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TECHNICAL ARTICLE

Experimental Evaluation of Phase Change Material Blister Panels for Building Application

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Phase Change Materials (PCMs) are characterised by their capacity to absorb available thermal energy, store it, and passively release it by utilizing latent heat during phase change, thus reducing temperature peaks and improving thermal comfort. This paper experimentally investigates the feasibility of a novel blister PCM panel for ceiling tile applications. Experimental panels enhance the thermal conductivity of the PCM with the addition of steel and aluminium wool particles at 3.77 wt% and 23 wt%, respectively. During the experimental procedure, the blister panels where able to absorb the heat coming from the environmental chamber, proving that the encapsulation material was able to promote the heat exchange. Furthermore, the PCM enhancement indicates that both the aluminium and steel wool particles improved the blister panel thermal performance. These results were confirmed by thermal conductive, calculated at 0.733 W/(m K) for the base panel, 0.739 W/(m K) for the aluminium wool, and 0.784 W/W/(m K) for the steel wool. The experiment suggest that the application of PCM blister ceiling tiles can be considered as an innovative method for thermal performance control and energy saving.

Keywords: blister panels; energy storage; phase change materials; thermal performance

1. Introduction

Phase change materials (PCMs) absorb, store, and passively release available thermal energy via latent heat transfer during phase change, thereby reducing peak demand and improving thermal comfort (Salunkhe and Shembekar, 2012; Kalnæs and Jelle, 2015; Wang et al., 2020). The thermal performance of PCMs is based on their melting point, thermal conductivity, and energy storage density. For this reason, when applied as energy storage, they require an instant melting and solidification point (Ji et al., 2014; Ma, Lin and Sohel, 2016).

Paraffins, salt hydrates, and fatty acids are the most commonly used PCMs, having a melting temperature within human thermal comfort, making them suitable for building applications. However, such materials have major drawbacks, including low thermal conductivity, especially for organic PCMs. As a result, performance enhancements of PCMs are eagerly researched, to develop improved techniques (Fan and Khodadadi, 2011). Such methods require the addition of highly conductive materials, which can be done by modification of the encapsulation material, the shape of the container, using heat pipes, heat exchangers, micro- and macro-encapsulation, or the addition of highly conductive nanoparticles in the base fluid, creating nano-enhanced PCM (Babaei, Keblinski and Khodadadi, 2013; Ma, Lin and Sohel, 2016). Further techniques proposed the integration of metallic fins, foam wools, and graphite (Ji et al., 2014; Fan et al., 2013). The literature views of PCM enhancement materials have identified graphite, aluminium, and carbon as the most frequently applied materials for organic PCM enhancement.

There are two methods to integrate PCM in building elements. The first method, "shape-stabilized", considers the direct addition of the PCM into a building element, such as a gypsum wall (Silva, Vicente and Rodrigues, 2016). The second method requires the PCMs to be encapsulated for technical use, as otherwise the material would disperse from the location (Cabeza et al., 2011). For this reason, the encapsulation method is the most commonly used form of integration and has become a topic of analysis in recent years. The geometry of the encapsulation can take any shape, but the most popular forms are tubes, pouches, spheres, and panels. Encapsulation geometry could potentially be harnessed as a heat enhancement method, improving the thermal conductivity of the PCMs (Amin, Bruno and Belusko, 2014). Additional benefits of encapsulation include the capacity to counteract phase segregation, which is a regular phenomenon particularly prevalent with salt hydrates, in which the high storage density of the material disperse in layers, leading to the decline in the storage efficiency.

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Popular materials for encapsulation include plastic containers, such as polypropylene and polyurethane; for metals, copper and aluminium; and for inorganic materials, silicones and resins (Salunkhe and Shembekar, 2012). In the case of the salt hydrates, their corrosiveness affecting metals tends to reduce possible encapsulation solutions, thus plastic materials are more suitable. Basic encapsulation requirements include a heat transfer surface, structural stability, corrosion resistance, and the ability to offer thermal stability (Bland et al., 2017). **Table 1** discusses potential containers materials for PCM encapsulation (Jacob and Bruno, 2015).

