

Research on Thermal Storage using Rock Wool PCM Ceiling Board

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1. ABSTRACT

This study examined the effects of a peak shaving control of air conditioning systems using PCM (Phase Change Material) for ceiling boards in an office building. Rock wool PCM ceiling board (PCM ceiling board) was enhanced by adding microcapsulate PCM, with a melting point, of about 25 °C, close to room temperature. The load on the air-handling unit (AHU) can be reduced by using the thermal storage of the PCM ceiling board during the peak shaving control period. At the same time, the radiation field in the room can be also improved, due to stabilization of the ceiling board temperature at the PCM melting point.

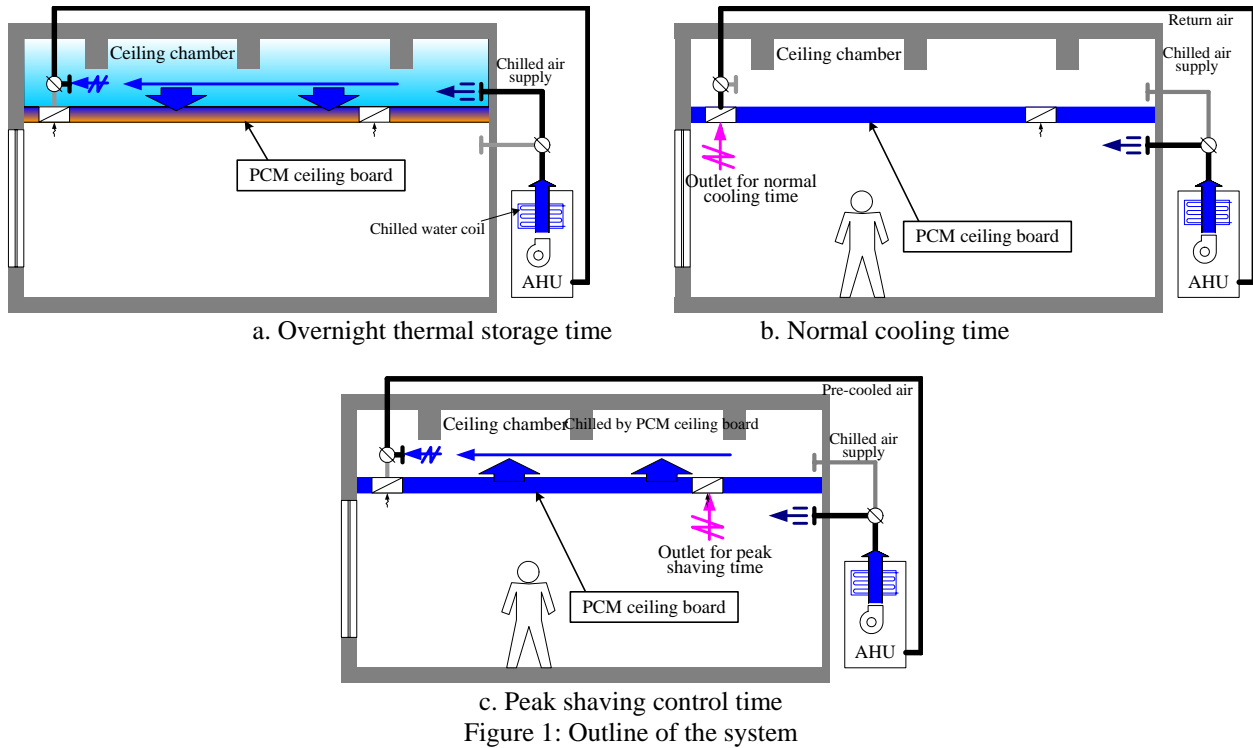
During overnight thermal storage, cool air from the AHU flows into the ceiling chamber space and chills the PCM ceiling board, storing cooling thermal energy. During the peak shaving period, when the thermal load peaks, the air from the room returns to the AHU via the ceiling chamber space. As a result of passing through the cooled-down PCM ceiling board, the warm air returning from the room cools down before returning to the AHU. The maximum thermal load and the capacity of heat source can thus be reduced.

