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COMPUTER EFFORT SAVING METHODS IN UNSTEADY CALCULATIONS OF ROOM AIRFLOWS AND THERMAL ENVIRONMENTS

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ABSTRACT

In the unsteady calculations of room thermal environments, two simple and effective methods were introduced to reduce computer efforts through two case studies. One method(method-A) was applied to a passive solar room analysis(caseA) and another method(method-B) was applied to estimation of energy consumption in an air-conditioned room(caseB). In method-A, flow fields are calculated intermittently, namely, calculated every N_{ts} time step while temperature fields are calculated every time step,here,$N_{ts} \geq 1$. In method-B, only flow fields are calculated every N_{ts} time step as method-A, however, several flow patterns stored in the computer mass storage in previous calculations are used according as the supply air temperature level. In the calculations, CFD code 'SCIENCE' developed by authors was used. In both cases CPU times were saved efficiently without distorting results.

KEYWORDS

CFD, Computer effort saving, Air flow pattern, Residential buildings

INTRODUCTION

In practical applications of CFD simulation to room airflows and thermal environments analyses, how to minimize CPU times often becomes one of the important issues from the practical point of view. Especially it may be a serious problem in long term simulations such as evaluation of thermal performance of passive solar houses or energy consumption estimation in air-conditioned rooms etc.

Recent investigations(Onishi et al., 1996, Onishi et al., 1997, Koga et al., 1998) indicate that intermittent calculations of flow fields are useful means to save computing time in unsteady time marching simulations of room flow and thermal environments.

The aim of present study is to introduce some efficient methods of computer efforts saving and to confirm quantitatively their performances through two case studies. The methods are based upon a simple concept, that is, in some unsteady time marching procedures flow fields calculations may be allowed to execute intermittently without distorting results.

One method(method-A) was applied to a passive solar room analysis(caseA) and another method(method-B) was applied to estimation of the amount of energy consumption in an air-conditioned room(caseB). In method-A, flow fields are calculated intermittently,namely,calculated every N_{ts}time step while temperature fields are calculated every time step,here,N_{ts} greater than 1. In method-B, only flow fields are calculated every N_{ts} time step as method-A, however, several flow patterns stored in the computer mass storage in previous calculations are used according as the supply air temperature level. In the calculations, CFD code 'SCIENCE' developed by authors was used(Onishi et al.,1995). Basic equations were discretized using a finite difference method and solved with SIMPLE algorithm. As a time marching procedure, a fully implicit method was adopted. All calculations were performed with similar weather models based upon measured weather data. In both cases, cputimes were saved efficiently without distorting results.

PROBLEM DESCRIPTION

In Case A, a passive solar room with a massive wall is used(Figure 1). The test room geometries are $2.4m \times 3.6m \times 2.7m$ and a massive wall made of concrete is installed 10cm apart from the glazing. To simulate the thermal environments in passive solar rooms, natural convective flows induced by solar heat gains are dominant, so they are essentially non-steady and transient heat exchanges between room air and solid bodies such as walls or floors are most important phenomena. In the simulations, non-steady and long time span (during several days) calculations are requested.

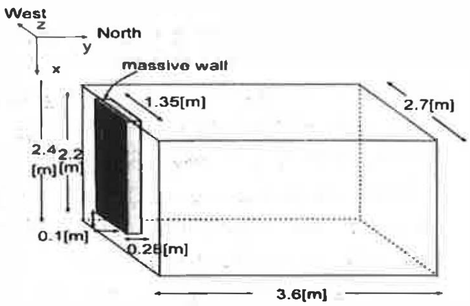


Figure 1 Test room, case A.

In Case B, a room model shown in Figure 2 is used. Two air-conditioner room units are installed near the ceiling. The supply air is discharged horizontally from northern side of the each unit and the return air is exhausted upward through lower side of them. The supply air temperature is changed every moment according as the operating control of the power unit(compressor set outside the room) and as the level of room thermal load. Therefore, the room airflows become unsteady forced convection flows.

