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Practical solutions with PCM for providing thermal stability of temporary house, school and hospital in disaster situations

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ABSTRACT

Globally, humanity is at risk from the coronavirus disease (COVID-19). To address the shortage of beds in quarantining those infected with COVID-19, hospitals have prepared temporary beds. However, for temporary hospital beds, it is difficult to maintain a comfortable temperature due to lack of insulation and heat storage. Phase change materials (PCMs) are used to provide temperature stability and control for temporary structure. Therefore, this study aimed to conduct experiments that analyze the effect of room temperature stabilization using a PCM. The method of macro packed PCM (MPPCM) was used to apply the PCM to buildings. The MPPCM installation location was selected and the effect of reducing the box temperature was analyzed, according to the strength of the heat source. As a result, a maximum reduction of 4.9 °C in the box temperature was achieved. Therefore, the application of MPPCM to buildings give to stabilize the box temperature. And the result showed the possibility of providing a comfortable indoor space for temporary hospital beds.

1. Introduction

Natural disasters (e.g., earthquakes, tsunamis, and volcanoes) and man-made disasters (e.g., nuclear power plant explosions, wars, and chemical leaks) cause enormous environmental, economic, and human damage. The 2004 Indian Ocean tsunami killed about 280,000 people and caused extensive destruction to buildings [1,2]. The 2011 Great East Japan Earthquake resulted in 18,434 deaths, 400,000 destroyed buildings, and countless missing persons [3]. The destruction of the first Fukushima nuclear power plant caused serious accidents, raising serious concerns not only in Japan but also around the world [4]. In addition, war creates large scale death and forced migration. As a result of ongoing conflict, many countries in Africa are experiencing refugee crises; temporary shelters are being used to house migrants [5]. Alongside these disasters, the global health pandemic has caused chaos. Since its onset in January 2020, COVID-19 has been considered the worst infectious disease in the 21st century. There have been about 100 million confirmed cases worldwide and 16 million in the United States alone. Public health systems have surpassed their capacity and quarantine hospitals have reached saturation. Korea has been successful in preventing the spread of the coronavirus and it is jokingly called K-quarantine [6]; however, 2000 confirmed cases occur daily and there are no more hospital beds in which to quarantine confirmed patients (As of August 11, 2021, there were 2223 patients). In such a crisis, temporary hospital beds are provided (see Fig. 1).

Table 1 shows the physical properties of each wall for the Normal and Temporary buildings shown in Fig. 2 are presented. In a general building, finishing materials such as gypsum board or granite are installed inside and outside, and heat capacity can be secured through the structure, and the insulation is also installed according to the insulation standard. However, in the case of a temporary building, it has a thin metal outer shell, and only a thin insulation material of about 100 mm is installed inside. Therefore, thermal insulation performance is degraded, and there is no heat storage element that can adequately retain heat. If the building is not properly insulated, it is difficult to comfortably maintain the indoor temperature; frequent and rapid temperature drops will occur.

In particular, the temperature control of hospital beds should be stricter than for the general public [8]. In spaces that require a high degree of concentration, such as an operating room, appropriate temperature control can increase survival and success rates [9]. Hashiguchi et al. mentioned that better thermal comfort should be given to medical personnel who care for and treat patients [10]. In particular, low temperatures and humidity can provide long-term viability of the COVID-19 virus and promote infectious transmission [11]. In addition, COVID-19 can be prevented from spreading outside the hospital room by

