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A Type of Dynamic Calculation of Indoor Temperature Distributions

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Abstract

The requirements to know indoor thermal comfort ask for a more detailed study of room temperature responses. Although CFD (Computational Fluid Dynamics) techniques can be applied successfully to the prediction of indoor temperature distributions, using them for the dynamic calculation of temperatures and air flows is still a very expensive expenditure. For indoor climate control systems, it is necessary to make quick calculations of the dynamic temperature distributions in a room. To compromise, we are trying to use a limited number of fixed air flow patterns to perform the dynamic calculations. Some of our initial study results are presented in this paper. For a typical heating situation, the dynamic indoor temperature distributions can be calculated satisfactorily with only one fixed air flow pattern. Further study indicates that when the heating power has changed, this flow pattern can be used once again for the dynamic calculations of air temperature responses.

1. Introduction

In recent years, there is an ever increasing concern with the indoor thermal comfort, in addition to building energy consumption, among HVAC specialists. This concern motivates people to take investigations on indoor temperature distributions and air flow patterns. It also makes the so-called "*one-point model*", in which a homogeneous indoor air temperature distribution is assumed, no longer sufficient. These investigations are especially necessary in the study of control systems of passive indoor climate buildings where natural ventilation is used as a cooling source and the sensation of draught is potentially possible if the window openings are not controlled properly.

As an alternative to experiment, the CFD (Computational Fluid Dynamics) theory supplies us a method of studying the indoor temperature distributions, air flow patterns and thermal comfort. With the help of CFD codes, a lot of valuable results and important conclusions have been obtained. Nonetheless, since the energy, mass and especially momentum balance equations of thousands of grid points need to be solved iteratively, and the iterations have to be continued adequately until all dependent variables converge to some satisfactory extent, the CFD calculation takes so much computing time that it is only suitable for some steady state calculations. The use of CFD codes to study the dynamic temperature distributions and the dynamic air flow patterns can be quite costly due to the limited computing power of the presently widely available computers, such as 486 computers, work stations, or even faster computers. Although in the future the development of computer technology will eventually make the fast dynamic CFD calculation possible, at present we have to find out some trade-off methods concerning the dynamic calculation of room temperature distributions which is essential in the study of indoor climate control systems.

2. The Dynamic Calculation of Indoor Temperature Distributions

For a typical type of heating or cooling situation, although the indoor air flow pattern may vary with time because of the existence of turbulence, the prevailing air flow pattern which has dominant effects on air temperature distributions and the sensation of draught almost does not change. In reality there are only a number of typical heating and cooling situations and thus a number of typical air flow patterns for a specific building room of our concern. These air flow patterns and the corresponding air velocity datafiles can be precalculated with the CFD code.

