PERGAMON

Renewable Energy 22 (2001) 61–66

RENEWABLE ENERGY

www.elsevier.com/locate/renene

Numerical study on a low energy architecture based upon distributed heat storage system

Junji Onishi[a,*], Haruo Soeda[b], Minoru Mizuno[b]

[a]Department of Intelligent Machine Engineering, Osaka Electro-Communication University, 18-8 Hatsu Cho, Neyagawa, Osaka, Japan

[b]Department of Environmental Engineering, Osaka University, 2-1 Yamada-Oka, Suita, Osaka, Japan

Abstract

Basic performance of a hybrid heating system was investigated numerically through several case studies including examinations of effects of PCM as a heat storing materials. A simple test room assuming passive utilization of solar energy was used with a thermal storage wall (Trombe wall) inside it. Unsteady simulation was performed with a CFD code developed by authors. As the outdoor conditions, standardized weather data of Sapporo city, a cold climate district in Japan, were used. In the simulation, the room air was controlled with the heater operations setting the target air temperature at 18 degree Celsius. Simulated results indicate the effectiveness of PCM and suggest the possibility of developing low energy houses with hybrid system introduced in this study.

1. Introduction

Recently, how to design ecological and energy conservative architectures has become a subject of world wide attention. In such low energy architectures, as a distributed heat storage system (DHSS), massive walls often play an important role in keeping the thermal environment comfortable throughout the day with the minimum energy consumption. Moreover, various investigations for phase change

* Corresponding author.

PII: S0960-1481(00)00049-5

materials (PCM) indicate that the performance of DHSS may be improved appreciably through utilizing PCM as wall materials. This state of the arts suggests a possibility that some energy conservative houses with a hybrid air-conditioning system may be developed combining DHSS with heating systems as well as passive utilization of solar energy in the heating season.

In the investigation of such systems as described above, experimental approaches are not appropriate because they require much labor and money. Therefore, the authors tried to apply a CFD (computational fluid dynamics) simulation to investigate passive solar systems numerically and it proved to be a useful means to evaluate their performances quantitatively [1–3]. The final aim of our study is to propose an energy conservative house with a hybrid air-conditioning system, combining a passive system together with an active one. Although this hybrid system may be possible to apply to both heating and cooling seasons, we restrict our following discussions to the systems in winter heating seasons.

The passive system is based upon DHSS in which solar gain is partly stored in a massive wall inside the room and also in other structure walls in the daytime. The stored energy serves to keep room thermal environments warmer throughout the day. However, the amount of solar gain depends on the weather conditions. A room temperature level usually becomes lower than the comfortable temperature in nocturnal hours and so even in the daytime solar gain is not sufficient. Therefore, as a subsidiary heat source, an active heating system should be installed to maintain comfortable room thermal environments.

In this paper, the basic performances of the hybrid system were investigated numerically through several case studies using a simple test room and assuming winter heating seasons.

2. Test room and test conditions

The test room configuration is shown in Fig. 1. It has a massive wall (a heat storage wall) inside it. Thermal performance of following cases was examined using CFD simulations.

- Case 1: a passive solar room with a 50-mm thick concrete wall (Trombe wall) inside it and no active heat supply throughout the day.
- Case 2: a passive solar room with a 50-mm thick concrete–PCM combination wall inside it and no active heat supply. PCM is inorganic and its proportion is 25 wt%. It is assumed that the phase change of PCM occurs at 30–31°C.
- Case 3: same conditions as Case 2 except that the phase change of PCM is assumed to occur at 35–36°C.
- Case 4: same conditions as Case 2 except that the phase change of PCM is assumed to occur at 20–21°C.
- Case 5: same conditions as Case 1 except that an electric heater is installed inside the Trombe wall.

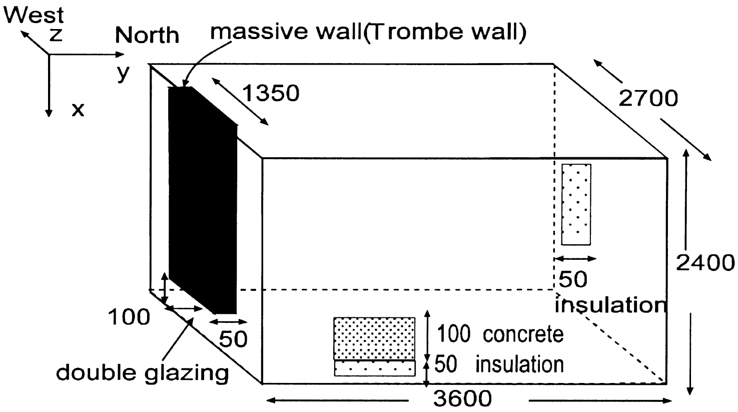

Fig. 1. Test room configuration.

