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# Thermal Mass Performance of Concrete Panels Incorporated with Phase Change Materials

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# Thermal mass performance of concrete panels incorporated with phase change materials

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**Abstract:** Using the mass of a building as a thermal storage system can reduce the demand on the auxiliary heating and cooling systems of the building. Concrete combines a high specific heat capacity with a thermal conductivity that is appropriate for the diurnal heating and cooling cycle of buildings. The heat storage capacity of concrete can be enhanced by adding phase change materials (PCMs) which provide a high latent heat storage capacity. However the addition of PCM to concrete reduces the conductivity of the concrete which may affect the ability of a PCM-concrete panel to absorb and release heat within the desired time period. In this study two different methods of combining concrete and phase change materials were used to form PCM/concrete composite panels. The panels were exposed to radiative heat energy in a controlled environment for a specified time period during which the surface and internal temperatures of the panel were recorded. The temperature data together with the measured density and thermal conductivity was used to evaluate and compare the thermal mass behaviour of each type of PCM/concrete composite material. The addition of PCM to the concrete significantly increased the overall thermal storage capacity of the concrete despite reducing the density and thermal conductivity of the concrete.

## 1. Introduction and Context

The research presented in this paper for the COST action TU1205 focused on ‘Building Integrated Renewable Systems’ forms the proof of technology for research currently being carried out as part of a European funded Horizon 2020 project. The project titled IMPRESS (http://www.project-impress.eu) aims to develop innovative precast products for the renovation of existing building stock thereby improving the performance and energy efficiency of European buildings. A PCM enhanced concrete forms one of the core technologies being investigated (Figure 1). The work outlined in this paper preceded this project and is the foundation on which this ongoing research is built. Current project research is first presented for context, followed by general theory of thermal storage in buildings and experimental results that verify the increase in thermal storage capacity from this innovative mix of concrete with phase change materials.

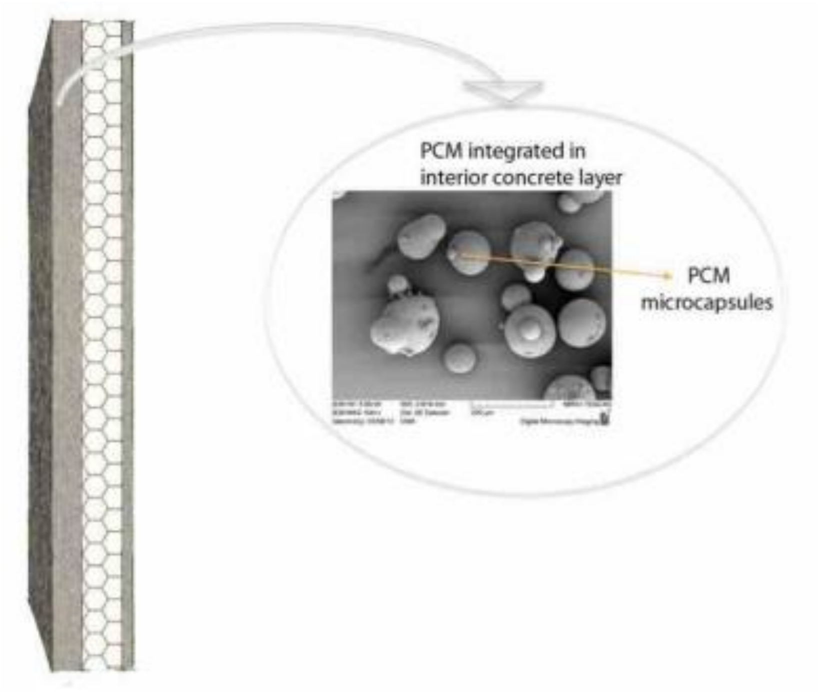

Figure 1. Thin sandwich panels containing PCMs

Three demonstration huts have been constructed with the assistance of the Horizon 2020 project partners Techrete Ltd. (Figure 2). These are developed so as to refine the manufacturing process and observe the performance of the PCM-concrete composite panels in a full scale scenario, over a long duration. To fulfil this objective, precast cladding panels comprising of 70mm thick concrete outer leaf, 120mm insulation and 125mm PCM-concrete composite internal leaf have been developed (Figure 3). These cladding panels will be used to re-clad part of a school building in the UK in July 2017.

