CFD SIMULATION OF AIRFLOWS AND THERMAL ENVIRONMENT IN PASSIVE ARCHITECTURES —APPLICATION TO A ROOM WITH TROMBE WALL SYSTEM

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ABSTRACT Applicability of CFD simulation to designing passive architectures was investigated using a passive solar room with a Trombe wall system inside it. In the investigation, non-steady numerical simulation was performed to predict thermal environment in the test room. Two weather models assuming a typical fine winter day were compared, one was the model based upon the data in Osaka and the other was that in Sapporo. The test room has glazing in the south side wall and in the north side one. Each glazing was covered with a insulating door during night. The simulations were executed under the condition that each insulating door was closed with the sunset and was opened at sunrise. This condition realized a highly insulated and air tight space.

Following facts were confirmed through the simulations. Because of the warm climate in Osaka, the room averaged temperature θ_{avg} is maintained more than 18 °C throughout the day in Osaka, while the maximum θ_{avg} is less than 18 °C in Sapporo. To maintain the moderate thermal environment in Sapporo, it is sufficient to supply 8 kWh heat input inside the Trombe wall during the night. These results proved the CFD simulation to be one of the useful tools to design various passive architectures

1. INTRODUCTION

In designing various passive and low energy architectures(PLEA), experimental investigations often require much labor and money. The alternative approach may be applying CFD simulations which can rather easily realize detailed flow and thermal environments in PLEA with required conditions. In this paper, a passive solar system was introduced and investigated with a CFD simulation method.

In the passive solar rooms, natural convection flows induced by solar heat gains are dominant, so they are essentially non-steady, three dimensional(3-D) turbulent flows and transient heat exchanges between room air and solid bodies such as walls or floors are most important phenomena. To simulate the thermal environment in passive solar rooms numerically, non-steady and long time span (at least 24 hours) calculations are also requested.

In the previous paper,we tried to simulate flow and temperature fields in a 3-D passive solar room assuming a fine winter day in Osaka and confirmed that CFD method was a convenient and useful means to investigate thermal environments and or energy consumption in passive solar systems[1].

In the present paper, similar simulations as reference [1] were performed using weather data not only in Osaka(warm climate) but also in Sapporo(cold climate). As a case study,a hybrid system was also introduced in the simulation for Sapporo City.

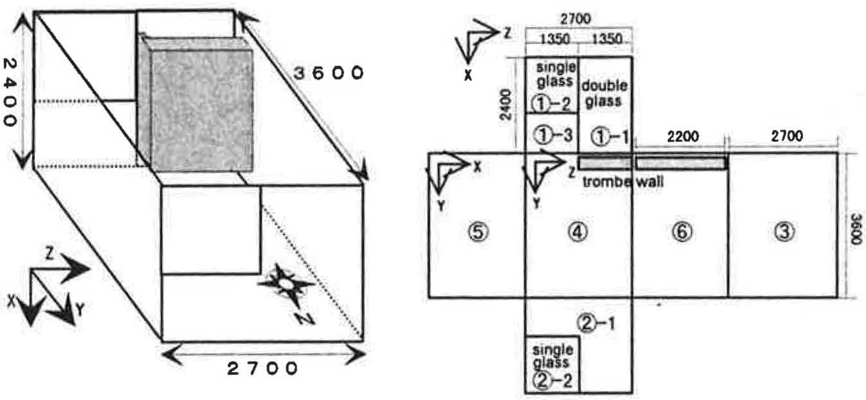
For the simulations, a CFD code 'SCIENCE' developed by authors[2] was applied. The basic equations were discretized and solved with a finite difference method and SIMPLE algorithm. Fully implicit method was adopted for the time integration.

It was found that massive wall in the room is applicable not only to passive solar system but also to various distributed heat storage systems.

2. NUMERICAL SIMULATION

2.1 Details of the Room

Test room configurations are shown in Figure1 **(a)**,**(b)**. A massive thermal storage wall(Trombe wall) made of concrete the thickness of which is 28cm is installed 8cm apart from the southern glazing(1-1) and covers half area of the x-z cross section. Both at the top and the bottom of it 10cm clearance(vent) is set so that air circulation occurs during daytime,then the heated air between glazing and Trombe wall is exchanged with the cool air in the room.



(a) Geometry of the room. (b) Numbering of walls.

Figure 1 Test room configurations.

