Manufacture of optimized PCM within thermal comfort range to improve building energy performance

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Abstract. The objective of study is to manufacture the optimized PCM within thermal comfort range to improve thermal performance and building energy performance. In order to prepare the melting temperature of PCM close to the thermal comfort range, n-octadecane (OT), n-heptadecane (HT), and n-hexadecane (HX) were selected. According to the circulation water bath test to investigate the melting temperature of PCM, the mixed PCMs of OT and HT (OTHT) with 22 to 23 °C were close to the thermal comfort range. In addition, the circulation water bath test of OTHT depending on various mixing ratio, divided into ratios of 9:1 to 1:9, was conducted to evaluate the ideal PCM melting temperature. As a result, melting temperature of OTHTs were measured to be 24 to 26 °C, 23 to 24 °C, 23 to 24 °C, 21 to 23 °C, and 20 to 22 °C, respectively. According to the analysis of thermal performance of OTHTs, OTHT91, where phase change temperature appeared at 24 to 26 °C, were the optimized PCM due to the highest latent heat capacity and ideal melting temperature within thermal comfort range. This indicate that building materials with application of OTHT91 can contribute to reducing building energy consumption and improving thermal comfort of occupants when the indoor condition in buildings is maintained at thermal comfort range.

1. Introduction

A current issue in building sector is to decrease the environmental load from energy-saving technology since the wide growth and pursuit of the occupants' comfort in buildings lead to increase the building energy consumptions. Therefore, many studies have been actively researched to decrease the building energy consumptions. Recent studies for building energy savings focused on the Thermal Energy Storage (TES) system, one of the promising technologies for building energy reductions [1].

Phase change materials (PCM) are one of the effective ways in passive TES systems by using latent heat energy storage (LHTES) method. Many research studied how to apply PCM to the building and to analyze the building energy performance and thermal comfort by PCM [2]. In addition, PCM requires PCM encapsulation for application to the buildings since there are some problems to leak out from the building materials with PCM. Therefore, the various methods to prevent the leakage of liquid PCM are introduced: shape-stabilized PCM (SSPCM) [3], microencapsulated PCM (MPCM) [4], macro-packed PCM (MPPCM) [5], and the direct incorporation of PCM techniques [6].

To provide thermal comfort and energy reduction by PCM application to the buildings, the ideal melting temperature of PCM is important, which is highly influenced by the indoor temperature of the buildings with PCM application [7, 8]. Thus, the consideration of PCM melting temperature within thermal comfort zone ranging from 20 to 26 °C is necessary. In this paper, investigation of the optimized PCM within thermal comfort range has been studied. The selected PCMs were n-octadecane (OT), n-heptadecane (HT), and n-hexadecane (HX), which are series of paraffinic PCMs. PCMs with ideal melting temperature were prepared by mixing these PCMs. The melting temperature of PCMs were evaluated by the circulation water bath test. Thermo-physical properties and chemical stability of the
PCMs were analyzed by Differential scanning calorimetry (DSC) and Fourier transform infrared spectrometry (FTIR).

2. Methods

2.1. Materials and preparation

Table 1 shows the thermo-physical properties of the selected PCM. Those were obtained from the Celsius Korea Corporation and the Sigma-Aldrich Corporation. The melting temperature of OT, HT, and HX are 28.0, 22.0, and 18.0 °C close to the thermal comfort range based on ISO 13790. The circulation water bath test has been performed to investigate the ideal PCM melting temperature [9]. Before the test, OT, HT, HX, and mixed PCM by mixing OT, HT, and HX under 1:1 ratio were manufactured and named OTHT, OTHX, and HTHX. The process of circulation water bath was set from 15 to 30 °C on heating and from 30 to 15 °C on cooling.

| Melting temperature (°C) | Latent heat capacity (J/g) | Thermal conductivity (W/mK) | Density (kg/l) |
|--------------------------|---------------------------|-----------------------------|---------------|
| OT                       | 28.0                      | 256.5                       | 0.26          | 0.77          |
| HT                       | 22.0                      | 200.0                       | 0.14          | 0.77          |
| HX                       | 18.0                      | 257.7                       | 0.39          | 0.77          |

2.2. Characterization techniques

Analysis of thermal properties of the PCMs was measured by using DSC, performing at a 5 °C/min on heating and cooling rate over temperature ranges from 0 to 80 °C. Numerical integration of peaks depending on the state of PCM calculates the latent heat capacities of PCM. The measurement of the PCM's structure and special functional groups for evaluating chemical stability was conducted by the FTIR analysis (Nicolet 6700), investigating infrared energy of 2.5-1.5 μm penetrating substance-specific absorption spectra in the range of 650 to 4000 cm⁻¹. Thermal conductivities of the specimens were measured by TCi thermal conductivity analyzer (Thermal Technologes Ltd) that used the Modified Transient Plane Source (MTPS) method.

3. Results and discussion

In order to investigate the ideal PCM melting temperature within the thermal comfort range, circulation water bath test were performed as shown in Figure 1(a) and (b). The temperature changes of OT, HT, and HX were measured to be at 26 to 28 °C, 20 to 22 °C, and 16-18 °C, respectively. In case of OTHT, OTHX, and HTHX, the values of those were 22 to 23 °C, 18 to 20 °C, and 16-18 °C, respectively. This shows that the experimental melting temperature of OT, HT, and HX as the pure PCMs appeared at the theoretical values, and mixing each pure PCM at a ratio of 1:1 could contribute creating the specific melting temperature range within the thermal comfort range. As a result, OTHT had the ideal melting temperature of 22 to 23 °C within the thermal comfort range.