Figure 2. Prototype PCM huts

Figure 3. Prototype PCM panel under construction

## 2. Background

Thermal energy storage (TES) in buildings is a building integrated renewable technology that is proposed as one of the most effective approaches to reducing energy consumption of buildings. Buildings are widely regarded to be responsible for more than one third of global energy consumption with space heating and cooling consuming 33% of this energy, increasing to 50% in cold climates. A TES system can be used to absorb and store both solar energy and excess heat due to use and occupancy during the day which can then be released to the internal environment when the room temperatures fall at night. In this way a TES system provides a potential for improved indoor thermal comfort for occupants by moderating internal temperature fluctuations and reducing the overall energy consumption of the building due to load reduction and shifting electricity consumption to off-peak periods, (Figure 4).

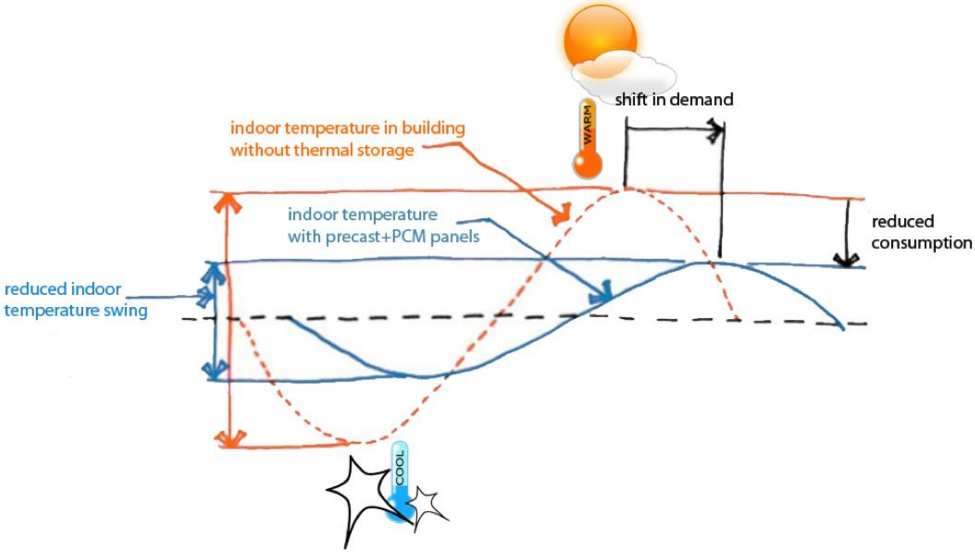

Figure 4. Impact of increased thermal mass (shown here as concrete enhanced with PCM) on internal temperatures

A thermal energy storage system can utilize sensible heat storage, latent heat storage or a combination of both. In sensible heat storage systems energy is stored in a material by increasing the temperature of the material. The capacity of a material to store energy depends on the amount of energy required to change the temperature of a unit amount of the material, ie the specific heat capacity of the material. The storage capacity of a sensible heat system is given by [1]:

$$Q = \int_{\mathrm{T_i}}^{\mathrm{T_f}} \mathrm{mC_p}\,\mathrm{dT} \qquad (1)$$

where:

Q = quantity of heat stored (Joules)
$T_f$ & $T_i$ = final temperature and initial temperature respectively ($^{o}$C)
m = mass of heat storage material
$C_p$ = specific heat capacity of material (J/kgK)

The ability of a material to store heat is referred to as its *Thermal Mass* and is the product *mCp*, mass x specific heat capacity. Materials of different conductivities (*k,* W/mK) will release this heat at different rates back to the environment. For a building material to provide good thermal mass an appropriate balance between the diffusion of heat through it (its thermal diffusivity) and the inertia to temperature change (its thermal inertia) is required, *i.e.* between its heat release and storage tendencies.