It is assumed that there is other space adjacent to the wall No.3(ceiling) and No.4(floor) respectively and other walls No.1,2,5 and No.6 are facing outside air directly. Grazing 1-1 is double glass and glazing 1-2,2-2 is single glass.

2.2 Weather Model

In the simulation, two weather models were compared, one was the model based upon measured winter data in Osaka(shown in Figure**2**) and the other was the model based upon that in Sapporo(shown in Figure**3**). θ_{oa} is outdoor temperature, I_{dn} is direct component of solar radiation, I_{sn} is diffusive component and $I_{tot} = I_{dn} + I_{sn}$.

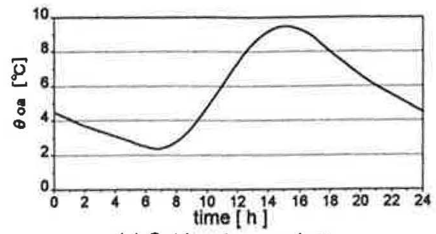
2.3 Treatment of Solar Radiation

In the simulation code SCIENCE, heat balance equation

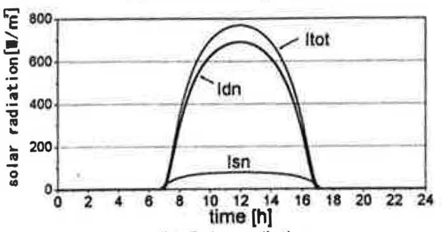
$$q_C + q_L + q_R + q_P = 0 \tag{1}$$

is solved at all surfaces of solid body calculating cells, where, q_C, q_R, q_L is convective,radiative and conductive heat flux of the cell surface respectively regarding the fluxes flowing into the surface positive. In the evaluation of q_R, a calculation procedure based upon Radiative Heat Ray method[3] is applied to get angle factors between cell surfaces.

In the present paper, similar technique is adopted to search the cell surface which solar

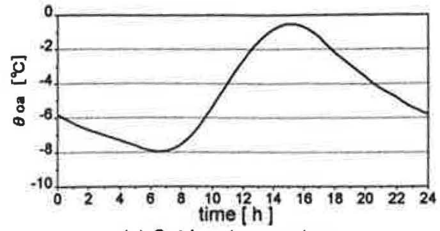


(a) Outdoor temperature.

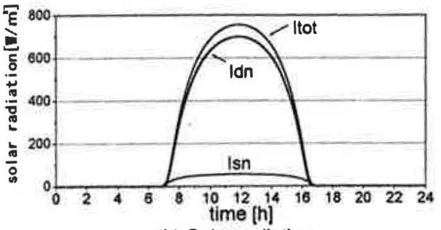


(b) Solar radiation.

Fig.2 Weather data, Osaka City.



(a) Outdoor temperature.



(b) Solar radiation.

Fig.3 Weather data, Sapporo City.

radiation through glazing strike directly. The amount of solar gain is proportional to the number of heat ray striking the cell surface. Then, it is set as the heat source q_P at the cell surface. Here,it is assumed that the solar radiative flux directly hit the solid surfaces is entirely absorbed and becomes heat source there. Reflections of solar direct gains are not considered.

2.4 Boundary Conditions

Thermal boundary conditions are as follows.

For the outside walls (wall No.1,2,5,6), two kinds of conditions are used according as the solar radiation exists or not. During daytime sol air temperate is given at the outside surface while during night outside air temperature θ_{oa} is given as the boundary condition with a uniform surface conductance $\alpha_o(= 15\ \mathrm{W/m^2h})$. For the ceiling(wall No.3) and floor(wall No.4), $(\theta_{avg} + \theta_{oa})/2$ is given as the boundary condition with constant surface conductance α_o. At the inner surface, equation(1) is solved at first, then using the results, $q_C = \alpha_C(\theta_P - \theta_w)$ or $q_L = \lambda_s \frac{\partial\theta}{\partial s}$ is given at the calculation cell surface according as the cell belong to the solid body or to the room air. Where, θ_w is surface temperature,θ_P is the air temperature of the calculating cell adjacent to the wall, λ_s is thermal conductivity of the wall(solid). α_C is the surface conductance and derived using wall functions based upon logarithmic law[2].