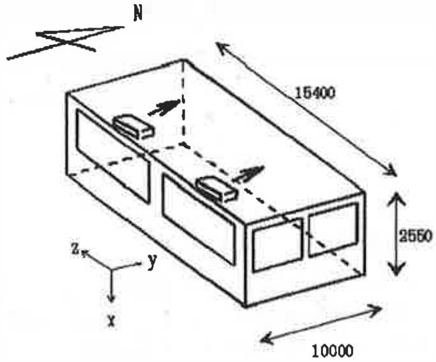


Figure 2 Test room, case B.

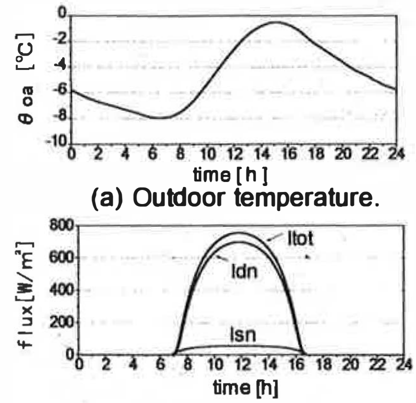
To investigate the relation between the amount of energy consumption and the operating control of the power unit of air-conditioner numerically, non-steady and long time span calculations are requested also in this case.

Main subject of the present study is to investigate how to minimize computer efforts in calculating these phenomena described above.

NUMERICAL SIMULATION

Weather data

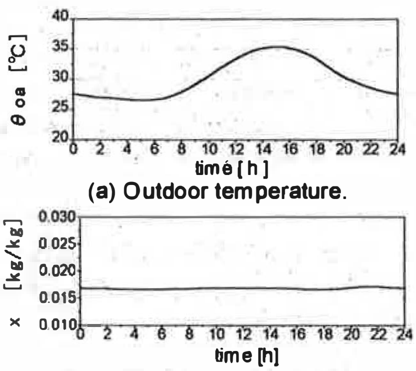
In Case A, winter heating season was assumed, while in Case B, summer cooling season was assumed, and all simulations were executed with weather models based upon measured data. Figure 3 shows weather model used in Case A and the outdoor temperature θ_{oa} is based upon measured winter data in Sapporo. I_{dn} is direct component , I_{sn} is diffusive component and $I_{tot} = I_{dn} + I_{sn}$. The weather model used in Case B is shown in Figure 4 which is based upon measured summer data in Osaka, here, x is humidity ratio of the outdoor air. The solar radiation data is obtained by the similar theoretical model as shown in Figure 3.



(a) Outdoor temperature.

(b) Solar radiation.

Figure 3 Weather data, Sapporo city, case A.



(a) Outdoor temperature.

(b) Humidity ratio.

Figure 4 Weather data, Osaka city, case B.

Basic concept

As mentioned above, a fully implicit method is adopted in the simulation, then, at each time step n, all valuables are calculated iteratively until they satisfy the convergence criteria. However, under some conditions, all valuables should not be calculated at every time step n. In the room thermal environment analyses, various test runs suggest that temperature fields should be calculated at each time step ,otherwise, calculations do not proceed correctly, while flow fields may be allowed to calculate intermittently(not calculate at every n). In other words, a computer efforts saving method proposed in the present study is based upon following two properties of flow and temperature fields in rooms. (1)Airflows respond to the change of flow conditions quickly compared with solid wall temperature response to the change of room thermal conditions. (2)Room flow fields are not influenced by a slight change of solid wall temperatures.

Case A(Natural convection)

In Case A, natural convection is dominant in room airflows and calculations often become unstable, especially when calculating time step Δt is set larger than 60 seconds. Several test runs indicate that simulations are stable throughout the days when Δt is set less than 30 seconds. Therefore, all calculations are performed setting $\Delta t \leq 30$ seconds.

Method-A applied in case A adopts a simple algorithm as is shown in Figure 5.

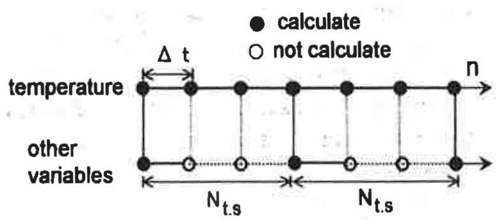


Figure 5 Intermittent calculation, case A.

In the normal calculation, all variables are calculated, while only temperature is calculated at all time steps n, and other variables are calculated at every N_{ts} time step intermittently. Optimum value of N_{ts} depends on each phenomenon.

