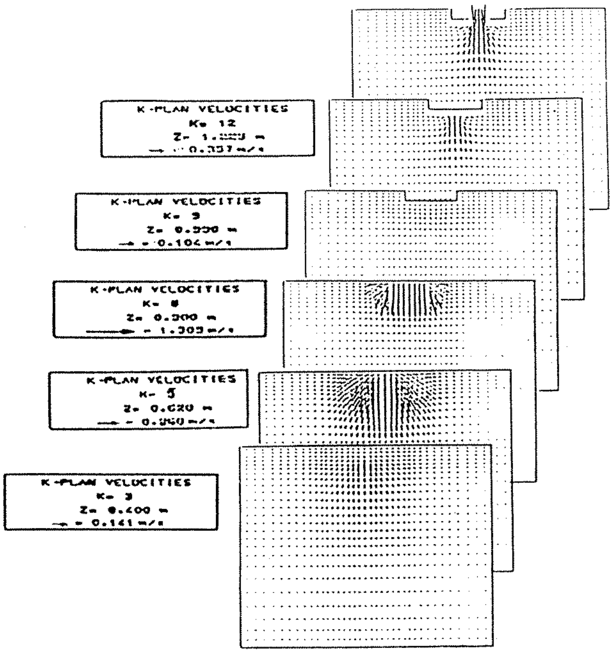

Fig. 1a) - Calculated velocity field in vertical planes (case 1)

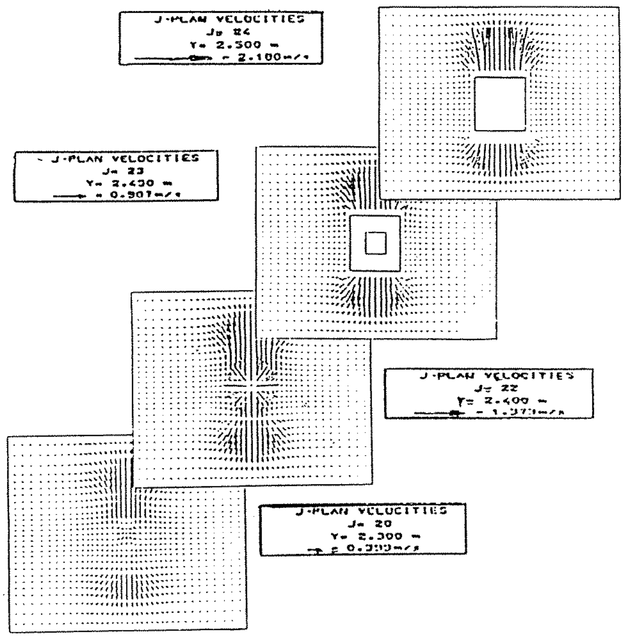

Fig. 1b) - Calculated velocity field in horizontal planes (case 1)

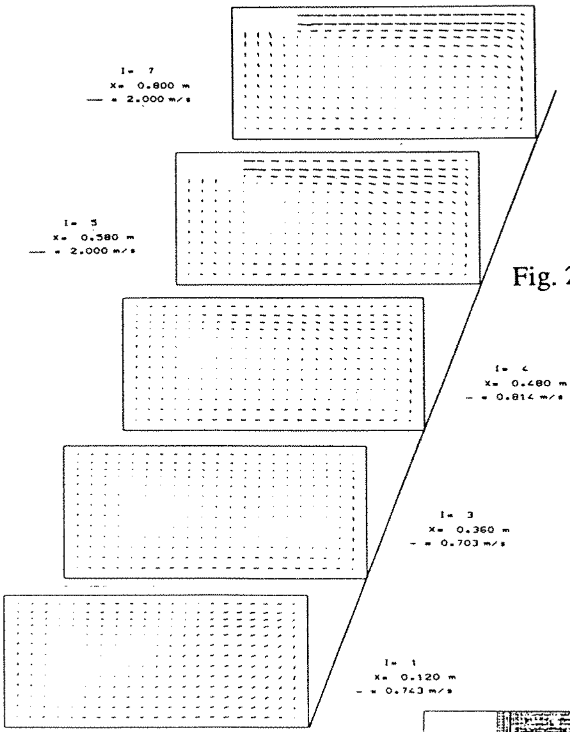

Fig. 2a) - Calculated velocity field in vertical planes (case 2)

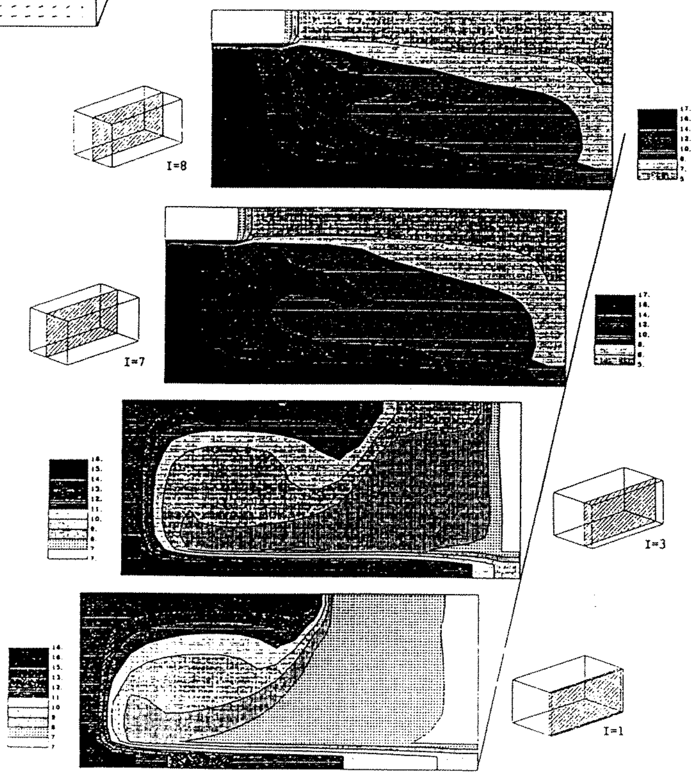

Fig. 2b) - Calculated temperature distribution in vertical planes (case 2)

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