Latent heat storage capability in different type of mortars

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Abstract

The application of mortars with latent heat storage capabilities has been extensively studied during the last decade. It is already proven the ability of these materials to store latent heat. These materials will reduce the HVAC (heating, ventilation, and air conditioning systems) operation time and contribute to save energy. However, the incorporation of microcapsules of phase change materials (PCM) into the mortar matrix change the internal structure, affecting its hardened state properties. Understanding these microstructural modifications can contribute to optimize the PCM content and the mortars performance. This work aims to study the relationship between the hardened state properties of mortars containing PCM and its internal microstructure. The mortars were prepared using different binders (lime, cement and gypsum) and different PCM contents. Their hardened state properties, microstructural modifications and heat storage capabilities were assessed. It was determined a strong relationship with the mortars microstructure. It was verified that a higher PCM content does not necessarily implies an increase in the latent heat transfer. The internal pore distribution plays an important role in the latent heat storage process. The use of PCM mortars proved to be an efficient strategy to develop both new and renovated sustainable buildings.

Keywords: *Mortars, PCM materials, Sustainability*

Introduction

The construction materials account for several environmental impacts during their life cycle, and a significant part results from operational energy consumption. The need for new solutions, which improve the environmental performance without compromising the buildings interior comfort, has emerged. In recent years, new materials with innovative features have been developed. Numerous research efforts have been lead in the past decades to increase energy efficiency in buildings, and the result was a number of technologies and solutions. Among them, the thermal energy storage (TES) is recognized as one of the most effective approaches for energy demand reduction in construction. There are three different methods to effectively store thermal energy: sensible heat, latent heat and chemical heat storage. TES allows temperature to be temporarily stored for later use [1, 2]. Several studies have been conducted to develop construction materials with latent heat storage potential

[3-5]. PCM can be incorporated in mortars to provide them with energy saving capabilities. The PCM suitable for mortars incorporation is an organic type, consisting of a mixture of paraffin waxes encapsulated in a polymer. This organic PCM exhibits physical and chemical properties that allow it to store and release heat, contributing to maintain the indoor temperature in the comfort zone, reducing the building energy loads [6, 7].

Use of latent heat storage can be a practical and efficient mean of storing heat. Phase Change Materials (PCM) offer good density storage that results from the high latent heat of fusion at a constant temperature, known as phase transition temperature. When the temperature raise above the PCM phase transition an endothermic reaction occurs, the PCM turns from solid to liquid and the heat is stored. A temperature decrease causes the inverse change turning the liquid PCM to solid, an exothermic reaction, causing the heat to be released [3, 4].

The present research work examines the direct incorporation of a Phase Change Material in aerial lime, cement and gypsum based mortar. The thermal properties of a reference mix and several compositions containing different amounts of PCM were assessed. Some hardened state properties, such as mechanical strength, porosity and pore size distribution were also evaluated. This study aims to show that it is viable to prepare mortars able of latent heat storage that, combined with other passive design strategies, can reduce energy demand in buildings [8].

The incorporation in construction materials and components can be done through direct incorporation, immersion or encapsulation. Phase Change Materials can be incorporated in passive building systems such as building blocks, walls, roofs, floors and ceilings. Alternatively, the PCM can be included in active heating and cooling systems [9-13]. Some research studies have been conducted on PCM incorporation in concrete mortars and gypsum plaster; however, there are no studies conducted with aerial lime compositions [10, 14, 15].

Experimental

Different mortar mixtures were prepared with three commercial binders: hydrated lime, Portland cement CEM II 32.5N and gypsum, a siliceous sand was used as fine aggregate. The phase change material (Micronal DS 5008) comprises a capsule with an average particle size of 6 µm, transition temperature of 23ºC and enthalpy of 135 kJ/kg.

The samples were prepared and its mechanical strength tests were evaluated following the procedure described in the European Standard EN 1015-11. The pore size and pore distribution was determined using a mercury intrusion porosimeter (AutoPore IV Micromeritics) The PCM and the mortars microstructure were investigated using a scanning electron microscope (SEM).

The mortars latent heat storage evaluation was performed with tests that simulate as faithfully as possible the real application conditions. For this purpose test cells made with an insulating material (extruded polystyrene) were developed. The cells were covered on the inside with a mortar layer of 3 mm. For each composition, cells with different amounts of PCM (0, 20 and 30 wt.%) were tested. Several thermocouples were placed inside for temperature measurement and the experimental setup is represented in Figure 1. The tests subjected the cells to a cycle of temperatures between 10ºC and 40ºC.