To augment heat storage in buildings, materials of high latent heat are considered for integration into the building fabric. PCM composite materials offer potential for heat storage enhancement - the heat capacity is a combination of specific heat capacity and latent heat capacity. Equation (1) can be rearranged to give:

$$C_p = \frac{\Delta \mathrm{Q}}{m \Delta T} \quad \text{(J/kgK)} \qquad (2)$$

However for a PCM/concrete composite material the heat capacity varies during the phase transition therefore, as proposed by [2], eq. (2) must be modified to include the temperature gradient over time:

$$C_p = \frac{\mathrm{A.q}}{m\frac{dT}{dt}} \quad \text{(J/kgK).} \qquad (3)$$

where ‘A’ is the area of the sample (m$^2$), q is the heat energy supplied to the sample (W/m$^2$), m is the mass (kg), dT/dt = increase in sample temperature in a given time step ($^{o}$C/s).

The latent heat capacity of a PCM is the heat energy absorbed when the PCM changes phase. The temperature of the PCM remains reasonably constant during phase change. The heat capacity of a PCM/concrete composite material is not constant as it varies in accordance with the amount of phase change that has occured. The selection of a phase change material for a given application requires consideration of the properties of the phase change materials.

Depending on the application, PCMs should first be selected based on their melting temperature. For a space heating application in a building, only PCMs with a melting temperature within the range of human comfort temperature (18-22°C) can be deemed suitable [3]. For this study the primary requirements for the PCM are:

- Fusion temperature around the human comfort temperature 18°C and 22°C
- Chemical compatibility with concrete, steel (reinforcing bars) and timber (formwork)
- Low volume change during phase change

## 2. Methodology

Six samples were tested, including 2 control mix panels, 2 concrete with microencapsulated (ME) PCM and 2 with PCM impregnated in lightweight aggregate (LWA). Each concrete test panel is 200mm x 200mm x 200mm. In order to record the temperature within the panels during testing each panel has 3No. thermocouples cast into the concrete at equal depth intervals of 50mm, together with thermocouples located on the front and rear faces. Two primary tests were undertaken to characterise the PCM+concretes including; a 'light box test' to calculate the heat capacity and hot plate testing to characterise the conductivity. The testing and calculation procedures are described in Niall et al 2015 [4]. Prior to this the exact latent heat capacity of the PCMs was determined using Differential Scanning Calorimetry (Figure 5). The results of these tests enabled the amount of latent heat capacity added to the panels to be accurately determined and equalised for each type of panel.