The encapsulation can be classified by the size of the container surrounding the PCM. Macroencapsulation covers diameters from 1 mm or higher, and is the most used method for PCM encapsulation. Microencapsulation covers from 1 μm to 1 mm, and nanoencapsulation refers to diameters of less than 1 μm (Jacob and Bruno, 2015). Microencapsulation represents higher complexity than macroencapsulation, but the development of new technological advancements has introduced nano-scale encapsulation, resulting in higher heat transfer rates in comparison to macroencapsulation (Hawlader, Uddin and Khin, 2003; Khudhair and Farid, 2004).

The aim of this paper is to experimentally investigate the feasibility of a novel blister PCM panel for ceiling tile applications. Different encapsulation methods were studied in order to determine the most adequate implementation according to thermal performance. Laboratory analysis of different encapsulation panels was carried out, favouring the blister encapsulation method. A set of three samples were tested, with INERTEK 23 as the base fluid: a base panel, containing only pure PCM; a second composite sample, integrating aluminium wool at 3.77 wt.%; and a third composite, using steel wool at a concentration of 2.3 wt.%.

2. Methods and Materials

2.1. Experimental setup

An experimental set-up was prepared to analyse the effect of the blister panels and enhancement methods. A set of experiments performed in the Environmental Climatic Chamber developed by SJJ System Services Ltd. (Serial No. A2520). The experimental set-up consisted of a control box of 70 × 67 × 73 cm dimensions, in which the blister PCM panels where allocated over a metallic mesh. The temperature measurements were made using type K thermocouples, and all readings were collected by the data logger (DT85), with a standard deviation of ±0.3 °C. Sensors were placed in the inlet, outlet, and inside the PCM blister panel, as shown in **Figure 1**. Both the inlet and outlet had openings of 18 cm in diameter, with airflow coming from the Environmental Chamber blown through with the assistance of an electric fan.

2.2. Methodology

The experiments consisted of creating an airflow through the control box at a desired temperature, in order to analyse the thermal performance of the PCM blister panel. The aim of the laboratory set-up was to detect the panel temperature to analyse the energy storage capacity.

In the first experimental set-up the temperature was maintain constant at 28 °C to ensure the melting temperature of the PCM, whose enthalpy values range between 18 to 28 °C. The chamber temperature was stabilized for an hour before the testing period. After this interval, the panels were allocated over a metal mesh and the experiment began. The testing time was of 6 hours, and each test was repeated three times, during which the average temperature was noted.

In the second test, the chamber temperature was increased in two-hour intervals in order to analyse the response of the temperature over the panels. In this case, the starting temperature was considered at 23 °C and the finishing temperature was stablished at 27 °C. As in the first experiment, the chamber temperature was stabilized an hour before the testing period. The testing time was 6 hours, and each test was repeated three times, during which the average temperature was noted.

The data extracted from the experiment was analysed in order to determine the thermal characteristics of the enhancement material over the PCM blister panels. The specific heat capacity of the PCM was calculated through the addition of the enhancement material to the blister panel using the following equation:

$$C_{composite} = C_{PCM} \bullet X_{PCM} + C_{matrix} \bullet \left(1 - X_{PCM}\right)$$

where:

$C_{composite}$ is the specific heat capacity of the composite, J/kgK

C_{PCM} is the specific heat capacity of the PCM, J/kgK

Table 1: Shell materials for PCMs.

