An Application Study of a 3D CFD Code "TASC" for Predicting Transient Thermal Problems of Indoor Enviro...

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ABSTRACT

In Japan, room air-conditioners with inverter equipment are widely used to create thermally more comfortable environments by using smaller amount of energy consumption. Recently new housings have been designed to reduce thermal heat load by improving insulation and ventilation performances. In order to design better air-conditioners, we need to evaluate indoor thermal environments more correctly by considering not only air-conditioner controllability but also housing thermal performances.

This paper describes the applicability of our 3D transient CFD code "TASC" (Total Air-conditioning system Simulation Code) to predict indoor thermal environments. TASC is designed to solve coupled heat transfer between airflow and indoor materials (wall envelopes and furniture), including convective heat transfer, radiation exchange among indoor materials, heat conduction through walls and heat source/sink like radiation panels. This code will be a powerful tool for many recent design problems as described above.

Some numerical examples are shown on the transient indoor thermal environments when a room is heated up by heat-pump type room air-conditioners. Effects of a computation time step on accuracy and computational efforts are investigated through numerical experiments. We confirmed TASC could compute stably at the time step of 30 seconds, that was approximately equal to the control interval for room air-conditioners. A practical computation time step are examined under the conditions where the inputs from air-conditioners (eg. volume flow or jet temperature) change quickly. We also show that TASC is successfully applied to compare the heating-up ability of different types of heat-pumps.

KEYWORDS

Air-Conditioning, CFD, Numerical methods, Thermal comfort

INTRODUCTION

As it becomes increasing needs to create thermally more comfortable indoor environments with smaller amount of energy consumption, the improvement and optimization of air-conditioning systems have been playing a significant role in the HVAC design. Recently CFD techniques are widely applied to practical indoor thermal problems, and enable HVAC engineers to predict thermal environments and to suggest some ideas for the improvement and optimization.

We have been developing the 3D transient CFD code TASC for predicting indoor environments. TASC can consider thermal performances of houses/buildings by solving coupled transient heat transfer interactively caused between solids (wall and furniture etc.) and airflow. This paper shows an applicability of TASC to the transient problems especially on the prediction of the heating-up ability of heat-pump type air-conditioners.

Recent remarkable progress of the computer performances enables us to

Table 1 Computation conditions

Case No.	time step [sec]	Changing way of Input condition	
		Volume flow rate	Jet temperature
1	30	constant	constant
2	2	constant	constant
3	2	linear*	constant
4	2	constant	linear*
5	10	linear*	constant
6	10	constant	linear*

*"linear" means the input condition linearly changes within 30 seconds.

In most room air-conditioners an interval time for controlling their actuators is about 1 minutes, and thermal changes occur within the same order. So the maximum value is set at 30 seconds in this study.

Instability or divergence was not observed in the process of each computation even when a time step was 30 seconds. This may be because TASC adopts fully implicit scheme as a time marching method.

The condition difference between Case 1 and 2 simply lies in their computation time steps. Figure 4 shows room airflow after 30 seconds of both cases. There is little difference observed between them. The values of the averaged room air temperature in Table 2 are almost the same, too. Case 2 takes the execution time about 2.5 times as long as Case 1. However, the value per one time step is much shorter because a shorter computation time step can reduce iteration steps. This suggests that there be an appropriate computation time step which enables both to deal with sudden change of boundary condition and to save computational efforts.

Table 2 Average air temperature and execution time

Case No.	Average temperature [℃]	Relative execution time	
		whole	each time step average
1	10.0	1.00	1.00
2	9.9	2.51	0.17
3	8.7	3.66	0.24
4	8.7	3.03	0.20
5	9.0	2.04	0.68
6	9.0	1.89	0.63

Case 3 to 6 are for investigating the effects in the transient operation conditions for the air-conditioner. The time trends of averaged room air temperature are shown in Figure 5. A significant difference between Case2 and Case 3 or 5 is observed because they are given different boundary conditions. This means a large error may occur when changes within 30 seconds are neglected. Case 5 or 6 gives results close to Case 3 or 4, respectively.

Table 2 also shows the execution time of Case 3 to 6 to get results at 30 seconds. We conclude that about 10 seconds may be appropriate as an practical computation time step in such cases where air-conditioners change their operating condition.