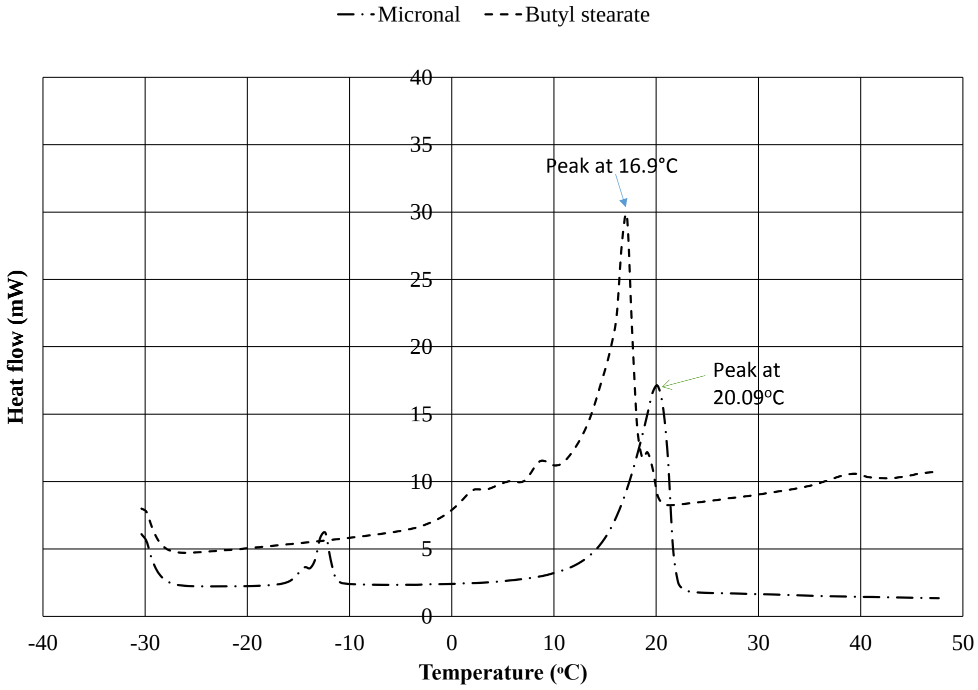

Figure 5. Heat flow vs temperature for PCMs

## 3. Results

### 3.1 The effect of PCMs on the thermal properties of concrete

The thermal conductivity of each panel is a critical parameter as it directly influences the heat flux through the samples. The addition of both types of PCM resulted in a reduction in thermal conductivity of the concrete. The lower conductivity of the PCM panels resulted in reduced thermal diffusivity which in turn reduced the effectiveness of the PCM as depth increased as the heat took longer to reach the PCM.

The density of both types of PCM/concrete composites (Table 1) was lower than the control concrete due to the lower density of the PCM relative to the density of cement paste. The conductivity and density of the materials influence the thermal behaviour however the effect that they have varies depending on the ratio of conductivity to density of the material.

Table 1: Densities and conductivities of the various panels

| Panel Type | Density (kg/m$^3$) | Conductivity (W/mK) |
|---|---|---|
| Control (C3) | 2284 | 1.56 |
| Control (C4) | 2295 | 2.10 |
| ME PCM 1 | 2075 | 1.20 |
| ME PCM 2 | 2112 | 0.98 |
| LWA/PCM 1 | 2076 | 0.82 |
| LWA/PCM 2 | 2010 | 1.18 |

### 3.2 Heating behaviour

In the light box tests carried out as part of this research each of the panels was exposed to equal amounts of heat energy from the lamp over an equal time period of 12 hours, hence the ‘q’ value is the same for each panel. Also the area exposed to the light is the same for each panel at 0.2m$^2$. Hence, the overall thermal storage capacity of the panels can be compared by evaluating the $m\frac{dT}{dt}$ value for each panel.

Fig. 6 shows a plot of the relative overall thermal storage, as recorded at 50mm depth. It is clear that the panels containing PCM provide greater thermal storage capacity. The percentage of additional thermal storage provided by the PCM panels was determined by calculating the area under each curve and setting the value for the control curve at 100%. It is noted that the LWA PCM panel provides the greatest increase in thermal storage of 62%. The panel with microencapsulated PCM (ME PCM) panel also provides a significant increase in thermal storage of 58%. These results together with results calculated at depths of 100mm and 150 mm are shown in Table 2.

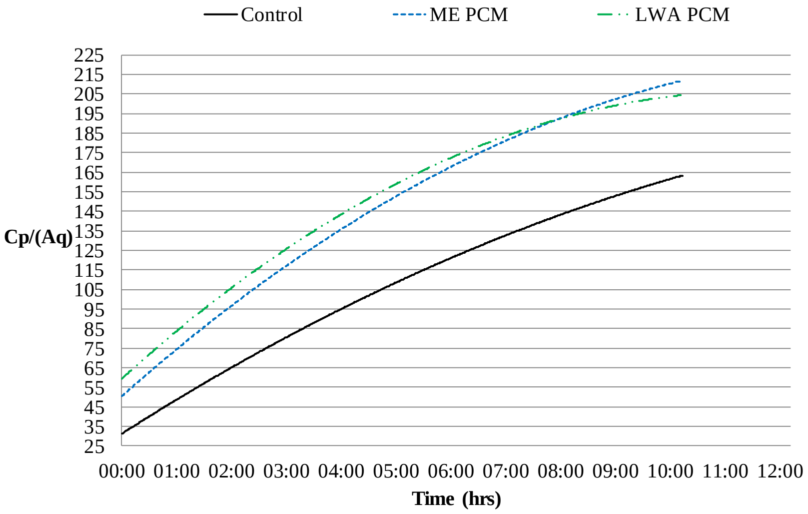

Figure 7. Curves showing relative overall thermal capacity at 50mm

Table 2. Additional thermal storage provided by PCM panels at 50mm, 100mm and 150mm depth