The circulation water bath test was re-performed to investigate the most optimized PCM by various mixing ratio of OTHT as shown in Table 2. The mixing ratio of OT and HT was divided into five methods in odd integer ratio of 9:1 to 1:9, and the prepared PCMs were named OTHT91, OTHT73, OTHT55, OTHT37, and OTHT19, respectively. Figure 2 shows the temperature changes of those PCMs on heating and cooling. According to the results of circulation water bath, the phase changes of OTHT91, OTHT73, OTHT55, OTHT37, and OTHT19 appeared at 24 to 26 °C, 23 to 24 °C, 22 to 23 °C, 21 to 23 °C, and 20 to 22 °C, respectively. Since those melting temperature included in the thermal comfort range rather than the pure PCMs, the efficiency of PCMs would be higher when applied to the buildings.
Figure 1. Circulation water bath test of selected PCMs on (a) heating and (b) cooling.

Figure 2. Circulation water bath test of OTHT on (a) heating and (b) cooling according to various mixing ratio.

Table 2. Various mixing ratios of OTHT for circulation water bath test.

| Specimen | OT (%) | HT (%) |
|----------|--------|--------|
| OTHT91   | 90     | 10     |
| OTHT73   | 70     | 30     |
| OTHT55   | 50     | 50     |
| OTHT37   | 30     | 70     |
| OTHT19   | 10     | 90     |
Figure 3 and Table 3 shows the FTIR absorption spectra of pure PCM, OT and HT, and OTHTs for the chemical stability of PCMs. OT and HT appear at theoretical structures which were alkane chains as mentioned above, and OTHT as the mixed PCM consists of both chemical properties of OT and HT. In other words, since alkanes consist of hydrogen and carbon atoms, OT and HT contain –CH2 and –CH3 bonding. OTHT as mixture of OT and HT is only composed of –CH2 and –CH3 bonding peaks, which indicates that properties of OH in OTHT do not change after the mixing process. Therefore, the characteristics of OTHT91 to OTHT19 could maintain the structure of OT and HT by the physical bonding without a change in those chemical properties.

![Figure 3. FTIR spectra of selected PCMs.](image)

**Table 3.** FTIR spectra of selected PCMs.

| Vibration                                | Wave number range (cm⁻¹) |
|------------------------------------------|--------------------------|
| C-H₃ and C-H₂ asymmetric stretch         | 2,962±10                 |
| C-H₃ symmetric stretch                   | 2,872±10                 |
| C-H₂ symmetric stretch                   | 2,855±10                 |
| C-H₃ umbrella bending vibration          | 1,377±10                 |
| C-H₂ rocking vibration                   | 720±10                   |

Table 4 shows the latent heat capacities of OTHTs. When the mixing ratio of HT increased, OTHT91 to OTHT19 had specific solid-solid phase change state in the endothermic process and the exothermic process. In addition, the temperature of solid-solid phase change state was decreased to sub-zero temperature depending on the mixing ratio. The latent heat capacities of OTHT91 to OTHT19 were 207.8, 183.2, 171.8, 171.4, and 191.1 J/g in the endothermic process, and 192.0, 194.5, 156.5, 169.0, and 173.6 J/g in the exothermic process. The differences between endothermic and exothermic process of OTHTs was higher than pure PCMs since super-cooling could be occurred but insignificant difference. According to the melting temperature of OTHTs, the values of OTHT91 to OTHT19 were measured at 26.46, 24.47, 24.33, 22.61, and 21.38 °C in the endothermic process, and 23.42, 22.39, 20.94, 20.15, and 19.73 °C in the exothermic process. Compared with the other PCMs experimented, thermal properties of OTHTs were suitable for the most energy efficiency within thermal comfort range, this could be concluded that OTHTs could be optimized in the comfort temperature zone.
Table 4. Latent heat capacities and melting temperature of the PCMs.

| Specimen | Latent heat capacity (J/g) | Melting temperature (℃) |
|----------|----------------------------|-------------------------|
|          | Heating                     | Cooling                 | Heating   | Cooling |
| OT       | 247.6                       | 245.8                   | 29.81     | 26.22   |
| OTHT91   | 207.8                       | 194.5                   | 26.46     | 23.42   |
| OTHT73   | 183.2                       | 192.0                   | 24.47     | 22.39   |
| OTHT55   | 171.8                       | 156.5                   | 24.33     | 20.94   |
| OTHT37   | 171.4                       | 169.0                   | 22.61     | 20.15   |
| OTHT19   | 191.1                       | 173.6                   | 21.38     | 19.73   |
| HT       | 216.7                       | 213.2                   | 21.24     | 19.52   |

4. Conclusion

To improve building energy savings by PCM application in the building of indoor conditions maintained at thermal comfort range, it is necessary to investigate the optimized PCM including similar melting temperature with 20 to 26 ℃. Therefore, in this work, development of the optimized PCM within thermal comfort range was conducted. OT, HT, and HX were selected for experiment and be mixed to investigate the ideal melting temperature. According to the circulation water bath test, OTHTs depending on various mixing ratio were considered the ideal PCMs. Among OTHTs, OTHT91, where phase change temperature appeared at 24 to 26 ℃, were the optimized PCM due to the highest latent heat capacity and ideal melting temperature within thermal comfort range. This could be seen that application of OTHT91 in building can reduce building energy consumption and improve thermal comfort of occupants. The further study of PCM application to building is required to evaluate the specific building energy performance quantitatively.

5. References

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