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PCMs have been ongoing. Various research studies related to energy saving in buildings have been conducted in parallel with research on reducing indoor temperature. Maria et al. found that by applying 1.4 cm thick PCM in the wall, the cooling load is reduced by up to 30% in preventing temperature rise due to solar radiation [20]. Pasupathy and Velraj reduced the cooling load by inserting a 2.5 cm thick PCM into roof layers and reducing the room width; the temperature changed by 6.8 °C [21]. Park et al. conducted an optimization study on the phase change temperature of a PCM for comfortable temperatures in Korea. Energy saving performance was analyzed using a gypsum board with PCM inside the building. The result was that a PCM with a phase change temperature of 23–24 °C was optimized [22]. Existing studies reduce energy consumption with a wall or ceiling insert, as an alternative to PCMs [23, 24]. Studies have also been conducted to increase the efficiency of HVAC system use the PCM. In a study by Liu et al., a PCM was introduced into the ventilation system to increase thermal efficiency. As a result, a PCM was placed in the outer diameter of the air pipe, improving thermal efficiency of the heat exchange ventilator and increasing ventilation efficiency [25]. In addition, research has been conducted to increase the efficiency of PCMs. By injecting air bubbles into a PCM, Plytaria et al. found an efficient method of heat transfer, devised to solve the temperature differentiation of the PCM and phase change [26]. There is also risk of fire [27]. In order to overcome these limitations, the authors’ previous research found that it energy savings can be achieved by simply using a PCM indoors [28]. However, previous studies employed simulations without actual verification. Therefore, the purpose of this study is to verify the effect of stabilizing the box temperature by simply placing the PCM indoors and maintain comfortable in box temperatures. To this end, a phase stabilization technique was used to efficiently use a PCM in the form of an MPPCM. Through the box test, evaluation was performed according to the application location and heat source of the MPPCM.

2. Experiment

2.1. Materials and preparation

A PCM was used in this study to stabilize the room temperature, considering the room temperature range. Comfortable room temperatures range between 20 and 28 °C. In addition, the optimum condition for the cooling temperature is between 26 and 28 °C, and thus n-octadecane (a paraffinic organic PCM with a phase change temperature of 28 °C) was used. The PCM was purchased from Celsius Korea, and the aluminum package was purchased at the local market. The physical properties of the PCM and aluminum package are shown in Table 2.

Since PCM requires phase stabilization, aluminum packing was used in this study. The aluminum packaging consists of aluminum outside and inside, and aluminum polyethylene in between. Since aluminum has a high thermal conductivity of 237 W/m·K, it compensates for the low thermal conductivity of the PCM by hastening the phase change. Polyethylene shows stability during phase change because almost chemical reactions rarely occurs. Therefore, a vacuum-sealed aluminum-packaged PCM was used in three different compartments; 60 g was packed in each area (a total of 180 g was packed). The packaged MPPCM is shown in Fig. 3.

2.2. Characterization techniques

Differential scanning calorimetry (DSC) analysis was performed to confirm the thermal storage performance of the MPPCM. The analysis range was 5–50 °C. The phase change temperature was confirmed through each peak heat flow by heating and cooling at a temperature increase rate of 5 min/°C.

Fourier transform infrared spectroscopy (FTIR; 300E, Jasco, Japan) analysis was performed to confirm the chemical changes after the MPPCM packaging and experimentation. The specimens were analyzed

Fig. 1. Temporary hospital bed installed in Seoul Medical Center [7].

![Normal building](image1.png)

![Temporary building](image2.png)

**Fig. 2.** Exterior and wall details of normal building and temporary building.

| Building type | Detail | Thermal conductivity (W/m·K) | Thickness (mm) | Specific heat (J/kg) | Density (kg/m³) |
|---------------|--------|------------------------------|----------------|---------------------|-----------------|
| General buildings | Inner finish (Gypsum board) | 0.2 | 20 | 1100 | 700 |
| | Concrete Insulation (XPS) | 1.6 | 150 | 950 | 2200 |
| | Outer finish (granite) | 0.028 | 200 | 1000 | 30 |
| | 2.8 | 30 | 1000 | 2600 |
| Temporary building | Aluminum Insulation (EPS) | 237 | 3 | 0.214 | 2.71 |
| | 0.032 | 100 | 1000 | 0.94 |
in the range of 650–4000 cm⁻¹, with a spectrum resolution of 4 cm⁻¹. This was done by packing the PCM in the packaging material and checking the chemical change after heating and cooling, confirming the chemical change caused by the packaging of MPPCM and showing the possibility of continuous use.

2.3. Experimental setup

The experimental setup is shown in Fig. 4. The setup constructed an open top box from medium-density (20 mm thick) fiberboard (MDF). The upper part of the box was covered with 5 mm thick glass, so that the radiant heat from the lamp could be transferred into the box. The box temperature was measured using a datalogger and a k-type thermo-couple sensor. To measure the box temperature, the sensor was located in the center of the box and a shield was installed atop the sensor (to prevent direct sunlight from the lamp).