Group	Proposed materials	Advantages	Disadvantages	Potential applications
Metals	Steel, aluminium, copper	- High thermal conductivity - Encapsulation by electroplating - High thermal stability - Strong structure	- Potential corrosion - Higher cost	High-temperature applications
Inorganic	Silicon, titanium dioxide, sodium silicate, silica, gelatin+acacia, melamine-resin	- High thermal stability - High thermal mechanical strength - Inexpensive	- Leakage risk	Industrial processes
Plastic	Polyolefine, propylene, polyester, polystyrene, polyethylene	- Inexpensive - Chemical and physical encapsulation methods	- Relative low thermal stability - Low thermal conductivity	Building integration Food industry

X_{PCM} is the weight ratio of the PCM to the composite
C_{matrix} is the specific heat capacity of the matrix material, J/kgK

2.3. Preparation of the composite-PCM

The sample PCM used in this research was a micro-encapsulated phase change material (MEPCMs) with granular particles ranging from 5 to 25 μm; the industrial reference is INERTEK 23©. The principle of microencapsulation is based on creating an envelope around the microparticles in the phase change, improving the heat transfer to the surroundings while avoiding phase segregation. INEREK 23 phase transition lies in the human comfort zone temperature; moreover, it has high latent heat, provides thermal stability, and avoids phase segregation. To enhance the thermal conductivity of the INERTEK 23, the addition of steel and aluminium wool particles was considered due to their low cost, light structure, and high thermal conductivity, germane to ensuring an extended contact area with the base material.

The nano-enhanced PCM was integrated using a two-step method, in which both materials were created separately. Generally, a powder is mixed with nanoparticles with the help of magnetic force agitation. Due to the high surface area and surface activity the powder particles tend to aggregate into the wool particles. The distribution of the materials was arbitrary (**Figure 2**), and the particles fluctuated in size, geometry, and volume, as shown in **Table 2**. Due to the manufacturing process the proportion of the composite varies; the proportion of the composite varies and were equivalent to the weight percentages of 3.77 wt.% for aluminium wool and 2.3 wt.% for the steel wool.

2.4. Panel design

The blister panel consist on an individual plastic blister measuring 15 × 15 × 2 cm. A schematic of the panel is shown in **Figure 3**. The PCM composite was allocated into the blister container and sealed with thermal conductive tape. The blister design promotes the airflow throughout the panel, facilitating the melting process of the PCM by

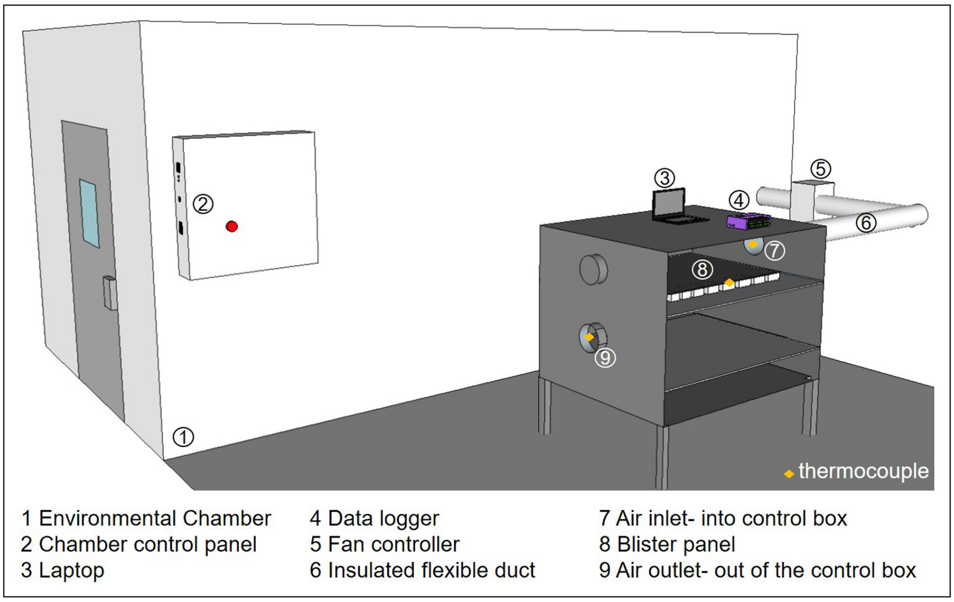

Figure 1: Schematic setup of the panel rig.