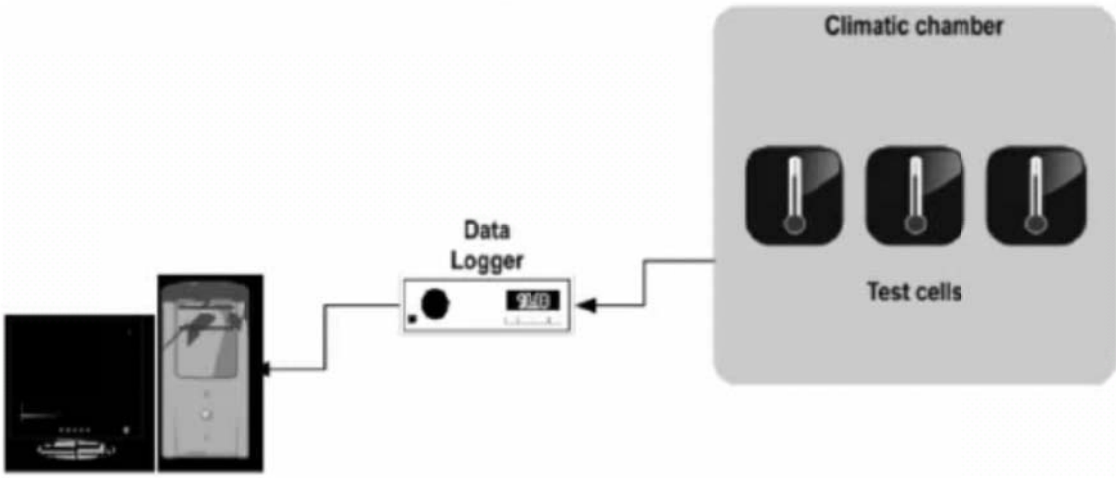

Figure 1. Experimental setup for the climatic chambre tests

Results and discussion

The results exhibited in Figures 2 and 3 for the flexural and compression strength show that the incorporation of PCM does not compromise the mechanical strength. Actually, at some extent it can be even beneficial. In the lime composition the introduction of PCM capsules increases the flexural and compression strength more than 50% compared to the reference value.

The small size of the microcapsules may contribute to better packing of the raw materials reducing the porosity and increasing the mechanical strength. The study of the internal pore distribution and the mortars microstructure can give important information to understand this behaviour.

It is possible to compare the evolution of the mechanical strength and the average pore size. In general the smallest average sizes (Figure 4) matches the highest strength values even when the porosity increases (Figure 5).