2. OUTLINE OF THE SYSTEM

In this system, a PCM ceiling board is used instead of a rock wool ceiling board. Figure 1 shows an outline of the system. During overnight thermal storage, the cool air from the AHU flows into the ceiling chamber space and chills the PCM ceiling board, thus storing cooling thermal energy. The cooling thermal energy was stored using cut-rate electricity (Figure 1a). During normal cooling time, the cool air from the AHU flows directly into the room (Figure 1b). During peak shaving time, when the thermal load peaks, the air from the room returns to the AHU via the ceiling chamber space. As a result of passing through the cooled-down PCM ceiling board, the warm air returning from the room is pre-cooled on its way back to the AHU (Figure 1c). The maximum thermal load and the capacity of the heat source can thus be reduced. Normal cooling time is from 7am to 1pm. The peak shaving time is from 1pm to the end of business hours. In this study, the thermal storage time is from 4am to 7am. The reduced use of maximum-charge electricity during the peak shaving period and the use of cheaper-rate nighttime electricity result in lower energy costs.

This thermal storage system has the following advantages over conventional building thermal storage systems that use concrete floor slabs.

1. More efficient thermal storage is expected, since high-density cool air pools on the PCM ceiling board that forms the floor of the ceiling space.
2. All of the ceiling board can be used for thermal storage, since the cool air can flow through the ceiling chamber without being interrupted by beams.
3. Since the surface temperature of the ceiling board is kept at the PCM melting point for an extended period, the indoor thermal environment, including the radiant field, can be improved.



3. ROCK WOOL PCM CEILING BOARD

The PCM ceiling board was developed by adding microcapsulate PCM to commonly used rock wool ceiling board. The microcapsulate PCM is commercial material from Mitsubishi paper mills Ltd., Japan. The PCM in microcapsule is a mixture of n-paraffins (C16 to C20), with a melting point of approximately 25 °C. The diameter of each of the PCM microcapsules is about 5 micrometers and comprises, by weight, 80% PCM and 20% microcapsule shell material. To add microcapsulate PCM more effectively to the rock wool ceiling board, some microcapsulate PCM was clustered into flake shaped clumps of about 1-2mm. Figure 2 shows clumpy microcapsulate PCM. The production process of the PCM ceiling board involves adding clumpy microcapsulate PCM into a mixture of rock wool, water, binder, etc. The mixture is poured flat onto gauze and water is removed. Subsequently, it is pressed, dried and baked at a lower temperature to prevent burning. More than 100 sheets of PCM ceiling boards and rock wool ceiling boards respectively were made for comparison. Figure 3 shows the section of PCM ceiling board and rock wool ceiling board. Table 1 shows the average specific gravity and constituent rate of these PCM ceiling boards and rock wool ceiling boards. The specific gravity was measured before these were made. The PCM gravity is approximately 3.6kg in the PCM ceiling boards. The latent heat capacity, calculated based on the PCM gravity and the result in the DSC measurement of the microcapsulate PCM, is 690 kJ/m².



Figure 2: Clumpy microcapsulate PCM

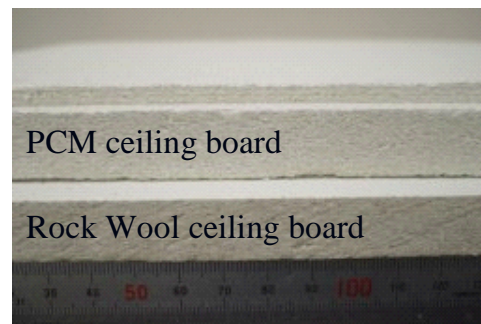


Figure 3: Section of ceiling boards

Table 1: Constituent of ceiling boards

		PCM ceiling board	Rock wool ceiling board
Size (Width*Depth*Thickness) [mm]		400 * 400 * 20	400 * 400 * 15
Specific gravity [kg/m ³] (Constituent rate) [%]	PCM	3.61 (44%)	-
	Rock wool	3.16 (39%)	3.95 (83%)
	Other organic material	0.81 (10%)	0.38 (8%)
	Other inorganic material	0.53 (7%)	0.43 (9%)
	Total	8.11(100%)	4.76 (100%)
Measured latent heat capacity by DSC [kJ/m ²]		191.3	-
Calculated latent heat capacity [kJ/m ²]		690.0	-