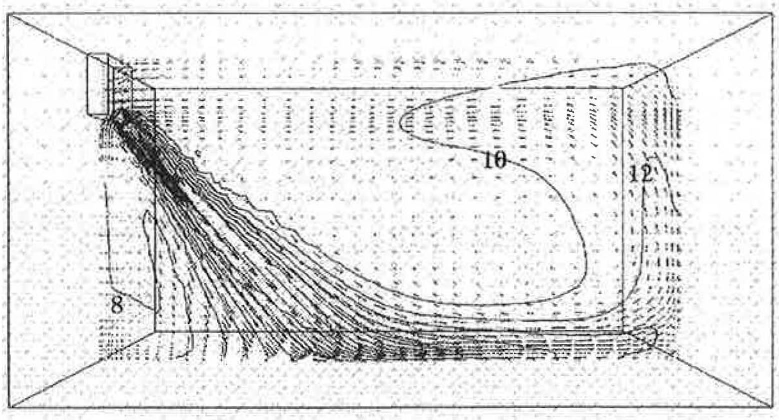


Figure 4 Room airflow and temperature distributions at 30 seconds(Case 1)

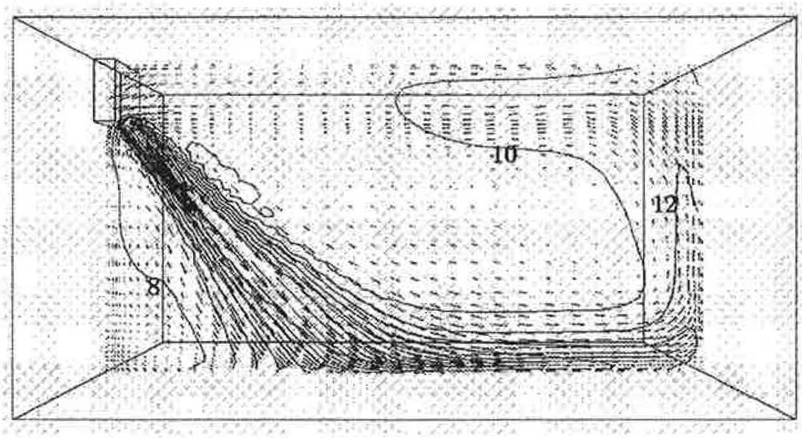


Figure 4 Room airflow and temperature distributions at 30 seconds(Case 2) (Continued)

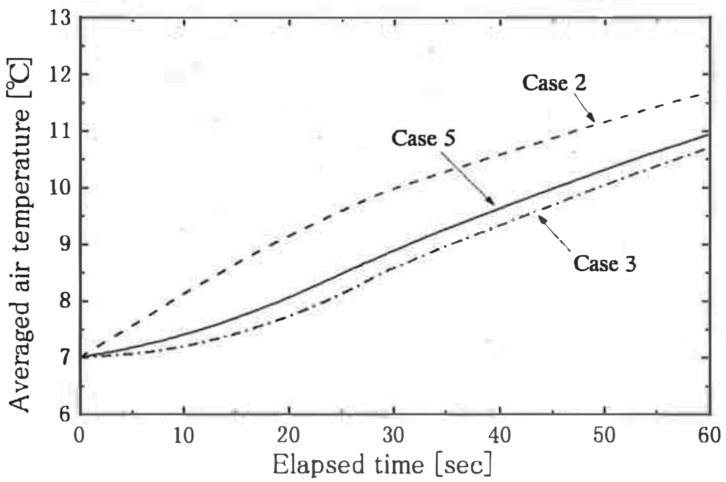


Figure 5 Comparison of the transient profile of the averaged room air temperature (Case 2, 3, and 5)

APPLICATION STUDY (2) PRACTICAL PREDICTION OF HEATING UP ABILITY

One of the desirable functions for the room air-conditioner is to heat up a room as fast as possible even in the very low outdoor air temperature conditions.

We compared heating-up abilities of two types of heat pumps. One of them is a conventional hung-on-wall type which uses only outdoor air as its heat source. The other is hung near a floor with two air outlets and its heat source is mainly stored hot water. This new type of the air-conditioner is designed to have the following two benefits: (i)It is expected to get warmer in the occupied zone near human's feet. (ii) Using stored hot water as heat source makes the unit give larger heat ability (its peak value is about 8.0 kW) regardless of outdoor air temperature. The simulation mentioned as follows are conducted under the low air temperature(–10℃). This condition is very difficult to artificially create in experiments.

(1)Model room

The model room is shown in Figure 6. The size is 2.4m(height) × 4.5m(length) × 3.6m(width). The overall heat coefficient of the room is about 3.7W/m^{2}K.