Case B(Forced convection)

In case B, as forced convection flow is dominant, calculations are stable compared with case A, then, time step Δt is set 60 seconds. The air flow fields are fixed during $(N_{ts}-1)$ time steps in case A, however, supply air conditions change every minute because of the power unit operating control in case B, therefore, similar algorithm is not appropriate in this case.

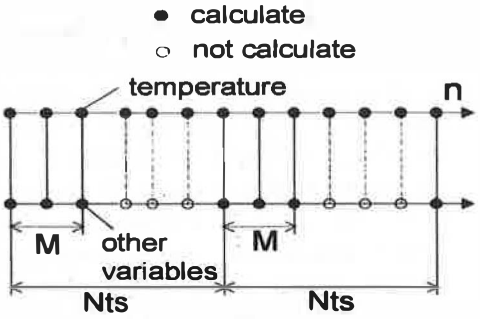


Figure 6 Intermittent calculation, case B.

Method-B introduced in case B is as follows. Figure 6 shows a concept of method-B. Only temperature fields are calculated every time step n, while flow fields calculations are executed at M time steps during N_{ts} time steps, here, $N_{ts}M$. In the calculations during M time steps, flow fields are stored in the computer mass storage classified according as the supply air temperature level. Then, at the $(N_{ts} - M)$ time steps, those previously calculated flow fields data is restored from computer mass storage and used for temperature fields calculations without executing flow fields calculations. The range width of supply air temperature classification is set 2 °C.

RESULTS AND DISCUSSIONS

Case A

Some results of case A are shown in Table 1 and in Figure 7, Figure 8. Simulation was started at 8:00 on first day and was continued during four days(88 hours) until periodically steady conditions were attained. The time step Δt is set 15 seconds and cputimes are those of 88 hours simulation. Calculating mesh size is $17 \times 21 \times 16$ and convergence criteria adopted in each time step is $\frac{|\phi^m - \phi^{m-1}|_{max}}{|\phi^m_{max}|} \le 10^{-3}$ Relations between intermittent calculation parameter N_{ts} and cputime are shown in Table 1. $N_{ts} = 1$ means a normal calculation, namely, all variables are calculated at every time step n.

Table 1 Relations between N_{ts} and cputime, case A.

N_{ts}	cputime [h]	cputime [%]
1	64.8	100
4	28.9	45
8	22.8	35
16	18.8	29
40	16.8	26

computer:HP model715

Figure 7 gives space averaged room temperature θ_{avg} of the fourth day's data in case A. The intermittent calculation parameter N_{ts} hardly influences θ_{avg}. The maximum discrepancy between the result of $N_{ts} = 1$ and results of other N_{ts} does not exceed 0.3 degree Celsius. Flow and temperature distributions of the central vertical plane are compared in Figure 8. Figure 7 indicates that even the result for $N_{ts} = 40$ is practically acceptable, however, as is shown in Figure 8, flow field for $N_{ts} = 16$ appreciably differs from that for $N_{ts} = 1$. Flow field for $N_{ts} = 40$ is unacceptably distorted compared with that for $N_{ts} = 1$.

Inspection of these results suggests that intermittent parameter $N_{ts} = 8$ is preferable in the simulation of case A. Method-A investigated here is a simple and useful one, however, optimum value of intermittent parameter is not applied generally, but it may depend on various calculating conditions or on various phenomena.