4. MEASUREMENT OF THE THERMAL CAPACITY OF THE PCM CEILING BOARD

The thermal capacity of the PCM ceiling board was measured using a small experimental chamber. Figure 4 shows an outline of the measurement system. The PCM ceiling board was installed between spaces 1 and 2. The size of the test piece PCM ceiling board is 300mm width, 400mm depth and 20mm thickness. Firstly, the air temperature of both spaces 1 and 2 was held at 16 °C. At this time, the cooling thermal energy is stored in the PCM ceiling board. Once the temperature of the PCM ceiling board reaches 16 °C, heater 1 heats the airspace of space 1, and heater 2 heats that of space 2 to 26°C. At this time, cooling thermal energy is transferred from the PCM ceiling board to the airspace of spaces 1 and 2. The thermal storage capacity of the PCM ceiling board is measured as the heat generation rate of heaters. For comparison, the thermal capacity of the rock wool ceiling board was measured using the same measurement system.

Figure 5 shows the fluctuations of the PCM ceiling board's inside, surface temperature and air temperature in spaces 1 and 2. Figure 6 shows the temperature fluctuations in the case of rock wool ceiling board. The temperature of the inside and surface of rock wool ceiling board rise at almost the same rate as the air temperature of spaces 1 and 2. However, the temperature of the inside and surface of the PCM ceiling board rises slowly. The temperature of the inside of the PCM ceiling board is about 2°C lower than the air temperature of spaces 1 and 2, one hour after the air temperature of spaces rise to 26°C.

Figure 7 shows the fluctuations in the heat generation rate of heater and the heat loss from the small experimental chamber to outside, in the case of the PCM ceiling board. Figure 8 shows that in the case for the rock wool ceiling board. Figure 9 and table 2 show the thermal capacity of the PCM ceiling board and the rock wool ceiling board, calculated by integrating the heat generation rate of heaters and the heat loss from the small experimental chamber to outside. The thermal capacity of the PCM ceiling board is approximately 663 kJ/m². It is 4.9 times that of ordinary rock wool ceiling board.