- Case 6: same conditions as Case 2 except that an electric heater is installed inside the Trombe wall.
- Case 7: same conditions as Case 3 except that an electric heater is installed inside the Trombe wall.

In Cases 5–7, the room air is controlled with the heater operations setting the target air temperature at 18°C. The heater is switched on during average room temperature $\theta_{avg} < 18\hat{}C$ and switched off during $\theta_{avg} > 18\hat{}C$. To minimize heat loss during the night, the glazing of the test room was covered with a 40-mm thick insulating door. It was closed at 17:00 and was opened at 7:00 in the morning.

3. Numerical simulation

As in outdoor conditions, standardized weather data of Sapporo city shown in Figs. 2 and 3 were used. Simulations were performed with a CFD code 'SCIENCE' developed by the authors [4]. Calculating mesh size is 24 × 37 × 16. A

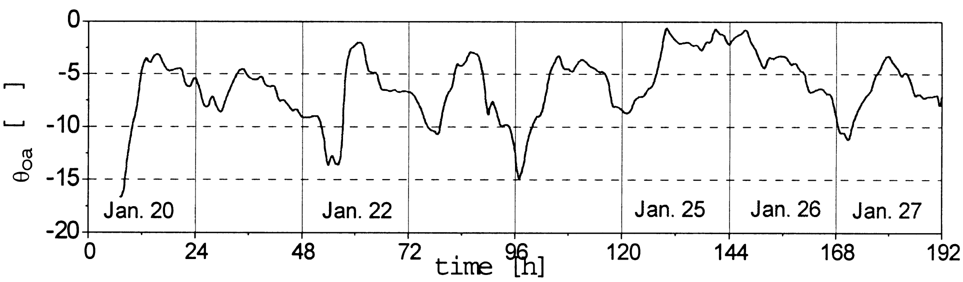

Fig. 2. Outdoor temperature in Sapporo.

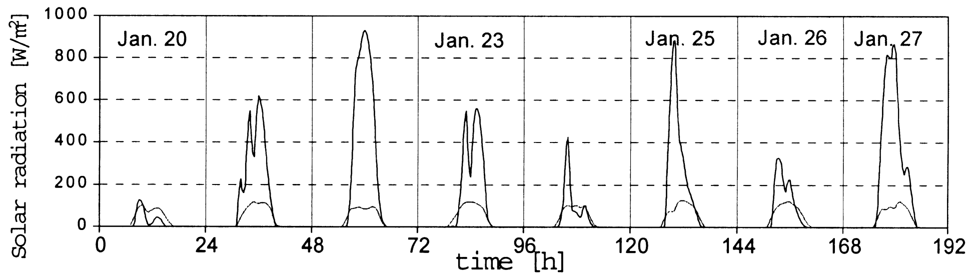

Fig. 3. Solar radiation data in Sapporo.

fully implicit method is adopted for the time integration and the calculating time step Δt is set at 15 s.

Preliminary calculations with the test room revealed that about 4–5 days approaching calculations were necessary to neglect the effect of initial temperature conditions. Therefore, although all cases were calculated from 20 January to 27 Jnauary, simulated results below are shown only the data for 25–27 January.

4. Results and discussions

Room average temperatures are shown in Fig. 4. The lower four curves are results for Cases 1–4, cases of no subsidiary heat supply. These results express basic thermal environments of the room as a passive solar system with a thermal storage wall. In Case 4, the effect of PCM was better than Case 2 or Case 3 and nocturnal room temperatures were maintained more than 2°C compared with Case 2 or Case 3. In all four cases, room air temperatures were maintained appreciably higher than outdoor temperatures, however, Sapporo is a cold climate district in Japan, so, it was necessary to use a subsidiary heat supply to maintain room thermal environments comfortable.

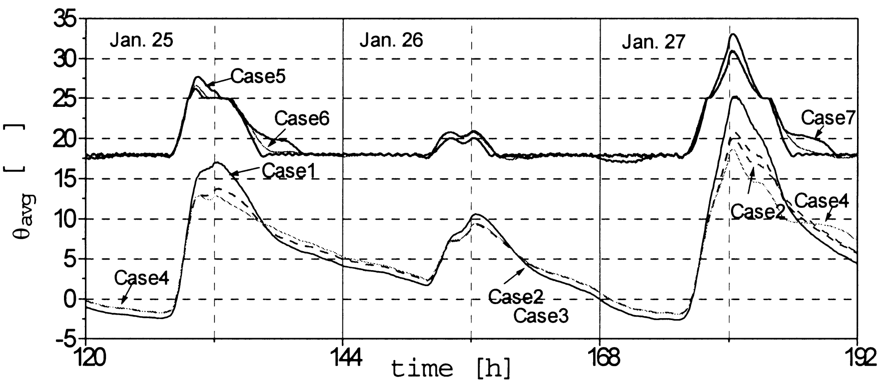

Fig. 4. Comparison of room average temperature.