Three experiments were performed using this setup.

1. Analysis for stabilizing box temperature according to the installation location of the MPPCM
2. Analysis for stabilizing the box temperature according to the change in the intensity of the heat source (50–250 W)
3. Analysis for stabilizing the box temperature effect of the MPPCM when an HVAC cooling unit is used

The first experiment analyzed the box temperature reduction effect according to the installation location of the MPPCM. It was divided into three configurations (see Fig. 5).

I. Four MPPCM sheets applied to each 4-wall surface
II. Two MPPCM sheets applied to the floor
III. Four MPPCM sheets applied to the floor

The second experiment was carried out to analyze the effect of the MPPCM in maintaining a comfortable box temperature, according to the intensity of the heat source (replicating seasonality) [29]. The heat sources were 50, 125, 150, 250 W infrared lamps and a halogen lamp. The heat conversion efficiency of each lamp was 90% [30]. The position of the Fig. 5 lamp was adjusted 10 cm above the glass so that all light from the light source presented in Fig. 6 entered the box. In addition, the transmittance of the glass at the top of the box showed a transmittance of 75% in the near-infrared rays of 800–1500 nm that provide thermal energy to the box.

3. Results and discussion

3.1. Thermal properties analysis

Fig. 7 shows the DSC analysis results of n-octadecane. As a result of DSC analysis, during endothermic, the phase change of PCM started from 21.89 °C and lasted up to 34.87 °C. In addition, during exothermic, the phase change started from 26.99 °C and ended at 18.36 °C. From this, it was confirmed that the phase change range of n-octadecane was 18.36–34.87 °C. The latent calories were 205.7 J/g and 202.6 J/g, respectively. These are higher than the latent heat value (less than about 100 J/g) generally used in other studies to measure latent heat; this means that more heat energy can be stored. Additionally, no supercooling phenomena were observed in n-octadecane. In general,
paraffinic PCMs such as \( n \)-octadecane rarely cause supercooling phenomena.

3.2. Chemical stability and usability analysis

FTIR analysis was performed to evaluate the continued usability of the MPPCM (see Fig. 8). The results analyzed repeated heating and cooling of 100 times from 20 °C to 80 °C, and the chemical change of the PCM without repeated heating and cooling. It was confirmed that each peak coincided, which means that when heating and cooling are repeated, the PCM remains chemically stable. Therefore, when PCM is applied to boxes and buildings, it can be used stably without chemical change for about 6 months.

3.3. Analysis of installation location of MPPCM

First, we analyzed the effect of stabilizing the box temperature, according to the installation location of the MPPCM. Then, we analyzed the effect according to the volume and location of the PCM, by dividing
the case into a wall and a floor and varying the amount of PCM applied to wall and floor. The analysis is shown in Fig. 9. The box was heated with an infrared lamp for a total of 6 h. When applying four MPPCM sheets (see Fig. 9 (a)). About 3.7 h, the temperature of the PCM box was maintained at about 2.6 °C lower than the non-PCM box. And after, the temperature difference was reversed, and the temperature in the PCM box became higher. This result is analyzed because the PCM starts to release the stored heat after the phase change. Fig. 9 (b) shows the case in which the MPPCM was applied to the bottom of two sheets. The temperature of each box increased during 1 h of heating. And during that time, the temperature of the PCM box was about 2.5 °C lower than that of the non-PCM box. As heating continued, the temperature difference between the boxes decreased, but it was confirmed that the temperature of the PCM box was consistently lower by about 1 °C. Fig. 9 (c) shows the case in which the MPPCM was applied to the bottom of four sheets. 1 h after the start of heating, the temperature of the PCM box was maintained at a maximum of 2.7 °C lower than that of the non-PCM box. In observing results of this experiment, the case of MPPCM applied to the wall was excluded from subsequent experiments because the box temperature was not maintained stably. In addition, the case in which two and four MPPCMs were applied to the floor, respectively, showed the effect of stabilizing the box temperature. However, there was no significant difference depending on the applied PCM capacity two or four sheet at bottom. Accordingly, the case in which two MPPCMs were applied was judged to be the optimal application method. As a result, that method of applying MPPCM in two layers was used to analyze box temperature stabilization, according to heat source intensity.