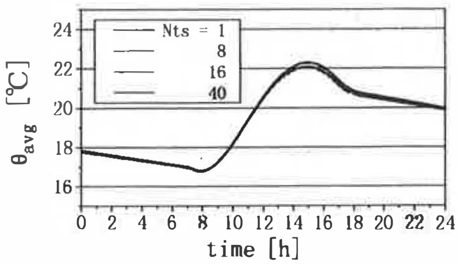


Figure 7 Comparison of room average temperature, case A

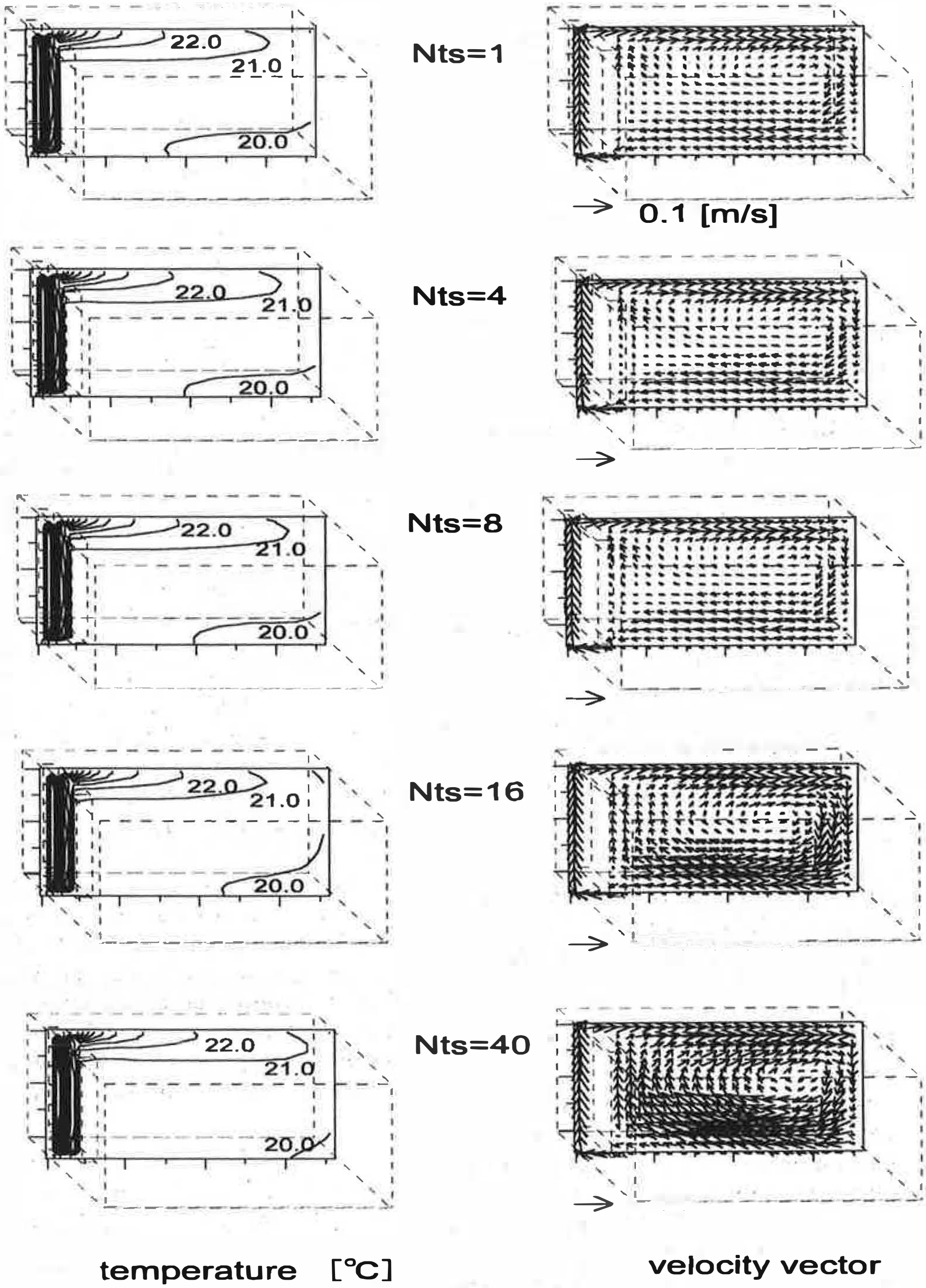


Figure8 Comparison of flow and temperature distributions, caseA

Case B

Following two types were compared in case B.

- Type 1 : All variables are calculated at every time step n ($N_{ts} = M = 1$).
- Type 2 : Calculation is executed with method-B shown in Figure 6.