2.5 Calculating Procedure

The basic equations governing 3-D non-isothermal flows are discretized and solved with a finite difference method and SIMPLE algorithm. As a turbulence model k-ϵ 2 equation model is adopted and Boussinesq approximation is assumed for the buoyant force expression. The number of calculating mesh is $17 \times 21 \times 16$. Fully implicit method is adopted for the time integration and the calculating time step Δt is set one minute.

To evaluate q_L, non-steady heat conduction equation should be solved inside solid walls. In the simulation code SCIENCE, one dimensional heat conduction is assumed for the room enclosing walls,while 3-D solution is applied for the Trombe wall. In each time step, minimum iteration number N_{min} was set 90~100 and overall heat balance H_{bal} was monitored[4].

To decrease the heat loss during night, all glazing are covered with 40mm thickness insulating materials scheduling that at the sunset(Osaka at 17:13, Sapporo at 15:52) the 'insulating door' is closed and at the sunrise (Osaka at 6:39, Sapporo at 6:37) it is opened.

Following three cases are compared.

case 1 : simulation for Osaka without heater

case2-1 : simulation for Sapporo without heater

case2-2 : simulation for Sapporo with heater(hybrid system)

In case2-2, it is assumed that an electric plate heater the thickness of which is negligible is installed in the x-z plane inside the Trombe wall. The heater switch is set on at 23:00 and set off at 7:00 assuming the midnight electric power utilization. The heater capacity is 1000 W and is assumed to be distributed uniformly in the plate heater.

3. RESULTS & DISCUSSIONS

Daily change of averaged room air temperature θ_{avg} is shown in Figure4. In case1 and case2-1,calculation was started at 8:00 and was continued until periodically steady state was attained. In both cases,about five days were necessary to attain the periodically steady condition. In Figure4, only 5th day(periodically steady state) is shown for case1. In cold climate(Sapporo), maximum θ_{avg} is lower than 18 °C, therefore, to maintain the moderate thermal environment, a subsidiary heating system should be added to the solar room, especially during nocturnal hours. Such a hybrid system is introduced in case2-2.

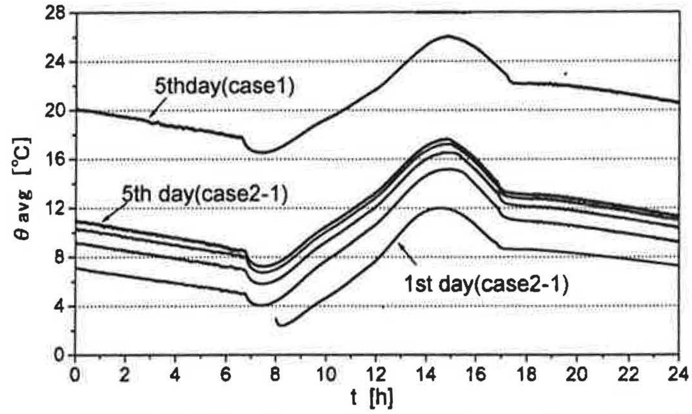
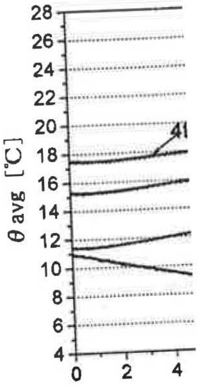


Figure 4 Daily change of room temperature,case1 (Osaka) and case2-1(Sapporo).

Results for case2-2 is shown in Figure5. The data of 1st day in Figure5 is same as that of 5th day in case2-1. The results indicate that 8 kWh heat input during the night is sufficient to maintain the θ_{avg} more than 18 °C throughout the day.

The room averaged PMV is compared in Figure6. In the calculation of PMV, human body is assumed to be a small sphere. Case1 and case2-1 are results of 5th day and case2-2 is those of 4th day. The hybrid system in case2-2 gives nearly same thermal sensation as that of case1. Figure7 shows comparison of storaged heat in the Trombe wall Q_{str}. The difference between case2-1 and case2-2 implies the effect of the heater in the Trombe wall.