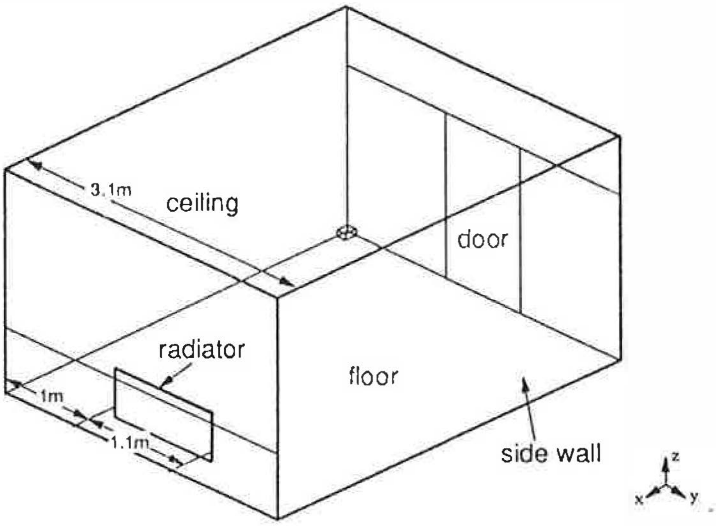

Figure 1. Configuration of the Test Room

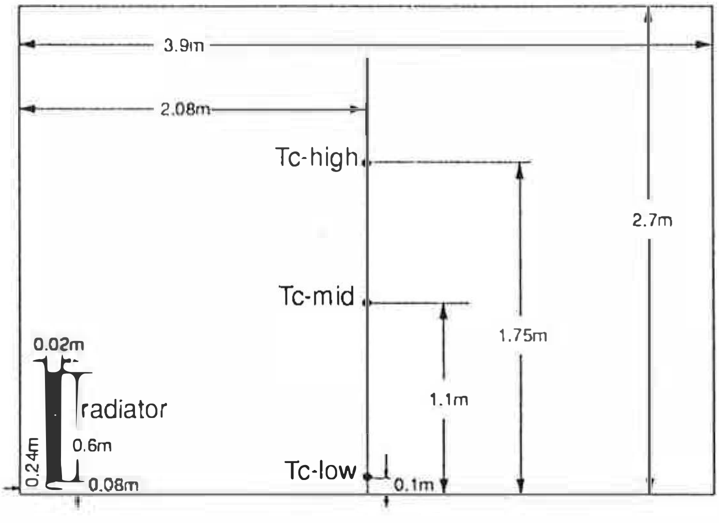

Figure 2. Configuration of the Test Room and arrangement of thermal couples

By using exactly the same grids of the CFD calculation and the precalculated air velocity datafile, and by solving the heat balance equations of all grid cells, the dynamic indoor temperature distributions can be calculated.

Our calculations and experiments are based on a full scale test room. The configuration of the test room and the arrangement of some thermal couples are shown in figure 1 and 2. The facade (window side) is south facing, with a movable insulating shutter mounted in front it. The door is on the rear wall (north facing). An electric radiator is placed near the window side. The power input to the radiator can be changed within the range of 0-1750 watts. The temperature of each side of a wall (or window) and the radiator is measured with a thermal couple. The indoor air temperatures are sampled at 9 different places. Figure 2 shows three of them (Tc-low, Tc-middle and Tc-high) at three altitudes at which the human body is most sensitive to local thermal comfort.

A measurement was carried out in the test room with the window, door and insulating shutter completely closed on 25 October 1993. The measurement was first continued for 20 minutes without heat input. Then the radiator was switched on with the step input power of 525 watts. The measurement lasted for 6 hours. Figure 5 shows the temperature responses of the three thermal couples in figure 2 (Meas-Low, Meas-Mid and Meas-High). The temperature responses of all walls were also obtained at the same time. Using the end values of the wall and radiator responses as the boundary conditions we performed the CFD calculations to get the air flow pattern and velocity datafile. The k-ε turbulence model was used in the CFD calculations. Parts of the air flow pattern and the corresponding air velocity distributions are shown in figure 3 and 4.

Now we suppose the air flow pattern, air velocities and effective exchange coefficients were constant during the process of measurement. Since the above calculated variables have guaranteed the mass and momentum conservation of every grid cell, we can calculate the dynamic air temperature responses of all grid cells with them.

The differential equation describing the heat balance of a grid cell of unit volume is (S.V. Patankar):

$$\frac{\partial \rho h}{\partial t} + div(\rho v h - \Gamma_{h,eff}\, grad h) = S_h \tag{1}$$

where :

t = time;

ρ = density of air;

h = enthalpy of air; $h = c_p T$, c_p is the specific heat of air, T is air temperature;

v = velocity vector;

$\Gamma_{h,eff}$ = effective exchange coefficients;

S_h = the source rate of h;

Discretizing the above equation and using the computational method introduced by D.B. Spalding and S.V. Patankar to solve the equations of all grid cells, we obtained the dynamic indoor temperature responses (Cal-Low, Cal-Mid and Cal-High in figure 5). From figure 5 we see that our calculations are in good agreement with the measurements.

To validate our calculation method, the second measurement was made on 7 June, 1994 from 10:35 through 16:35 (Meas-Low, Meas-Mid and Meas-High in figure 6) with different power input (350 W) to the radiator. Then using the above air flow pattern, the velocity datafile and the newly measured boundary conditions, we calculated the dynamic air temperature responses again. Figure 6 shows that a good agreement between the calculations and measurements have been got once again.