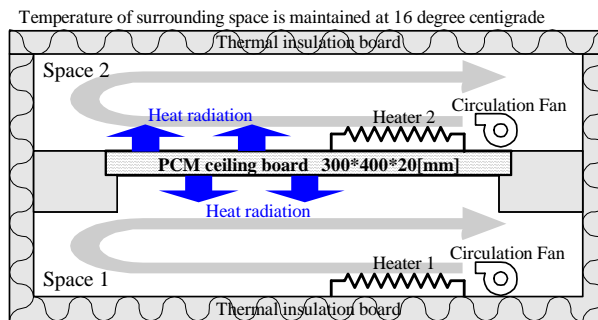


Figure 4: Thermal capacity measurement system

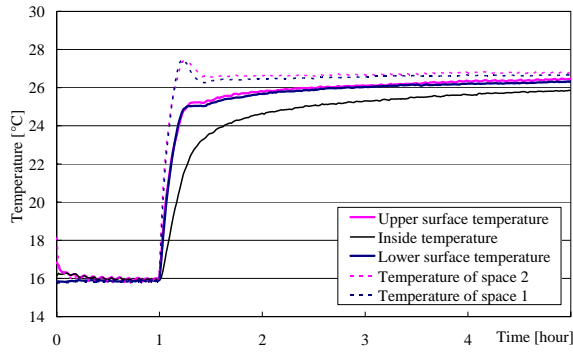


Figure 5: Temperature fluctuations of the PCM ceiling board

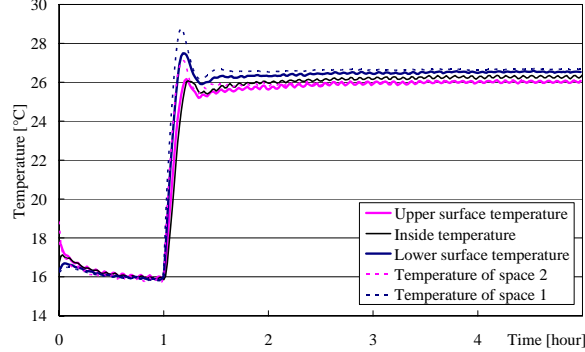


Figure 6: Temperature fluctuations of the rock wool ceiling board

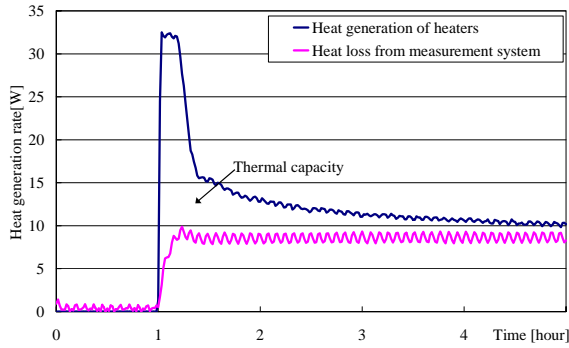


Figure 7: Heat generation rates of heaters in the case of the PCM ceiling board

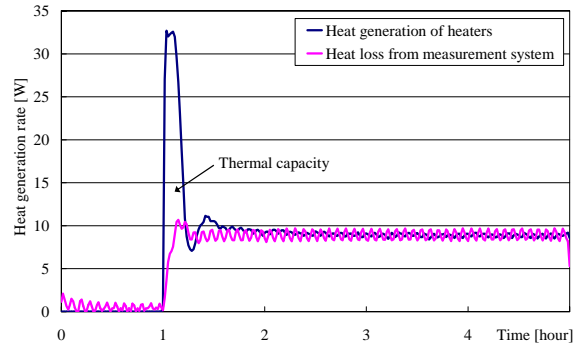


Figure 8: Heat generation rates of heaters in the case of the rock wool ceiling board

Table 2: Thermal capacity of the ceiling boards

	PCM ceiling board	Rock wool ceiling board
Measured thermal capacity [kJ/m ²]	663	135
Measured latent heat [kJ/m ²]	491	-
Measured sensible heat [kJ/m ²]	172	135

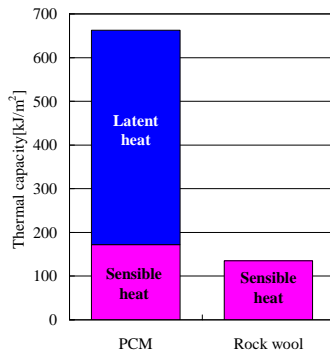


Figure 9: Thermal capacity of the ceiling boards

5. EXPERIMENTS USING THE EXPERIMENTAL CHAMBER

To examine the possibility of the peak shaving control using the PCM ceiling board, the experimental chamber was built. Figures 10 and 11 show the outline of the experimental chamber, while Figure 12 shows the inside of the same. The floor area is approximately 16 m², and the PCM ceiling board is used as the ceiling. The air temperature in the ceiling chamber space was controlled at 16°C by the AHU during overnight thermal storage time. During the normal cooling time, the cool air from the AHU flows into the ceiling chamber space at once, then the air from the ceiling chamber flows into the room space using the fan unit. The air temperature in the room space was controlled at 26°C by the fan unit. This is difference between the system outline on figure 1b. During the peak shaving time, the air from the room returns to the AHU via the ceiling chamber space. As a result of passing through the cooled-down PCM ceiling board, the warm air returning from the room is pre-cooled on its way back to the AHU. A comparison experiment was done using the rock wool ceiling board. The thermal storage time at night is from 4am

to 8am, and the normal cooling time is from 8am to 1pm. The peak shaving control time is from 1pm to 8pm. The room temperature of the adjoining space was maintained at 35°C as the outside temperature for all days. The air temperature of the surrounding space was about 26°C for all days.