These results may suggest that massive wall in the room is applicable not only to passive solar system but also to various distributed heat storage systems and that CFD method introduced



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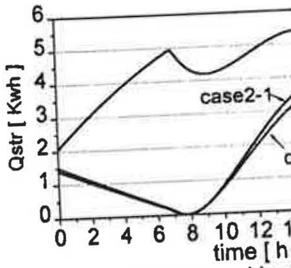

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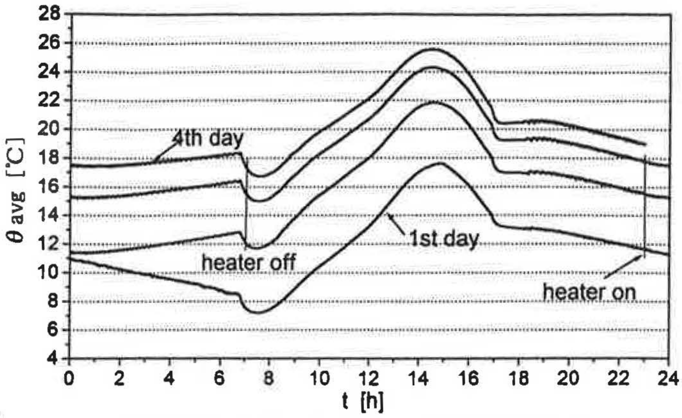

Figure 5 Daily change of room temperature, case2-2(Sapporo).

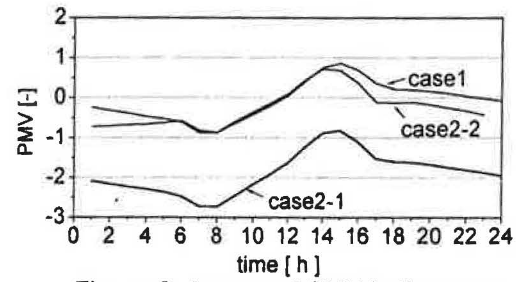

Figure 6 Averaged PMV in the room.

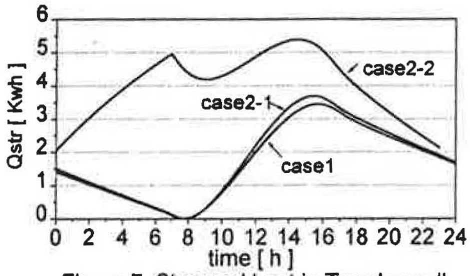

Figure 7 Storaged heat in Trombe wall.

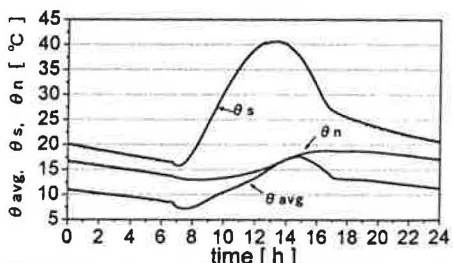

Figure 8 Surface temperature of Trombe wall, case2-1, 5th day.

in this study is convenient and useful means to investigate such systems quantitatively.

Figure8 and Figure9 are comparisons of Trombe wall surface temperature θ_s and θ_n. Figure8 is the results for case2-1 and Figure9 is those of case2-2. θ_s is the mean temperature of the Trombe wall surface facing the southern glazing and θ_n is that of room air side. The temperature difference between θ_n and room air temperature θ_{avg} at night decreases to be the order of 6°C in case2-1, while it is kept more than 12 °C in case2-2.

Although results for room airflow and temperature distributions are not shown in this paper,

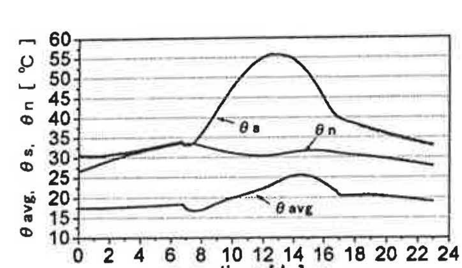

Figure 9 Surface temperature of Trombe wall, case2-2, 4th day.

the temperature distribution becomes fairly uniform especially during night, and maximum air velocity which occurs along Trombe wall surfaces does not exceed 20 cm/s.

4.CONCLUSIONS

Two weather model was compared in the CFD simulations of thermal environments in a passive solar room. In the warm climate simulation, maximum room averaged temperature θ_{avg} is maintained more than 18 °C throughout the day, while in the cold climate, it does not rise above 18 °C. However, 8 kWh heat input inside massive wall during night is sufficient to maintain the θ_{avg} more than 18 °C throughout the day even in cold climate.

Inspection of the results obtained in this study may suggest that massive wall in the room is applicable not only to passive solar system but also to various distributed heat storage systems and that CFD method introduced in this study is convenient and useful means to investigate such systems quantitatively

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ABSTRACT

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INTRODUCTION

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