Calculating mesh size is $17 \times 26 \times 28$. The same convergence criteria was used as case A at each time step calculations and time step Δt is set 60 seconds. Results are shown in Table 2 and Table 3. Table 2 is a result for on-off control and Table 3 for two step control, respectively. In case B, operation of the power unit installed outside the room is controlled with the temperature difference

$$\Delta\theta = \theta_{ret} - \theta_{set}$$

where, θ_{ret} is return air temperature and θ_{set} is target room air temperature, here, it is set 26 °C. In the on-off control, the compressor operation is switched on(100% operation) or off (0 %) monitoring $\Delta\theta$, while in the two step control, it is switched on(100 % operation) or on(50 % operation) or off according as the level of room thermal load. In these tables, the amounts of energy consumption and cpu time are compared relatively for 24 hours calculations.

Results indicate that computing times seem to be reduced appreciably in all cases except type 2 (c) in two step control(Table 2). In this case, energy consumption is overestimated about 8 %.

Table 2 Comparison of cpu time, case B, on-off control.

type	N_{ts},M	W [%]	cputime [%]
1	1 , 1	100.0	100.0
2	(a) 30, 5	100.3	26.4
2	(b) 60, 5	100.4	18.6
2	(c) 120, 5	100.4	14.1
2	(d) 30, 15	99.9	57.3
2	(e) 60, 15	100.1	31.8
2	(f) 120, 15	100.9	21.7

computer:HP model C160

Table 3 Comparison of cpu time, case B, two step control.

type	N_{ts},M	W [%]	cputime [%]
1	1, 1	100.0	100.0
2	(a) 30, 5	100.5	24.7
2	(b) 60, 5	100.4	16.7
2	(c) 120, 5	108.4	12.1

computer:HP model C160

Figure 9 and Figure 10 express examples of behavior of room average temperature θ_{avg} during four hours. Figures 9 and 10 show results for on-off control and two step control, respectively. The amplitudes of room temperature fractuations are nearly equal each other, however, the phases of them differ between type 1 and type 2 and this difference is larger in cases shown in Figure 10(two step control) than in cases shown in Figure 9 (on-off control) .

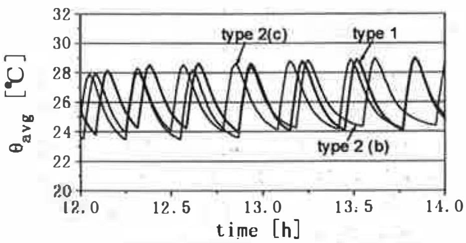


Figure 9 Comparison of room average temperature, case B, on-off control.

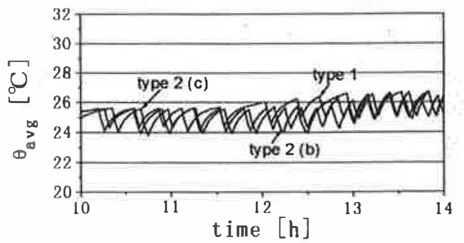


Figure 10 Comparison of room average temperature,case B,two step control.

This may be explained as follows. Small error(incorrectness) of restored flow fields causes error of return air temperature θ_{ret} which may affect delicately the switch timing of the operation control, then, as the calculation progresses, the phase of the operation control cycle gradually changes in the calculations with method-B. In cases applied two step control, the compressor on-off switching occurs more frequently than in cases applied on-off control. This is because the phase displacement is larger in two step control calculations.

Although in the intermittent calculations like method B, it is not easy to realize the same fluctuation patterns of room thermal environments as the exact calculations, as is shown in Table 2 and Table 3, the method introduced here may be a useful and effective means to estimate the amount of seasonal or annual energy consumption.

CONCLUSIONS

Two simple and effective methods were introduced to reduce computer efforts in unsteady calculations of room thermal environments through two case studies.

Method-A was applied to a natural convection flow analysis in a passive solar room(case A). It was proved that cpu time was saved about 65% in the calculation setting time step Δt = 15 seconds and the intermittent calculation parameter N_{ta} = 8 without distorting the result, however, the optimum value of the intermittent parameter is not applied generally, but it may depend on various calculating conditions or on properties of various phenomena.

Method-B was applied to a forced convection flow analysis in an air-conditioned room(case B). The computer efforts were saved more than 80% in the calculations setting time step Δt = 60 seconds. In this case, because of the operation control of air-conditioner included in the room airflow calculations, flow and temperature fields changes every minute, it is not easy to realize the same fluctuation patterns of room thermal environments as the exact calculations. However, the method introduced here may be a useful and effective means to estimate the amount of seasonal or annual energy consumption.

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