3.4. MPPCM efficiency analysis by heat source

After analyzing the effect based on application location, it was confirmed that the case in which two sheets of MPPCM were applied to the floor was the most effective. Accordingly, we conducted an experiment to evaluate the effect of stabilizing the box temperature of MPPCM by heat source strength. Fig. 10 shows that each case was repeated three times (2 h of heating and 2 h of cooling) for a total of 12 h. The purpose was to verify that the MPPCM can maintain stable box temperature under continuous heating and cooling conditions. When heated to 50 W, the temperature in both boxes reached the phase change temperature, but the box temperature did not reduce because the MPPCM was sufficiently heated to be liquefied. However, it was confirmed that the temperature of the PCM box was higher during cooling. Furthermore, it was determined that it would be appropriate to use when heating was needed, because the PCM stabilized the box temperature through phase change. In the case of 125 W, it was confirmed that the temperature of the non-PCM box reached 40 °C. There is a difference in reduction of the

![Fig. 9. Effect of box temperature stabilization according to the location of MPPCM.](image-url)
The reduction in the box temperature was 2.9 °C in the first cycle, 1.2 °C in the second cycle, and 1.2 °C in the third cycle. When cooled, it was kept at a temperature as high as 0.7 °C. In the case of 150 W, it was confirmed that the box temperature of the non-PCM box was increased to 45 °C. In the first cycle, the box temperature was reduced by 3.8 °C, 2.5 °C in the second cycle, and 2.1 °C in the third cycle. When cooled, it was kept at a temperature as high as 0.8 °C. In the 250 W case, it was confirmed that the box temperature of the non-PCM box was heated to 45 °C. In the first cycle, the box temperature was reduced by 4.9 °C, 2.3 °C in the second cycle, and 1.3 °C in the third. During cooling, it was kept at a temperature as high as 0.1 °C. See Table 3 for the reduction effect of the peak temperature. The experiment indicated that the stronger the intensity of the heat source (i.e., the higher the box temperature), the higher the temperature reduction effect. In addition, as the number of repetitions of the cycle increased, the effect of reducing the box temperature gradually decreased. However, the temperature of the PCM box did not rise above the non-PCM box during the three cycle repetitions. Therefore, it is determined that the effect of the MPPCM is maintained even during repeated heating and cooling. In conclusion, the application of the MPPCM reduced the rate of increase in box temperature and reduced the peak temperature. The factor of decrease in peak temperature can be analyzed as the effect through heat absorption during the phase change of the PCM. For the PCM to be liquified, it must absorb heat. However, in this process, the temperature of the PCM does not increase. Therefore, the air with high ambient temperature is dissipated, and the air temperature is lowered. In addition, since aluminum (the outermost part of the MPPCM) has high thermal conductivity, it can quickly remove heat from the air, allowing heat transfer to proceed quickly. As a result, it was confirmed that the application of the MPPCM can stabilize box temperatures.

4. Conclusions

To analyze the box temperature stabilization effect of PCMs, a PCM was phase-stabilized in the form of an MPPCM. And through experiments, we determined that the MPPCM can stabilize box temperature. In this study, the latent calorific value of the PCM was measured by DSC and found to be about 205 J/g. By examining the chemical change of repeated use, over 100 cycles, FTIR confirmed that hardly any chemical change occurred. Additionally, regarding application location and quantity, floor installation is most effective. As a result of the analysis, it was most effective to apply two MPPCM sheets equivalent to 0.6% of the box volume to the floor. The effect of annual MPPCM reduction in box temperature was analyzed by a heat source intensity experiment (50–250 W), which mimics seasonal insolation in the 30–50° north latitude region. As a result, in all cases, the MPPCM showed the effect of stabilizing box temperature. In particular, when a 250W heat source was applied to the box, the temperature inside the box could be lowered than non-PCM box 4.9 °C. This research was conducted in a small box unit experiment, and it is like a mock-up of a temporary building on a real scale unit. Therefore, in future studies, it is necessary to proceed with the application of PCM to real-scale temporary buildings.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
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