Simulation-based analysis of optimized PCM to improve building energy performance and indoor thermal environment

Ji Hun Park1, Seunghwan Wi1, Beom Yeol Yun1, Sungwoong Yang1, Jongki Lee1 and Sumin Kim1,*

1 Department of Architecture and Architectural Engineering, Yonsei University, Seoul 03722, Republic of Korea
* kimsumin@yonsei.ac.kr

Abstract. The objective of this paper is to evaluate the optimized PCM melting temperature installed in the building models by DesignBuilder and analyze the building energy performance depending on the different climate conditions in South Korea. The building model was followed the residential construction standard house established by the Korea Rural Community Corporation. The total floor area of building is 41.92 m², and the window-to-wall ratio is 30 %. The HVAC conditions were set to "simple HVAC" which is the basic load calculation algorithms to minimize the heating and cooling loads. Set-point temperatures set to the comfort temperature range, and set-back temperatures are based on the recommendation of the Ministry of Trade, Industry, and Energy of South Korea (MOTIE). The climate conditions to evaluate the simulation analysis were based on the Köppen-Geiger climate classification, which classifies the general climate of the world depending on temperature and precipitation. As a result of the simulation analysis, the maximum energy savings were shown by PCM with melting point of (22.39–24.47) °C in cooling, and PCM with (19.73–21.38) °C in heating. Consequently, the maximum total energy savings were achieved for PCM with (22.39–24.47) °C, which means that the best optimized PCM according to the four seasons.

1. Introduction
Phase change material (PCM), a thermal energy storage (TES) material, is considered an effective and promising material to reduce energy consumption; research on the application of PCM to provide higher comfort for occupants has been growing rapidly [1]. Recent studies showed the variety of PCM application to the buildings. Beltrán and Martínez-Gómez [2] evaluated the PCM application for building wallboards and roofs in Ecuadorian dwellings. Plytaria et al. [3] investigated a solar cooling system with or without PCMs in a building in Athens, Greece. Zhu et al. [4] analyzed buildings with double-layered shape-stabilized PCM (SSPCM) wall boards located in Wuhan city.

In South Korea, there are many studies for energy savings by PCM application to the buildings. However, not many studies for simulation-based analysis of PCM application to the buildings as passive energy-saving technology were performed. In this study, simulation-based analysis of optimized PCM application to the buildings by DesignBuilder simulation was conducted to analyze building energy performance according to the different climate conditions in South Korea.
2. Input data

2.1. PCM properties

The properties of selected PCMs were described specifically in previous study [5]. To evaluate the PCM, since the enthalpy-temperature function is required [6], the enthalpy properties of the optimized PCMs were analyzed as shown in Figure 1. The melting temperature of the PCM1 to PCM7 was 26 to 28 ℃, 23.46 to 26.46 ℃, 22.39 to 24.47 ℃, 20.94 to 24.33 ℃, 20.15 to 22.61 ℃, 19.73 to 21.38 ℃, and 20 to 22 ℃. In addition, any other thermal properties of PCM were used as shown in Table 1. Those PCMs were applied to the gypsum board as an interior finishing material. Then, building energy performance of building model with or without PCM was evaluated.

![Figure 1. Enthalpy of selected PCMs.](image)

**Table 1.** Thermal properties of selected PCMs.

| Specimen | Density (kg/m³) | Specific heat capacity (J/kgK) | Latent heat capacity (J/g) | Thermal conductivity (W/mK) |
|----------|----------------|-------------------------------|---------------------------|-----------------------------|
| REF      | 950            | 1000                          | -                         | 0.200                       |
| PCM1     | 948            | 1535                          | 247.6                     | 245.8                       | 0.248                       |
| PCM2     | 942            | 1600                          | 207.8                     | 194.5                       | 0.236                       |
| PCM3     | 926            | 2015                          | 183.2                     | 192.0                       | 0.214                       |
| PCM4     | 966            | 1330                          | 171.8                     | 156.5                       | 0.186                       |
| PCM5     | 957            | 1615                          | 171.4                     | 169.0                       | 0.172                       |
| PCM6     | 941            | 2155                          | 191.1                     | 173.6                       | 0.160                       |
| PCM7     | 956            | 1930                          | 216.7                     | 213.2                       | 0.146                       |

2.2. Building model description

The building modelling was the residential construction standard house established by the Korea Rural Community Corporation. The building is (6.0 m x 6.9 m x 3.9 m) (ceiling height of 2.4 m), a total floor area of 41.92 m². The building is south-oriented, with 30 % window-to-wall area. According to the boundary conditions, there are the main zone as a living space and the un-conditioned zone as storage. Table 2 shows the construction details of the model. The selected PCMs were installed on the interior finishing of the external wall by replacing with a conventional gypsum board of 9 mm as a reference (REF).
Table 2. Construction details of building model.