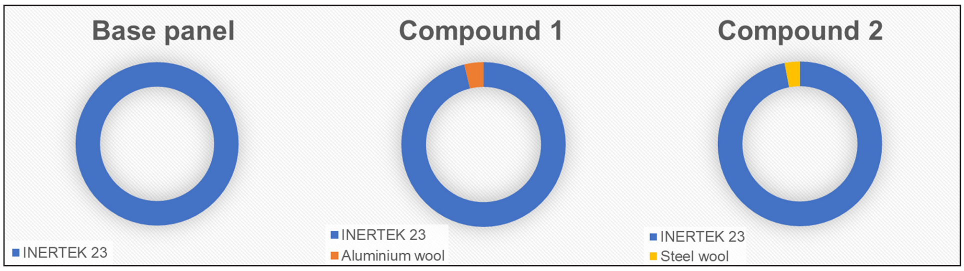

Figure 2: PCM blister panel schematic distribution.

Table 2: PCM blister panel composition.

Panel Name	PCM	Enhancement material	PCM mass (kg)	Enhancement mass (kg)	Total mass (kg)
Base Panel	INERTEK 23	N/A	0.538	N/A	0.538
Compound 1	INERTEK 23	Aluminium wool	0.371	0.014	0.385
Compound 2	INERTEK 23	Steel wool	0.385	0.009	0.399

increasing the contact area. To replicate a ceiling tile of 45 × 45 cm, an array of 3 × 3 blisters was added, having a total of 9 panels, as shown in **Figure 4**.

2.5. Thermal conductive analysis

The thermal conductivity analysis is one of the main parameters considered for the application of a composite-PCM for thermal energy storage buildings. The thermal conductivity of the different samples was calculated using the HFM-100 Heat Flow Meter method, which is a popular technique for thermal conductivity and thermal resistance measurements (**Figure 5**). The equipment contains two flux sensors with a thermal conductive range between 0.005 to 0.5 W/(m K). The temperature range varies from –20 °C to 70 °C, with accuracy ±3%. To ensure the accuracy of the measurement, expanded polystyrene board was tested as a calibration material. The operational temperature was set at 30 °C for the hot plate and 10 °C for the cold plate.

3. Experimental Results

In the first experimental set-up the environmental chamber temperature was kept constant at 28 °C.

Figure 6 shows the panel temperature of the different samples. It can be observed that the temperature of the panels increased rapidly, as the chamber's initial temperature was higher than the PCM melting point. After the initial surge, compounds 1 and 2 stagnated after 14,005 seconds (4 hr) of testing, while the base panel maintained temperature increments for most of the testing period. The base panel had the lowest values, reaching a maximum of 25.97 °C, with compound 1 and compound 2 presenting values of 26.17 °C and 26.34 °C, respectively.

The second experimental set-up compared the temperature variation of the three blister panels, as shown in **Figure 7**. The experiment was maintained for 21,600 seconds (6 hr), with 2 °C increments every 2 hrs. The starting temperature was 23 °C and the finishing temperature was 27 °C. The base panel and compound 1 presented similar behaviour, with a slightly higher temperature range in the aluminium mixture, reaching 25.66 °C and 25.93 °C, respectively. The compound 2 panel temperature levelled-up once the second temperature increment was applied, and from this point onwards the temperature increased until it reached 27.11 °C.

Based on the experimental results, the specific heat capacity was calculated to analyse the effect of the encapsulation method and enhancement material, as presented in **Table 3**. The specific heat capacity of the INERTEK 23 microcapsules was 66 (kJ/kg K) (Djamai, Si Larbi and Salvatore, 2019); that of the aluminium wool was 0.896 (kJ/kg K); and that of the steel wool was 0.502 (kJ/kg K), (Singh Rathore, Shukla and Gupta, 2020). There are two main factors to consider when analysing

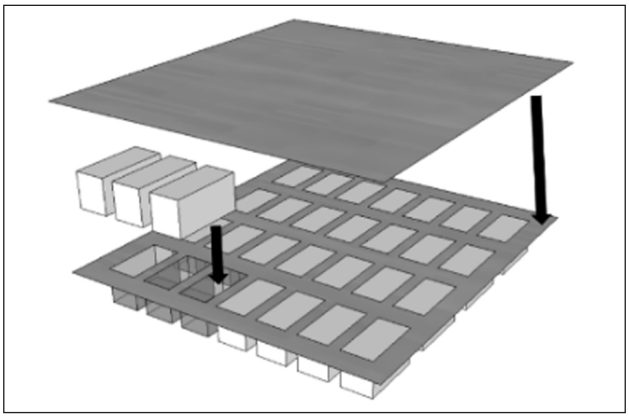

Figure 3: Schematic diagram of the blister panel utilized in the experiment.