A 37(height) × 43(length) × 33(width) non-uniform mesh arrangement is used. The initial room air temperature is assumed to be 7℃. This was determined empirically from some experiments on how much room air temperature descend to about 8 to 10 hour after an air-conditioner was switched off at low outdoor air temperature.

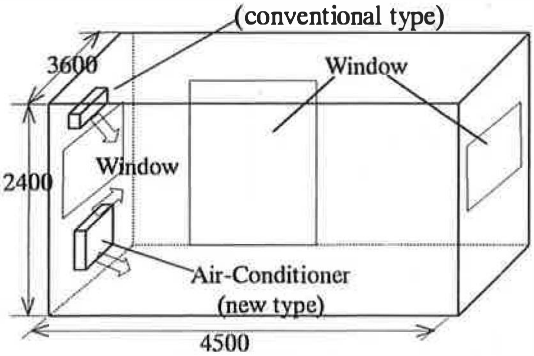
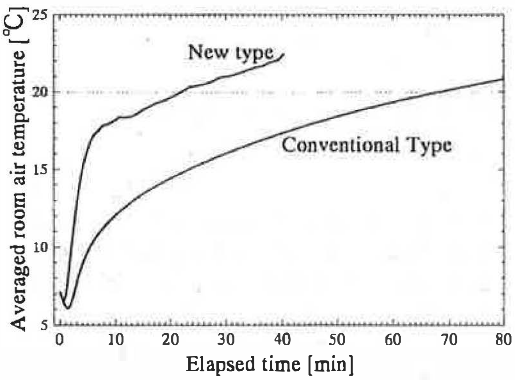


Figure 6 Model room

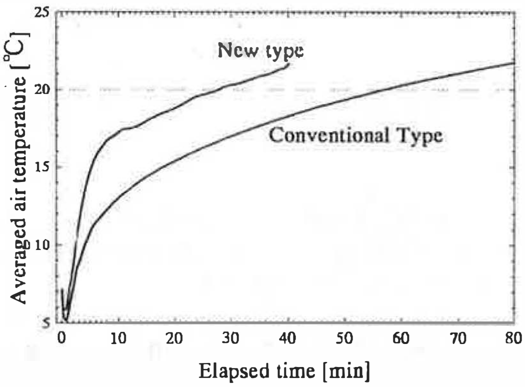
(2)Operating Conditions of air-conditioners

The heat capacity of the conventional type air-conditioner depends outdoor air temperature because it uses outdoor air as its heat source. In the simulation it is given from the laboratory experimental data, which is examined under the condition where the air temperature of both indoor and outdoor is constant. (Indoor at 20 ℃, Outdoor at −10℃, respectively) The volume flow rate is assumed to linearly give rise to 560 m^3/h in the 2 minutes after switched on.

The new type air-conditioner can initially give large amount of the heat ability regardless of outdoor air temperature by using stored hot water as its heat source. After it exhausts this water heat storage by about 10 to 15 minutes, it switches its heat source to outdoor air. In the simulation, the input heat capacity is also given from the laboratory experimental data measured in the same way as the conventional type, and this switching control is considered. Operation conditions changes suddenly and quickly. So 10 seconds are used as the computation time step.