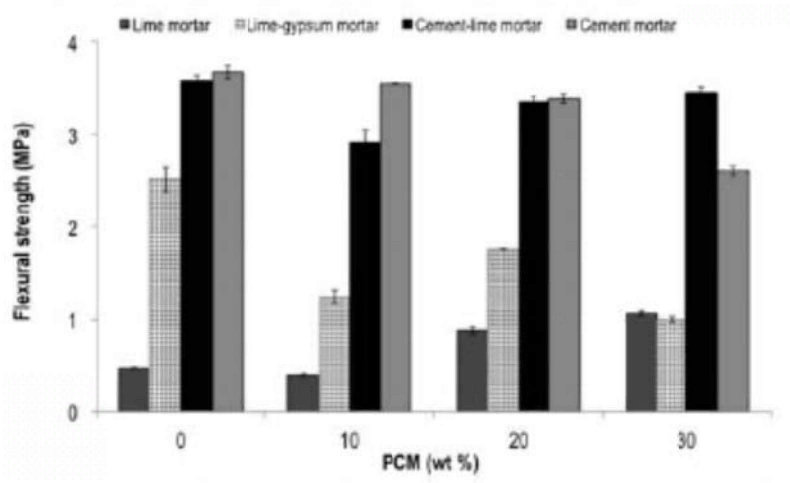

Figure 2. Flexural strenght of the mortars tested

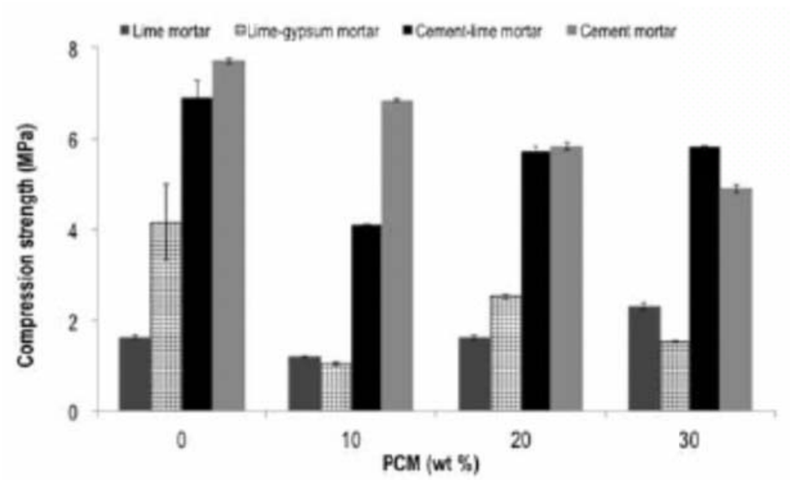

Figure 3. Compression strenght of the mortars tested

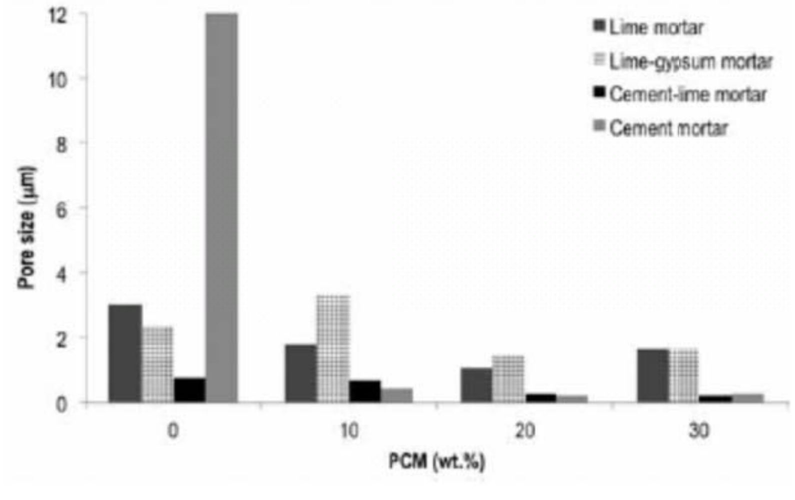

Figure 4. Average pore size of the mortars tested

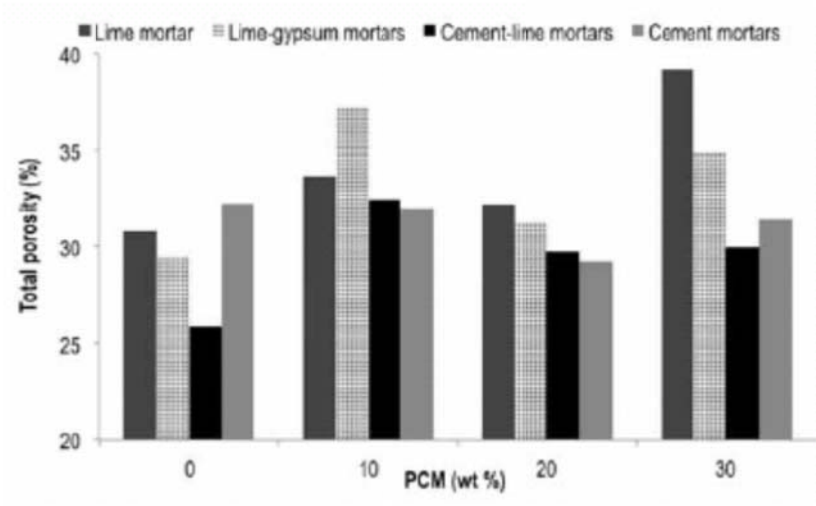

Figure 5. Total porosity of the mortars tested

This correlation between the internal porosity and the mechanical performance is more noticeable in the lime-based compositions. In these mortars, the hardened state behaviour is strongly influenced by the pores dimension and mortars with smallest ones exhibit higher mechanical strength [16].