Figure 5: HFM-100 thermal conductive analysis of the blister panel.

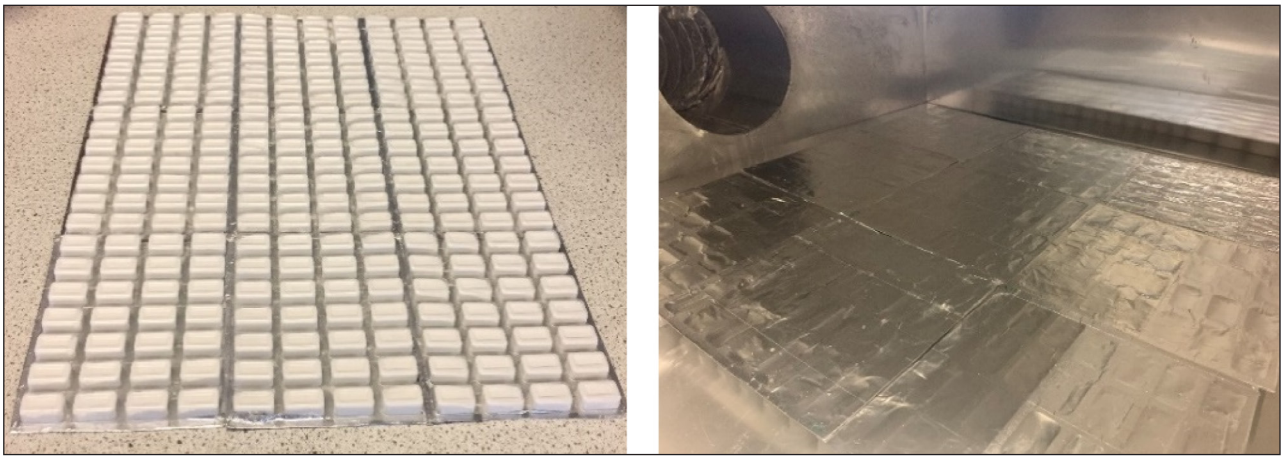

Figure 4: Left-set of 9 blister panels. Right-panel testing in the control box.

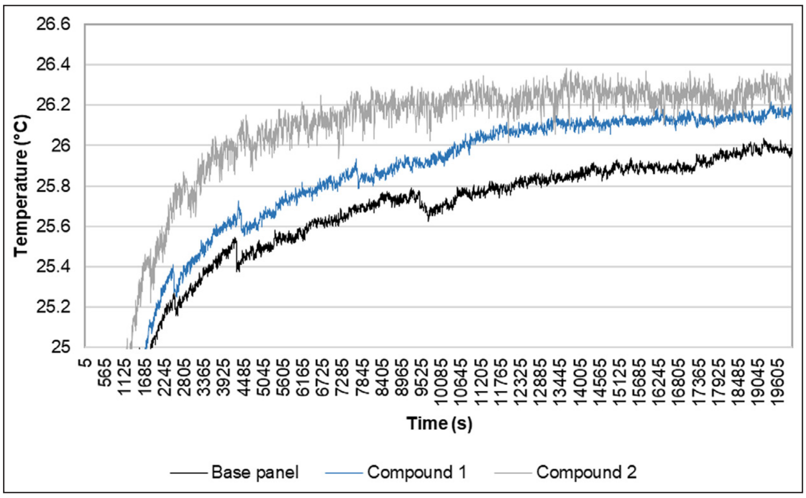

Figure 6: Test 1 – Blister panels comparison at 28 °C.