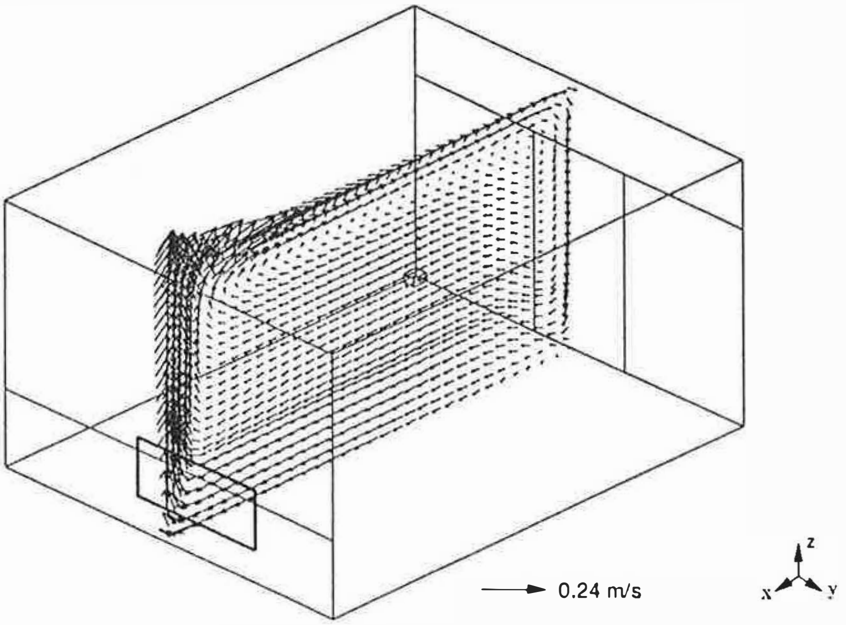

Figure 3. A Part of the Air Flow Pattern on the y Cross-section

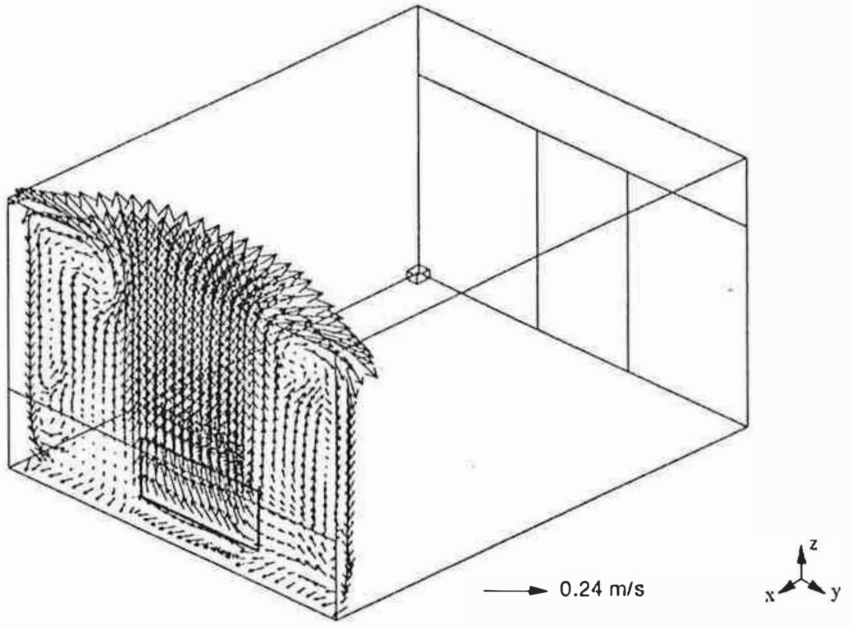

Figure 4. A Part of the Air Flow Pattern on the x Cross-section