| Construction details | Thickness (m) | U-Value (W/m²K) |
|----------------------|---------------|-----------------|
| External wall        | 0.26          | 0.174           |
| Roof                | 0.25          | 0.150           |
| Internal partition   | 0.14          | 1.869           |
| Ceiling              | 0.01          | 5.333           |
| Floor                | 0.15          | 0.359           |

Regarding HVAC system, the model is considered to have the common circulation activity of a residential building. To simulate the actual use of residential building, the schedules of occupancy, lighting, and equipment were set to 100% running from 18:00 to 08:00 on weekdays, and all day on weekends. The maximum heat gain provided by equipment is 3.00 W/m², and the target illumination level is 100 lux. The HVAC conditions were set to "simple HVAC", the basic load calculation algorithms to minimize space heating and cooling loads. Considering set-point temperatures, when the space is occupied, the heating and cooling set-point temperatures are set to 20 and 26 ℃, respectively. When unoccupied, the set-back temperatures of heating and cooling revert to 18 and 28 ℃ according to the recommendation of the Ministry of Trade, Industry, and Energy of South Korea (MOTIE).

2.3. Climatic conditions
Gangneung, Gwangju, Incheon, and Ulsan were selected as weather data for simulation as shown in Table 3, which shows the climate conditions of these cities. South Korea is located in a humid continental/subtropical climate with dry winter. In summer, the temperature of South Korea is relatively high, and the rainy season produces a lot of rain, especially from July to August. Compared to summer, winter is cold and dry. In addition, the annual difference of temperature is very large. Thus, the specific four districts of South Korea, included in Cfa, Dfa, and Dwa, were selected for energy performance of the optimized PCMs.

Table 3. Climatic conditions of selected locations.

| Location | Temperature (℃) | Relative humidity (%) |
|----------|-----------------|-----------------------|
|          | Max. | Min. | Max. | Min. |
| Gangneung | 24.6 | 0.4 | 78.1 | 47.8 |
| Gwangju  | 26.2 | 0.6 | 80   | 61.9 |
| Incheon  | 25.2 | -2.1| 82.2 | 61.5 |
| Ulsan    | 25.9 | 2.0 | 78.9 | 49.6 |

3. Results and discussion
According to the analysis results of building energy performance in buildings according to the PCMs and the locations as shown in Figure 2, optimized PCM for cooling and heating was different. In cooling, PCM3, having 22.39 to 24.47 ℃, contributed to reduce the highest cooling energy consumptions. On the contrary, PCM6, having melting temperature of 19.73 to 21.38 ℃, contributed to reduce a large amount of heating energy consumptions. This is because the indoor temperature of the buildings maintains from 20 to 26 ℃ by heating and cooling control, leading PCM efficiency close to the indoor temperature to be increased. In addition, according to the different locations, although building energy savings depending on the locations were different due to the outdoor conditions such as temperature, wind speed, and relative humidity [7], PCM3 and PCM6 showed the highest building energy savings in all locations. Considering the total energy consumptions in buildings, PCM6 was the most effective ways for energy savings in all locations. This indicates that PCM, including in melting temperature of 22 to 24 ℃, was required considering PCM application to residential building in South Korea.
4. Conclusion
In this study, evaluation of the optimized PCM melting temperature installed in the building was
analyzed for the building energy performance depending on the different climate conditions in South
Korea. According to the simulation results, the maximum energy savings were shown by PCM with
melting point of (22.39–24.47) °C in cooling, and PCM with (19.73–21.38) °C in heating. Consequently,
the maximum total energy savings were achieved in PCM of (22.39–24.47) °C, which indicates that
PCM application to building in South Korea is necessary within melting temperature of (22–24) °C. The
further study of mock-up test or PCM application to the real building is required to evaluate the utility
and applicability of experimented PCMs.

Figure 2. Building energy savings of buildings in (a) Gangneung, (b) Gwangju, (c) Incheon, and (d)
Ulsan according to the PCMs.

References
[1] Park JH, Jeon J, Lee J, Wi S, Yun BY and Kim S 2019 Build Environ 151 p 291–302
[2] Beltrán RD and Martínez-Gómez J 2019 J Build Eng 24 p 1-16
[3] Plytaria MT, Bellos E, Tzivanidis C and Antonopoulos KA 2019 Energy Convers Manag 188 p 40-53
[4] Zhu N, Hu N, Hu P and Li S 2019 Energy 167 p 1164-1180
[5] Park JH, Lee J, Wi S, Jeon J, Chang SJ, Chang JD and Kim S 2019 Energy Build 185 p 12–25
[6] Konstantinidou CA, Lang W and Papadopoulos AM 2018 Int J Energy Res 42 p 1–18
[7] Saffari M, Gracia A, Fernández C and Cabeza LF 2017 Appl Energy 202 p 424–434