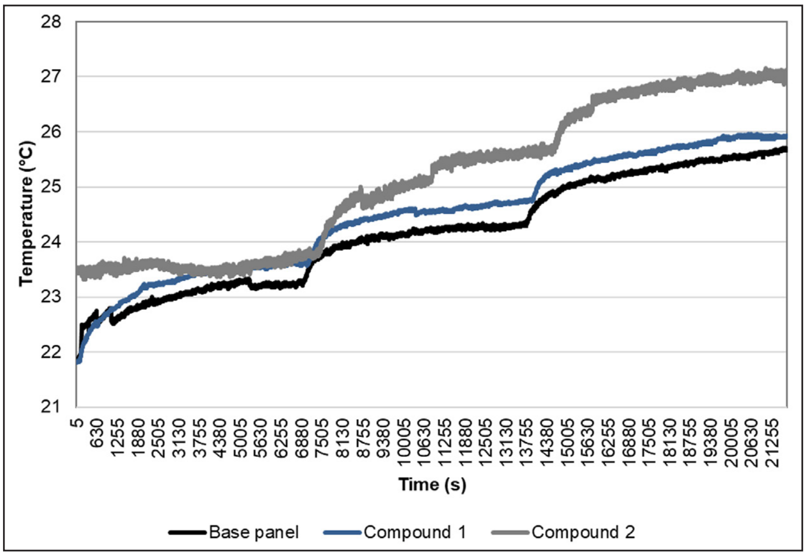

Figure 7: Test 2 – Blister panels comparison with 2 °C increments.

Table 3: Thermal performance analysis.

Property	Base panel	Compound 1	Compound 2
Storage Heat Capacity (J/g)	200 (PCM)	200 (PCM)	200 (PCM)
Specific Heat (J)	66000	63509	64457
Thermal Conductivity W/(mK)	0.733	0.739	0.784
Temperature Difference (°C)	2.29	3.12	3.4

the heat capacity. First, the heat transfer performance is correlational to the PCM mass, thus the base panel presents higher mass in comparison to the composite panels. Second, the particles distribution in the PCM must be considered, as the heat transfer rate is determined by the percentage of the enhancement nanoparticles added (Abdelrahman et al., 2019).

Results of the thermal conductive analysis found that the conductivity of the base panel was 0.733 W/(m K). The addition of the aluminium wool increased the thermal conductivity to 0.739 W/(m K); furthermore, the steel particles provided thermal conductivity of 0.784 W/ (m K). From the experimental results, it is clearly apparent that the addition of the enhancement material improved the thermal conductivity of the INERTEK 23.

From the experimental results, it is evident that the composite panels are able to absorb more heat as the PCM melts, confirming that the aluminium and steel wool particles enhance heat transfer performance.

4. Conclusions

Ceiling tiles are a practical method to integrate the material into building elements, increasing thermal mass, reducing temperature fluctuations, and assisting in energy performance by regulating the indoor temperature. The thermal performance of three different PCM blister panels was evaluated in terms of the heat absorption capacity and thermal conductivity. INERTEK 23 was selected as the base PCM, having a phase transition range compatible with the human thermal comfort temperatures. In this study, aluminium and steel wool were selected as composite materials to enhance the thermal performance of the PCM blister panels.

The results suggest that the application of the PCM blister ceiling tiles can be considered as an innovative method for building incorporation. During the experimental procedure, the blister panels were able to absorb the heat coming from the environmental chamber, proving that the encapsulation material was able to promote the heat exchange. Furthermore, the PCM enhancement indicates that both the aluminium and steel wool particles improved blister panel thermal performance. This result was confirmed by thermal conductive analysis. The base panel presented a thermal at 0.733 W/(m K), 0.739 W/(m K) for compound 1, and 0.784 W/(m K) for compound 2. The latter, with steel enhancement, can be considered as the sample which has the highest thermal performance.

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Competing Interests
Saffa Riffat is the Editor in Chief of this journal and was removed from all editorial duties involving the review and processing of the submission.

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