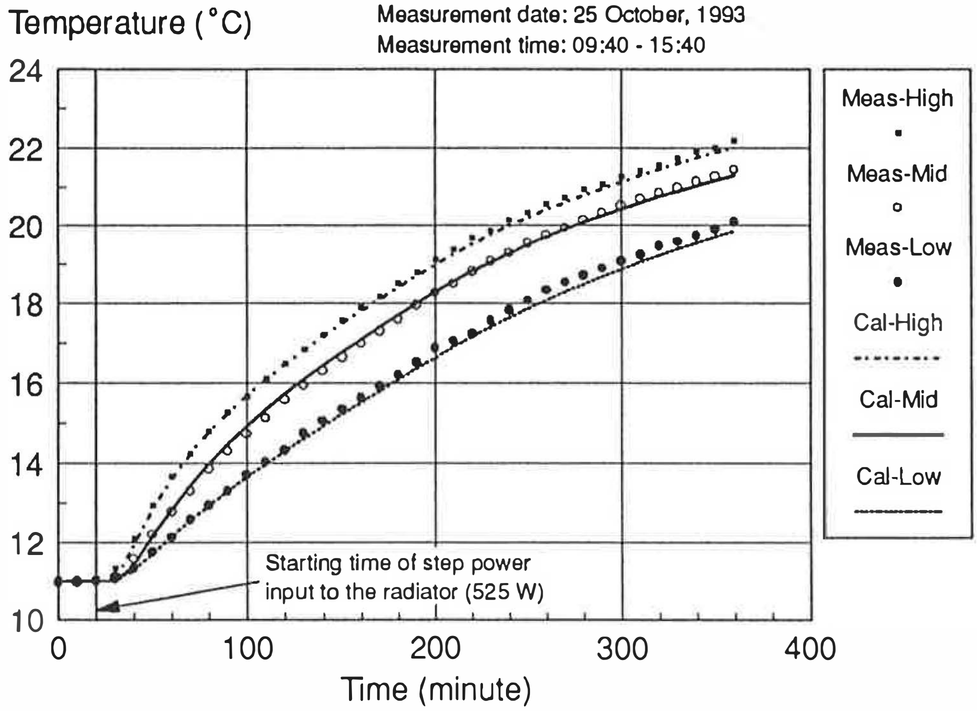

Figure 5. Indoor Air Temperature Responses (Calculations vs Measurements)

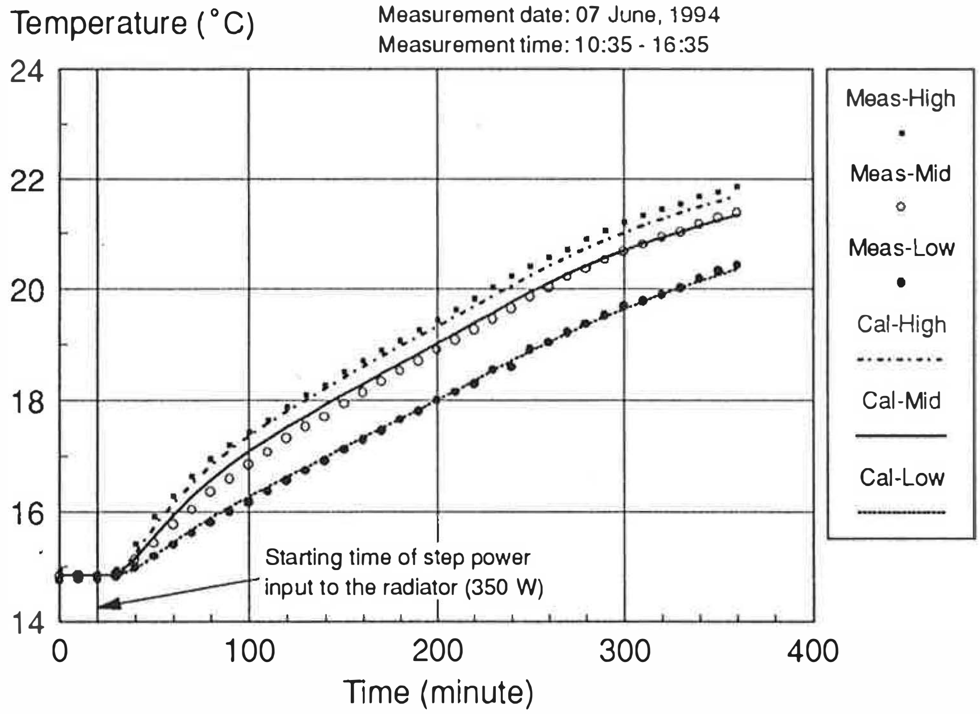

Figure 6. Indoor Air Temperature Responses (Calculations vs Measurements)