Figure 13 shows the room temperature fluctuations using the PCM ceiling board and rock wool ceiling board. Figure 14 shows the surface temperature fluctuations of the PCM ceiling board and rock wool ceiling board. It shows that the rise in the surface temperature of the PCM ceiling board is approximately 1.8°C less than that of the rock wool ceiling board at the end of the peak shaving control time. Moreover, it is approximately 2.1°C one hour after the peak-cut control time start.

Figure 15 shows the thermal load fluctuations, while Figure 16 shows the integration of the thermal loads. The maximum thermal load using the PCM ceiling board is 85.2% of that using the rock wool ceiling board. However, the integrated thermal load is 105.3% compared to that using the rock wool ceiling board. The integrated thermal load at peak shaving control time is 80.7% compared to that using the rock wool ceiling board. The transition rate of the thermal load at night was 25.1%

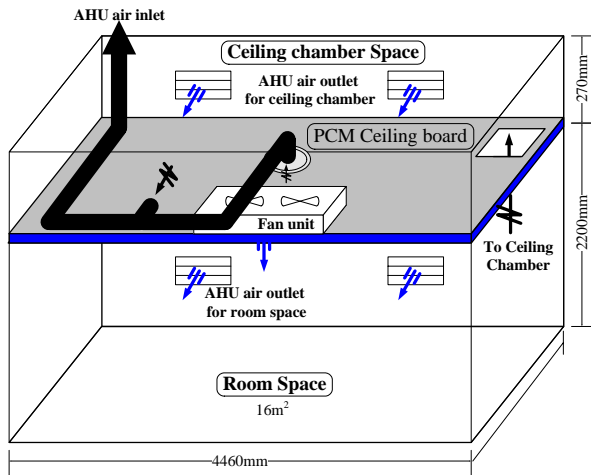


Figure 10: Outline of the experimental chamber

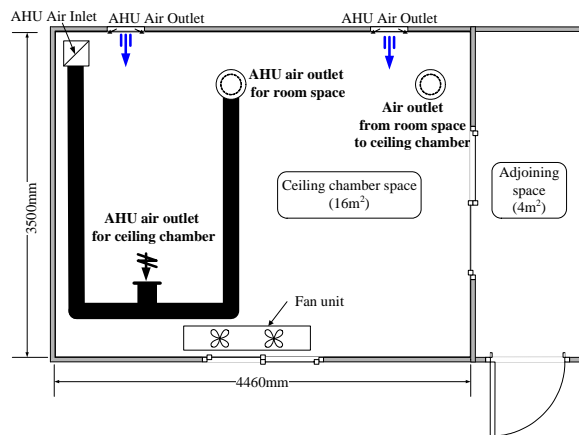


Figure 11: Plan of the experimental chamber



Figure 12: Inside the experimental chamber

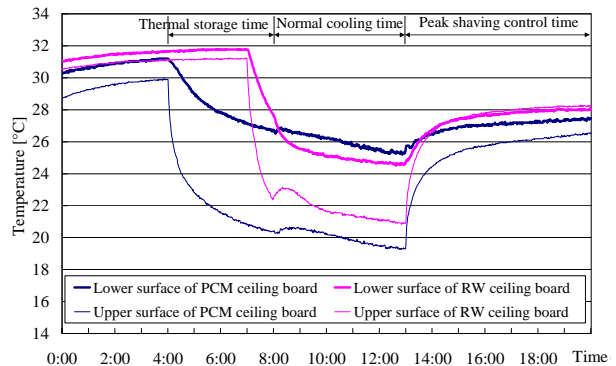
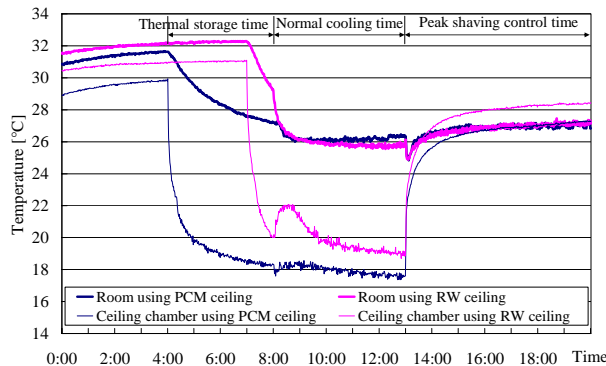