| Panel Type | % Overall thermal storage relative to control panel at: | | |
|---|---|---|---|
| | 50mm | 100mm | 150mm |
| Control | 100.0 | 100.0 | 100.0 |
| ME PCM | 157.5 | 147.0 | 152.0 |
| LWA PCM | 161.7 | 143.0 | 147.0 |

It can be noted that the overall thermal storage of the PCM panels reduces relative to the control panel. Part of the reason for this is that the overall thermal storage for the control panel increases. However another factor that contributes to this behaviour is that the diffusivity of the control panels is higher than the PCM panels and the LWA panels have the lowest diffusivity as shown in Fig. 7. This means that the heat is taking longer to reach 100mm in the LWA PCM panels, so over the 12 hours the overall heat reaching 100mm depth in the LWA PCM panels is less than that in the control panel and the ME PCM panels. Hence the PCM becomes less effective with increasing depth. These panels were subjected to a high level of heat energy for 12 hours. In a real application, a concrete floor or wall would not be exposed to such high levels of heat. The level of exposure depends on both local climate and position of the concrete element within the building, ie exposure to daylight. So the effective depth of the PCM will depend on the proposed location of the composite material. In applications where the heat energy is reaching up to a depth of 100mm into the composite PCM material, the LWA PCM panels provide a greater thermal storage capacity.

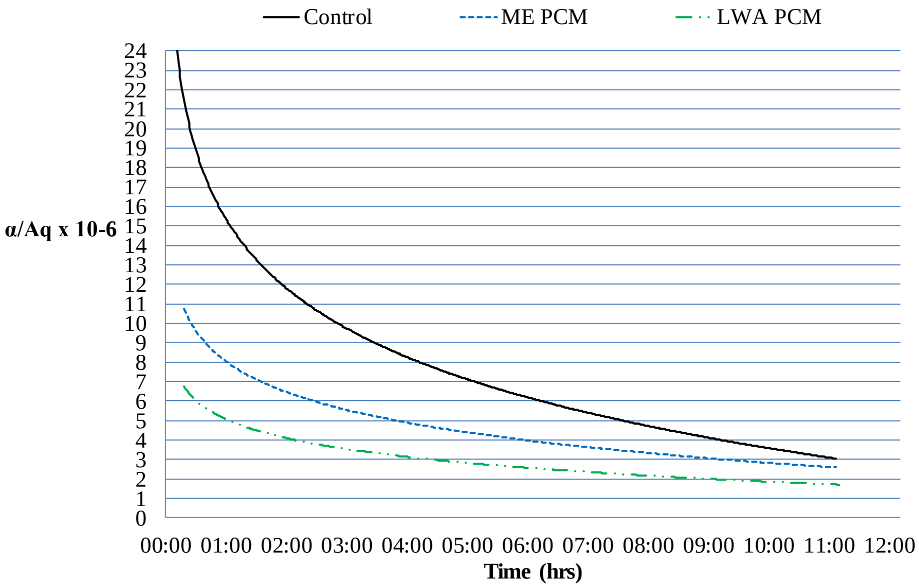

Fig. 7. Relative thermal diffusivity recorded at 50m

## 4. Conclusion

Adding PCM to concrete considerable increases the thermal storage capacity. At a depth of 50mm the LWA PCM panels provide the greatest increase in thermal storage capacity over and above the control panel. Interestingly the overall thermal storage of the PCM panels reduces relative to the control panel as depth increases due to the fact that the diffusivity of the control panels is higher than the PCM panels. The overall thermal storage of a panel will increase as the amount of heat energy transferred to the panel increases. In a real application where a PCM/concrete composite material is used in a building to store thermal energy, the effective depth of the PCM will depend on the local climate at the proposed location of the building.

## 6.References

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