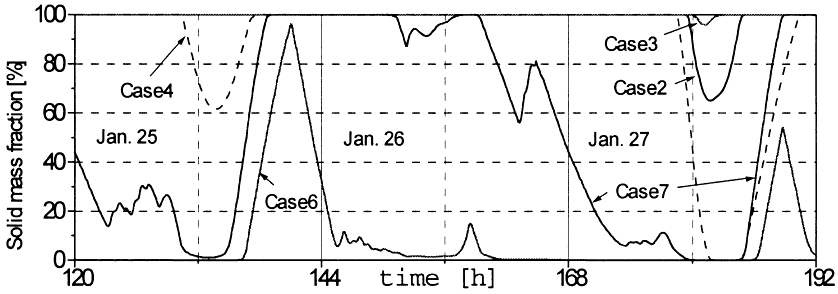

Fig. 5. Comparison of solid mass fraction of PCM.

The upper three curves of Fig. 4 are results for Cases 5, 6, and 7. Room average temperature θ_{avg} was maintained more than 18°C throughout all days, however, on fine days (25 and 27 January), room air was fairly overheated during the daytime. To utilize this surplus energy effectively, the amount of PCM (the thickness of the heat storage wall) or thermal properties (melting/freezing point) should be examined in detail.

Fig. 5 shows daily change of PCM solid mass fraction for Cases 2–7. In Fig. 5, a positive gradient of solid fraction curves express the freezing process (heat release) of PCM and the negative ones express melting process (heat absorption). In Cases 2, 3 and 4, the heater was not operated throughout the day, then, a phase change of PCM did not occur on a cloudy day (26 January) even in Case 4 which was assumed to be a relatively low melting/freezing point. However, PCM used in Case 4 may give acceptable thermal conditions without a subsidiary heater if a similar DHSS is applied in a district with a moderate climate. Comparison of results for Cases 6 and 7 indicates that the optimum PCM phase change point for this DHSS may be between 30 and 35°C.

As a reference, the total amount of electric power input and relative cost for

Table 1
Comparison of required electric power and cost

Case		25 January		26 January		27 January	
		(kwh)	Cost (–)	(kwh)	Cost (–)	(kwh)	Cost (–)
4	Daytime power	4.23	69	7.65	125	3.83	62
4	Midnight power	5.80	31	4.60	25	6.31	34
4	Total	10.03	100	12.25	150	10.15	96
6	Daytime power	2.70	44	7.83	128	3.03	49
6	Midnight power	6.23	33	5.81	31	6.73	36
6	Total	8.93	77	13.65	159	9.76	85
7	Daytime power	2.51	41	8.68	142	1.70	28
7	Midnight power	6.13	33	4.95	26	7.31	39
7	Total	8.65	74	13.63	168	9.01	67

Cases 5–7 are compared in Table 1. The cost of midnight electric power is about one third of that of daylight electric power in Japan. These data indicate that PCM systems have a lower cost and consume less energy on fine days (25 and 27 January) than those with no PCM systems (Case 5). However, on a cloudy day (26 January), the cost and energy consumption is almost the same in both systems. This is because PCM does not work effectively on cloudy days, as is shown in Fig. 5.

5. Conclusion

Basic performance of a hybrid heating system was investigated numerically through several case studies including examinations of effects of PCM as a heat storing materials. A simple test room was used with a thermal storage wall (Trombe wall) inside it. Simulated results indicate the effectiveness of PCM and suggest the possibility of developing low energy houses with the hybrid system introduced in this study. However, some systematic tests should be required to optimize PCM applications to DHSS for the selection and determination of PCM properties such as phase change points, PCM proportion in heat storage walls and their size, etc. These are areas for future study.

Acknowledgements

This study was supported by a grant-in-aid for scientific research from the Ministry of Education, Culture and Science, Japan.

References

[1] Onishi J, Shirahama S, Mizuno M. Study on CFD simulation of airflows and thermal environment in a passive solar room with a Trombe wall. In: Proceedings of the 5th International Conference on Air Distribution in Rooms, Yokohama, Japan, 1996. p. 213–8.
[2] Onishi J, Mizuno M. CFD Simulation of airflows and thermal environment in passive architectures — application to a room with Trombe wall system. In: Proceedings of the 14th International Conference on Passive and Low Energy Architecture, Kushiro, Japan, vol. 3, 1997. p. 63–68.
[3] Onishi J, Soeda H, Mizuno M. Numerical simulation of distributed heat storage system in a residential room with a massive wall. In: Proceedings of the 7th International Conference on Thermal Energy Storage, Sapporo, Japan, 1997. p. 343–8.
[4] Onishi J, Takeya N, Mizuno M. Study on numerical prediction methods for indoor air-flow and thermal environments (Part 1). Transactions of SHASEJ 1995;55:23–34 (in Japanese).