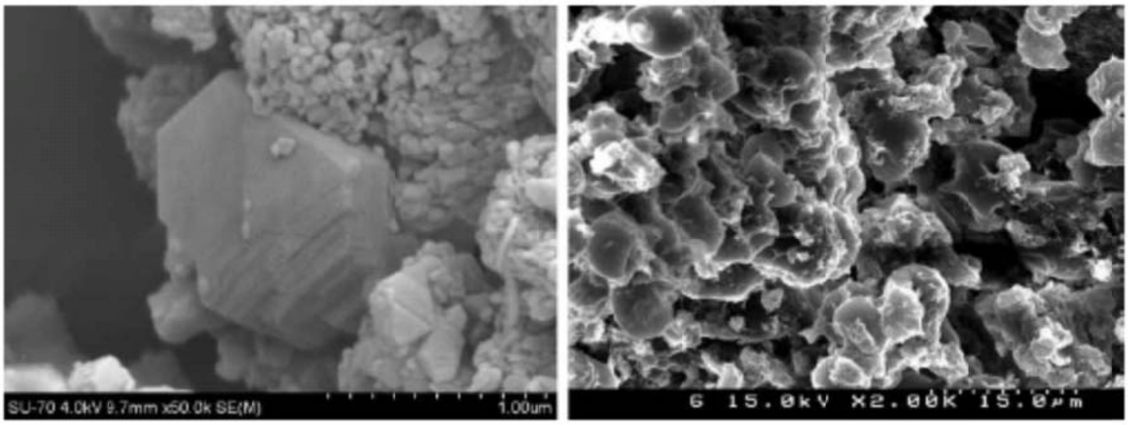

Figure 6. Lime mortar with 0 wt% of PCM (left) and 30 wt.% (right)

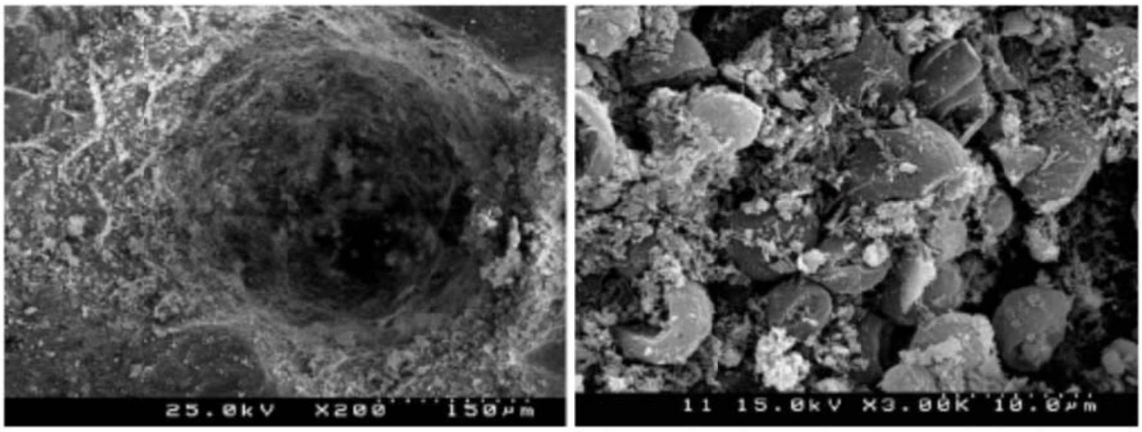

Figure 7. Lime-cement mortar with 0 wt% of PCM (left) and 30 wt.% (right)

The Figures 6 to 13, display the internal structure of the lime-based compositions, with 0 wt.% and 30 wt.% of PCM (L, LC, LG and C). It can be perceived that the way the capsules are distributed in the mortar matrix contributes to reduce the pores size. The internal structure of the mortar with PCM is more unified when compared to the reference mortar with bigger pores. The PCM has a good integrity and there is no sign of rupture or leakage. The microcapsules appear to tolerate the process of the mortar preparation (mixing, application and curing).

