Energy saving effect by air circulation heat storage system using natural energy

1. Introduction

In the field of housing and buildings, the final energy consumption is accounted for more than 30% in Japan. The increase in energy consumption and CO₂ emissions from the past is remarkable and plays a major role in realizing a low-carbon society. Thus further strengthening of energy conservation measures is required. In this study, the development of a system is aimed at reducing sensible heat load and peak load in a detached house by employing air circulation type of central air conditioning system using PCM UNIT, which has latent heat storage effect. The system is maximized by applying the air circulation through the roof ventilation layer, by which heat exhaust and radiation cooling in summer / the heat collection in winter are performed. It is expected that the system can be introduced into ventilation layer provided in a conventional house.

2. Experiment on PCM BOX

A latent heat storage material (hereinafter referred to as PCM: Phase Change Material) is a heat storage material utilizing latent heat (heat absorption during melting/heat release during solidification) when a substance undergoes a phase change from solid to liquid or from liquid to solid.

Figure 2.1.(a) shows the interior of the experimental room, and Figure 2.1.(b) to (d) shows the condition of PCM BOX. Small joists (thickness 6mm, width 25mm) are installed on both sides of PCM packing component. The internal dimension of the box is 300mm×300mm×300mm. The outside surface of the XPS (Styrofoam) is affixed with an aluminum tape. The number of ventilation can be regarded as 0 times/h because the box is sealed as much as possible. The experiment is set to three levels: (a) Blank (without PCM), (b) PCM 1st layer (PCM exposed on the inner surface of the box), (c) PCM 2nd layer (PCM placed on the back side of the floor).

2.2. Results of measurement and calculation

The experimental results were verified by using a software THERB for HAM, which is combined simulation of heat and moisture transfer, and air flow. The thermal environmental condition in the experimental room is the temperature of 23℃ and the relative humidity of 50% in curing time. When measuring, the temperature is 23±7℃ (24 hour period) and the relative humidity is 50%. Figure 2.2 shows the measurement result of the temperature. It can be confirmed that PCM absorbs the heat during melting in the heating process and releases the heat in solidification in the cooling process through the temperature change of the PCM surface. Thus, the effect of thermal regulation and the peak temperature reduction by PCM are found. The larger storage capacity of Case 2, where PCM is exposed to the air inside PCM BOX, is considered than Case 3, comparing the temperature inside PCM BOX.
3. Analysis of effect of reduction in sensible heat load

3.1. Overview of experimental house

Figure 3.1 shows the exterior of the experimental house and Table 3.1 shows the overview of the house, which is located in Yufuin, Oita prefecture, Japan. Figure 3.2 and Figure 3.3 show the cross section of roof and the plan, respectively, and temperature measurement point. Measurement of thermal environments such as the internal temperature of the roof ventilation layer (eaves, center, ridge), indoor temperature and humidity, internal wall temperature and humidity, external weather have been performed.

3.2. Air circulation route

(1) Summer mode

Figure 3.4 shows the air circulation route in the summer mode. Firstly, since the temperature of the roof ventilation layer can be expected to decrease by radiative cooling at night, when the temperature of the center of the roof ventilation layer is 25°C or less, indoor air is taken into the roof ventilation layer and blown to the PCM UNIT, simultaneously with the cold storage in the PCM, and

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Table 3.1. Overview of experimental house

<table>
<thead>
<tr>
<th>Location</th>
<th>Yufuin, Oita Prefecture, Japan</th>
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</thead>
<tbody>
<tr>
<td>Total floor area</td>
<td>235.61 m²</td>
</tr>
<tr>
<td>Area classification</td>
<td>Area 5</td>
</tr>
<tr>
<td>Annual insolation area classification</td>
<td>A3</td>
</tr>
<tr>
<td>Insolation area classification in heating season</td>
<td>H2</td>
</tr>
<tr>
<td>Mean heat transmission coefficient of external wall</td>
<td>0.34/(m²·K)</td>
</tr>
</tbody>
</table>

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**Figure 3.1. Experimental house**

**Figure 3.2. Section of roof**

**Figure 3.3. Plan of experimental house**

**Figure 3.4. Example of Summer route of air circulation**

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then the air is moved to the air conditioning room (night cooling: route ①). Meanwhile, in the daytime, the center temperature of the roof ventilation layer becomes 25℃ or more, so indoor air is blown to PCM UNIT by fan B, without passing through the ventilation layer, and then, the cold stored at night is recovered and sent to the air conditioning room (daytime cooling: route ②). At the same time, since the roof ventilation layer becomes high temperature due to solar radiation reception during the daytime, the forced fan operates to take in outside air and exhaust heat in the roof ventilation layer (daytime heat exhaust: route ③). Through these air circulation route, the effect of reducing the sensible heat load in the daytime can be expected by releasing the cold stored in the PCM at night.

(2) Winter mode

Firstly, since the temperature of the roof ventilation layer can be expected to increase by solar radiation in the daytime, when the temperature of the center of the roof ventilation layer is 25℃ or more, the indoor air is taken into the roof ventilation layer by forced fan A, and blown to the PCM UNIT, simultaneously with the heat storage in the PCM. And then, the air is moved to the air conditioning room (daytime heating: route ④).

Meanwhile, at nighttime, the temperature of the roof ventilation layer becomes 25℃ or less, so indoor air is blown to PCM UNIT by fan B without passing through the ventilation layer, and the collected heat stored at night is recovered and sent to the air-conditioning room (night heating: route ②). Through these air circulation route, the effect of reducing the sensible heat load at nighttime can be expected by releasing the heat stored in the PCM during the daytime.

4. Results of actual measurement and calculation

4.1 Analysis of actual measurement

Figure 3.5~3.8 show the effect in summer mode, which is the radiative cooling, the change in heat quantity in PCM BOX, the integrated quantity of cold storage, and the temperature change in the roof ventilation layer, respectively. The sensible heat load is reduced in the summer because cooled air is blown into the air conditioning room according to the cold energy released a maximum of 6.6kWh/day by PCM during the daytime. Figure 3.9~3.12 show the effect in winter mode. The sensible heat load is reduced in winter because heat air is blown into the air conditioning room according to the hot energy released a maximum of 6.2kWh/day by PCM during night.
4.2. Comparison of measured and calculated value

Figure 3.13 shows the comparison of the measured and calculated temperature change by THERB for HAM in winter mode, which is susceptible spaces to air circulation in the roof ventilation layer or the amount of solar radiation. The calculated value matches the measured value with high accuracy, and the high accuracy of the calculation is confirmed.

4.3. Effect of reduction in sensible heat load

Figure 3.14 shows calculation result in order to confirm the effect of the reduction in the sensible heat load of the whole building in winter. Case 1 is each room air conditioning, Case 2 is air circulation system using roof ventilation layer, and Case 3 is Case 2 with PCM UNIT. The rate of reduction about 28% by using the system is evaluated in both summer and winter in comparison with Case 1. The total sensible heat load between Case 2 and Case 3 does not show clear distinction because PCM store and release repeatedly in order to decrease peak-load or overheating.

5. Conclusion

The effect of reduction in sensible heat of the air circulation system with PCM UNIT is confirmed. The heat storage amount of 6kWh/day and the reduction in sensible heat about 28% was evaluated in comparison of each room air conditioning.

Reference