Figure 13: Ceiling boards surface temperature fluctuations

Figure 14: Room temperature fluctuations

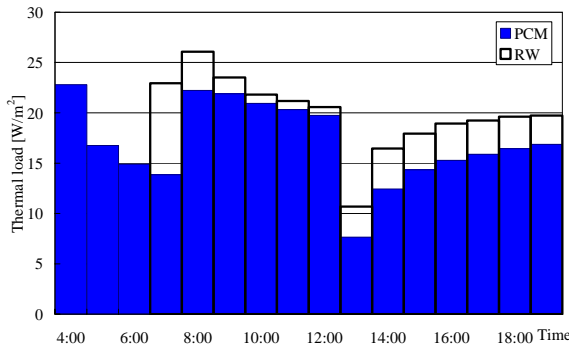


Figure 15: Thermal load fluctuations

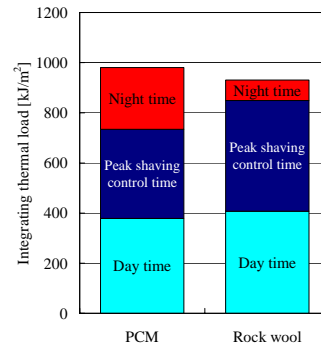


Figure 16: Integrating thermal load

6. CONCLUSION

In this study, the thermal capacity of the PCM ceiling board was measured by using a small experimental chamber. The thermal capacity of the PCM ceiling board is approximately 663 kJ/m^2 , which is 4.9 times that of an ordinary rock wool ceiling board.

The effects of peak shaving control were examined, using PCM ceiling board in the experimental chamber. The maximum thermal load using the PCM ceiling board was 85.2% of that of using rock wool ceiling board. As the maximum thermal load was reduced by 14.8% from the rock wool ceiling board, it can reduce the load on the AHU. However, the integrated thermal load was 5.3% greater than that using the rock wool ceiling board. The transition rate of the thermal load to the night was 25.1%. Discounted nighttime electricity, which is 75% cheaper than daytime electricity, can be used in Japan. The running cost is 91.6% lower than that of using the rock wool ceiling board. From these results, it can be concluded that the PCM ceiling system acts effectively to enable peak shaving control.

The PCM ceiling board has an issue of flammability. Although the flammability of PCM declines when it is added to a nonflammable rock wool ceiling board, it has not completely been solved. Improvement in the PCM ceiling bores is necessary for a practical system.

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REFERENCES

D.Banu,D.Feldman,D.Hawes, Evaluation of thermal storage as latent heat in phase change material wallboard by differential scanning calorimetry and large scale thermal testing, *Thermochimica Acta*, Volume 317, Issue 1, 6 July 1998, pp.39-45

M.Olszewski, Thermal energy storage technical progress report April 1992-March 1993, Oak Ridge National Laboratory, 1993

Katsunori Nagano, Sayaka Takeda, et al: Study on floor supply air conditioning system storing cold energy for building structure and granules including phase change material, *Journal of environmental engineering(Transactions of AIJ)*, No.579,2004

Takeshi Kondo, Tadahiko Ibamoto, Research on the thermal storage of PCM ceiling board, *Futurestock 2003 (9th International Conference on Thermal Energy Storage)*, Proceedings Volume 2, pp. 549-554, Warsaw, Poland