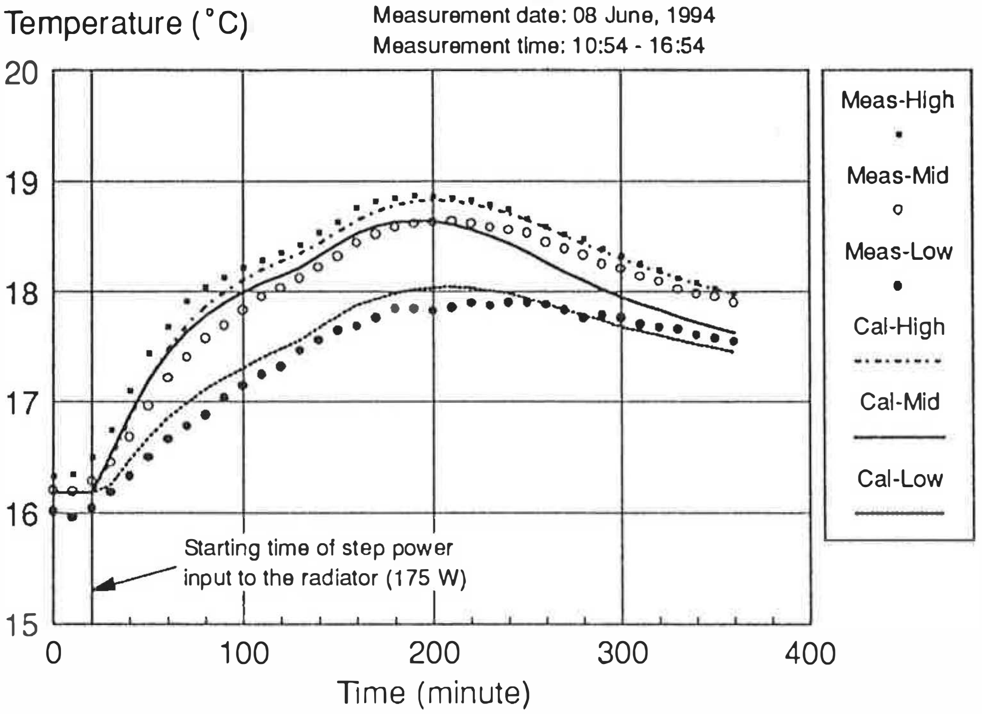

Figure 7. Indoor Air Temperature Responses (Calculations vs Measurements)

On 8 June 1994, a third measurement was done in the test room (figure 7). It was a sunny day in the morning but rainy in the afternoon. Using the same air flow pattern and velocity datafile but newly measured boundary conditions, we did the third calculations. From figure 7 we see that although the calculation results are not accurate predictions of the measurements, the temperature changing trends are well calculated. This discrepancy is probably caused by the small power input (175 w) to the radiator and the drastic change of outdoor weather conditions.

3. Conclusions

Although CFD can be used for the prediction of indoor temperature distributions and thermal comfort, the dynamic calculations are too time consuming to be feasible for the study of indoor climate control systems. This paper tries to find out a fast trade-off method to perform the dynamic calculations. Our basic idea is that for a typical heating or cooling situation, the changes of air flow pattern and air velocities are so small that they can be assumed to be constant in the process of calculations of indoor dynamic temperature distributions. Further we assume that the air flow pattern and air velocities are constant even if the heating power and outdoor weather conditions have changed under the same heating or cooling situation. With these assumptions, one air flow pattern can be used for several dynamic calculations under the same heating or cooling situation. It is quite understandable that these assumptions are controversial. But our initial calculations presented in this paper show that good agreements between calculations and measurements are obtained if the outdoor weather conditions do not change drastically.

The facts that the measurement was carried out in an enclosed room and there was no outdoor wind influence on the indoor air flow pattern perhaps contribute a lot to our good calculation results. Since our ultimate goal is to study the control system of passive indoor climate buildings, further study on natural ventilation rooms will be continued with this method.

4. References

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