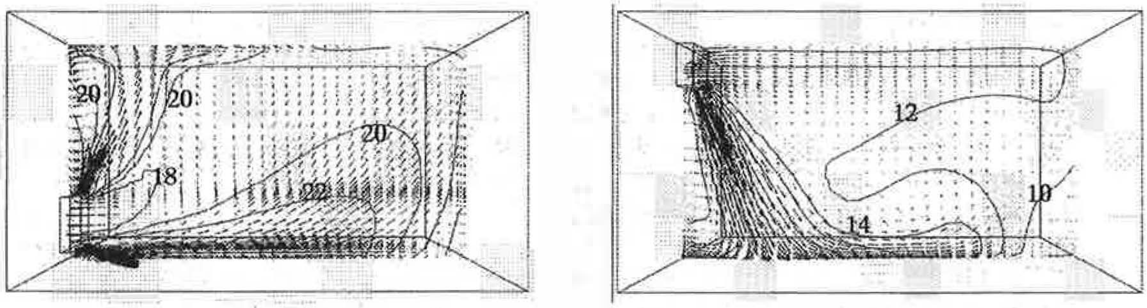


(a) Average of a Whole room

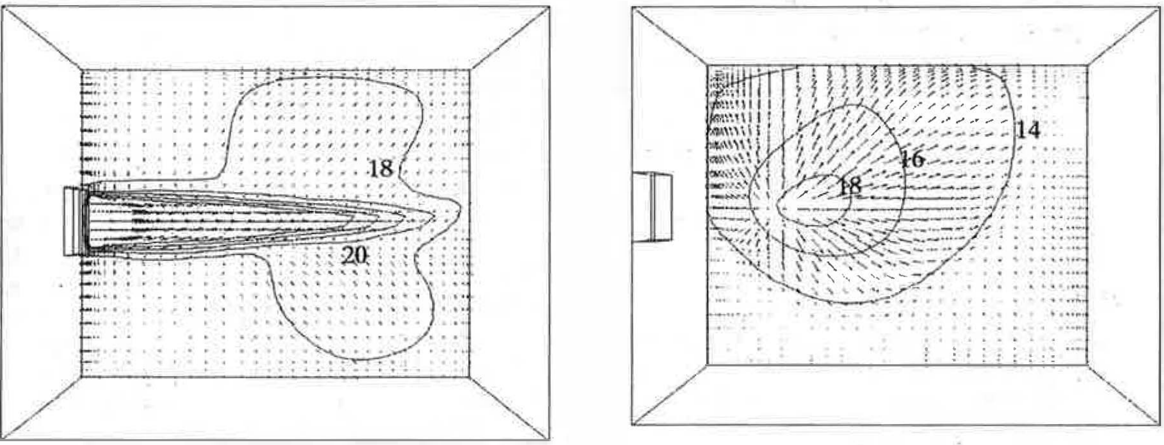


(b) Plane average of 5cm height from the floor

Figure 7 Trend comparison of the two type air-conditioners



(a) Vertical center plane



(b) Horizontal plane near feet

New type Conventional type

Figure 8 Airflow and temperature distributions after 10 minutes

(3) Results and Discussion

Figure 7 (a) shows the time trends of the averaged room air temperature. Comparing the elapsed time when the air temperature goes up across 20℃, the new type air-conditioner heats up the room more than twice as fast as the conventional one. The control of switching its heat source from stored hot water to outdoor air is successfully made without any temperature descent in the new type air conditioner.

A Comparison of the transient plane averaged air temperature near human's feet (a horizontal plane of 5cm height from the floor) are also made in Figure 7 (b). The new type air-conditioner will create thermal comfort faster in the occupied zone near human's feet.

Airflow and temperature distributions of each case after 10 minutes of elapsed time are shown in Figure 8. It is clear that the new type unit gives warmer room environments.

The heating-up speed of this new type unit is lower in the plane average near feet [Figure 7 (b)] than in the whole room average [Figure 7 (a)]. The new type has two outlets which are located both in its top and bottom. Though the bottom one blows a jet at a larger volume flow rate than the top one for comfort near feet, it is suggested this ratio be reviewed for more improvement.

There may be another aspect for the above discussions from the viewpoint of the computation conditions. In this simulation, –10℃ is uniformly given in each plane as outdoor air temperature. In most practical cases, a floor, ceiling or walls lying between another room are much warmer than outdoor air. It is one of the practical subject how to give thermal boundary conditions outside the wall.

In the results, a slight descent of air temperature is observed in the very early stage of the trends. This is due to the initial condition. The transient simulation by TASC needs interior temperature distributions of walls in addition to the initial room air temperature. They are not known in most cases. In this simulation, they are supposed to be in the steady state condition so that the room can be kept at the initial temperature 7℃. A more adequate way may be needed. For example, it may be a way to give these distributions to execute preparing computation of heat conduction of walls with room air temperature distributions assumed to be uniform.

CONCLUSIONS

A 3D CFD code TASC was applied to predict transient indoor environments when a room was heated up by several heat-pump type air-conditioners.

We studied on a practical computation time step when the operating condition of air-conditioners suddenly changed. Several computation time steps were examined by TASC. About 10 seconds might be appropriate in this study. Under the step change of boundary condition, TASC could compute stably and did not lose accuracy by using 30 seconds as a computation time step. Thus, appropriate evaluation for the practical value can be made by TASC in other various application cases.

Heating-up ability of the two types of air-conditioners under low outdoor temperature was predicted as a practical application of TASC. The results shows the superiority of the new type unit which uses stored hot water as its heat source.

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