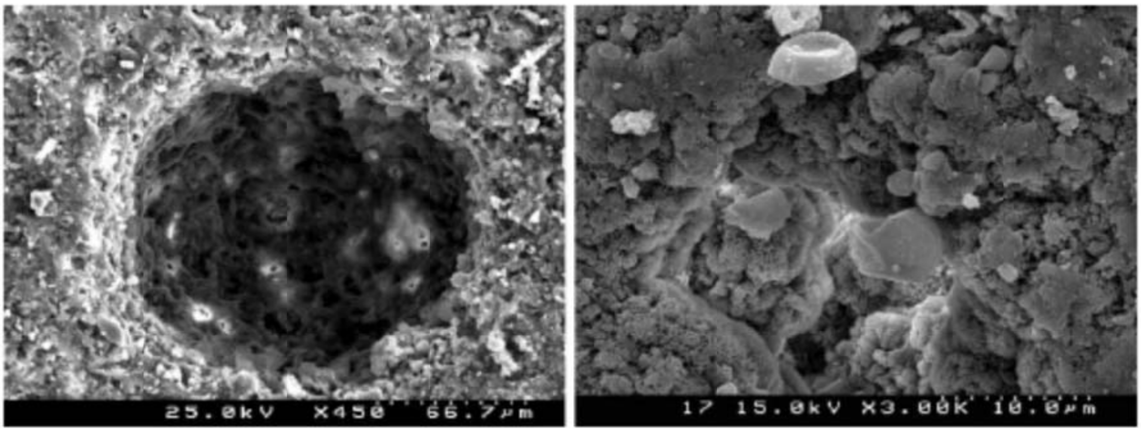

Figure 8. Lime-gypsum mortar with 0 wt% of PCM (left) and 30 wt.% (right)

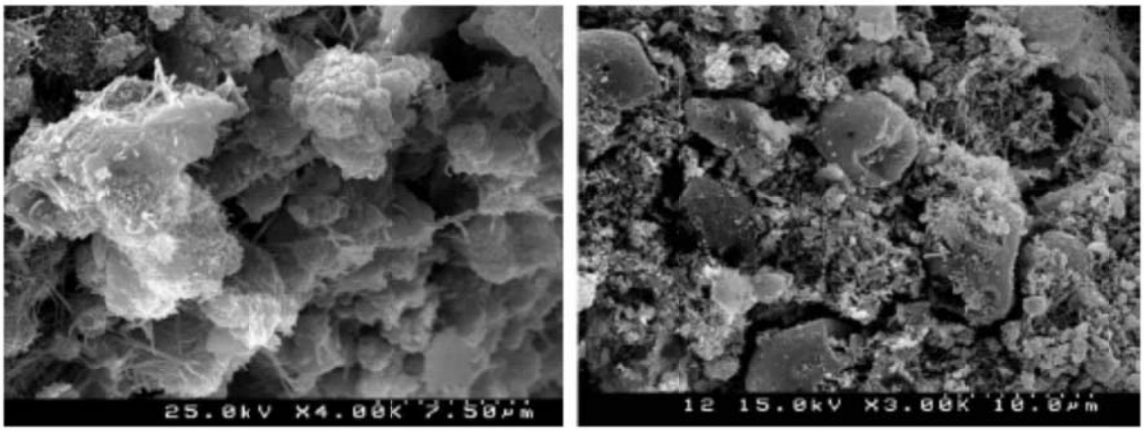

Figure 9. Cement mortar with 0 wt% of PCM (left) and 30 wt.% (right)

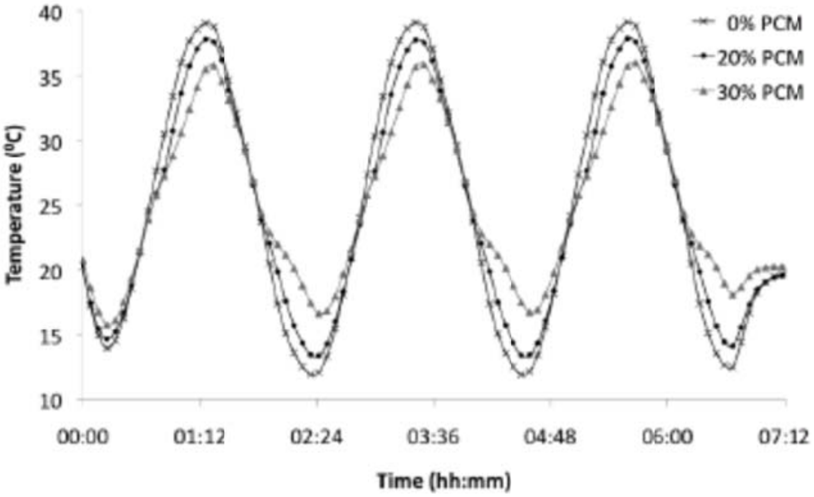

Figure 10. Temperature evolution in the test cells for the lime mortar

The tests performed in a climatic chamber to the compositions with 0, 20 and 30 wt.% of additive are represented in the Figures 10 to 13. The graphics show that the incorporation of PCM into the mortar matrix contributes to an effective reduction of the maximum temperature and increase of the minimum. The effect is pronounced in all the compositions tested and it is also visible that the mortars with PCM show a lower heating and cooling rate. This means that a building with a PCM-mortar can efficiently reduce the operation time of the heating and cooling systems.

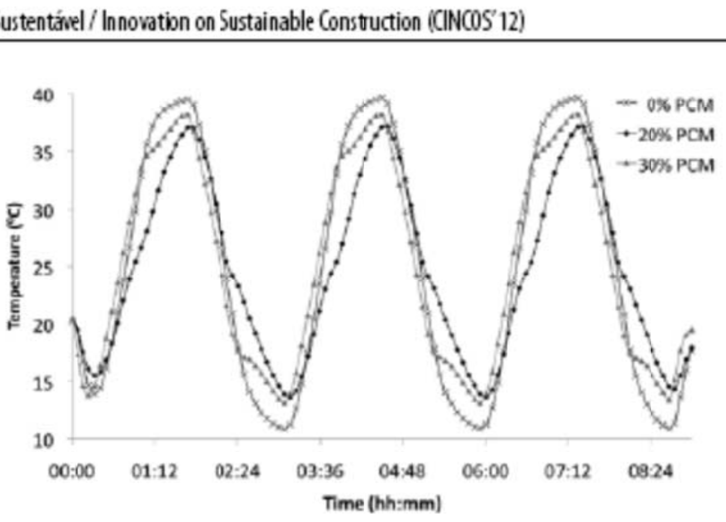

Figure 11. Temperature evolution in the test cells for the lime-cement mortar

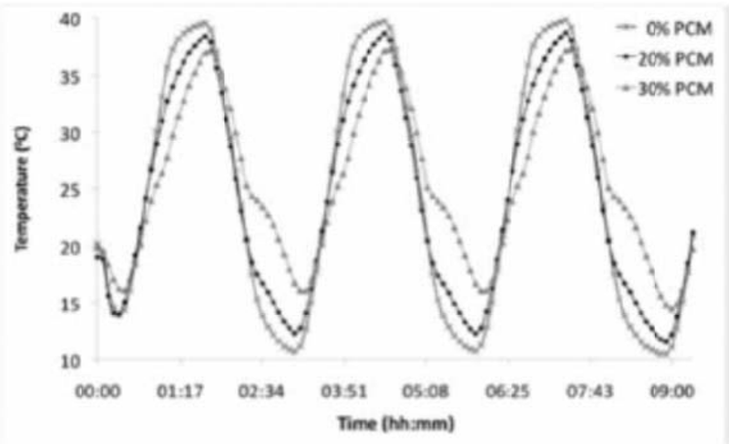

Figure 12. Temperature evolution in the test cells for the lime-gypsum mortar

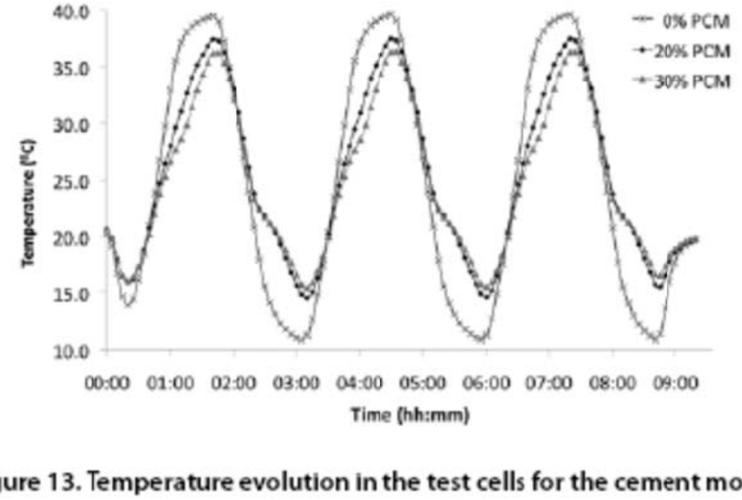

Figure 13. Temperature evolution in the test cells for the cement mortar

Conclusions

The introduction of PCM in aerial lime, gypsum and cement based mortars increase the mechanical strength and reduces the higher size pores in the hardened state. This results in a better product performance and durability. The microencapsulation has proven to be an efficient mean for PCM incorporation in mortars, since the capsules maintain their integrity even after the preparation and hardening process, thus contributing to the high thermal efficacy. The effect of the PCM amount on the thermal behaviour demonstrates that adding up to 30 wt.% results in a decrease of the heating and cooling rate on the samples tested.

The application of these mortars minimizes the HVAC equipment operation time and reduces the energy demand for new and renovated buildings.

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