

Gypsum plasters for energy conservation

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ABSTRACT: Energy conservation in buildings, through materials thermal storage, is relatively low relying only on sensible heat. There are however other materials, phase change materials (PCM), that have been incorporated in buildings as an effective solution both for more efficient use of energy and its consumption reduction, allowing the use of free energy in the environment, by latent heat storage, and so regulating thermal comfort parameters inside buildings.

This paper presents part of the ADI/2006/V4.1/0035, “GESREV – Development of new integrated system, based in gypsum, for interior plastering of construction systems” research project, financed by IDEIA – POCI 2010 Program. The objective to develop based on an existing technique, a new finishing gypsum plaster with thermal enhanced properties, namely latent heat storage capacity, by incorporating microencapsulated phase change materials. With the experimental work done so far, plaster composition was developed in order to fulfill the mechanical properties standard requirements, while thermal performance in Passys test cells is being carried.

1 INTRODUCTION

In Portugal residential buildings account for 20% of the final energy consumption, 25% of which is used for space heating and cooling. Despite over 20% of the buildings have less than 10 years, around 60% were built before 1990, not fulfilling energy efficiency regulations. Therefore much of the above mentioned energy is wasted both due to inefficient thermal insulation and lack of thermal energy storage systems (passive or active).

Thermal storage through materials is based on two important properties: sensible heat and latent heat, with the later much greater than the first. For instance, comparison between the sensible heat capacity of concrete (1.0 kJ/kg.°C) with the latent heat of a phase change material (PCM), such as a technical grade paraffin as octadecane (205 kJ/kg with a melting range temperature between 22.5-26 °C), shows significant difference between both properties.

In lightweight constructions, Trombe walls are used for direct solar gains. In typical Portuguese buildings high thermal mass masonry is used, making it suitable for passive solar applications. Nevertheless most buildings still present interior temperatures above comfort limits in summer and below in winter. Another problem is the variation on energy net demand, leading to differential pricing system for peak and off-peak periods.

Interior walls offer large areas for passive heat transfer. As the interior lining is usually made with multilayer gypsum plaster, in which the finishing layer is very thin, phase change materials can be easily added to the plaster and installed, both in new constructions and during rehabilitation processes with no additional cost, except for the material. Introducing latent heat thermal energy storage, contributes to stabilize the internal environment, improving thermal comfort by storing either heat or cool and releasing it in periods when the demand is higher, this way minimizing energy consumptions.

2 PHASE CHANGE MATERIALS (PCM)

Organic and inorganic compounds are the two most common groups of PCM. Organic PCM are divided in paraffins and non-paraffins, while inorganic PCM are divided in salt hydrates and metallics. There are also eutectics which are a minimum melting composition of two or more components. Some of the materials used as PCM and their properties are shown in Table 1.

Before selecting the appropriate PCM several characteristics should be considered: range of melting and freezing required; high latent heat of transition, thermal conductivity and specific heat; density; little or no subcooling during freezing; chemical stability; melting/freezing point congruency; low vapour pressure at room temperature; small transition volume change as well as renewable vegetable and animal sources of supply.

Commercial paraffin waxes are cheap, have moderate thermal storage densities (200 kJ/kg or 150 MJ/m³), present a wide range of melting temperatures, negligible subcooling, no phase segregation and are chemically inert and stable, however they present low thermal conductivities (0.2 W/m.°C).

Hydrated salts present high volumetric storage density (350 MJ/m³) when compared to paraffins, relatively high thermal conductivity (0.5 W/m.°C) and moderate costs, however due to phase segregation and subcooling their application is limited. Because they melt congruently, storage density decreases with thermal cycling.

Table 1. PCM and their properties (Tyagi et al. 2005 and Kelly 2000).

Compound	Melting Point (°C)	Heat of Fusion (kJ/kg)
KF.4H ₂ O	18,5	231
CaCl ₂ .6H ₂ O	29	190
Na ₂ SO ₄ .10H ₂ O	32	251
LiNO ₃ .3H ₂ O	30	296
Zn(NO ₃) ₂ .6H ₂ O	36,4	147
Butyl stearate	19	140
1-dodecanol	26	200
45/55 Capric-lauric acid	21	143
Propyl palmitate	19	186
1-tetradecanol	38	205
66,6% CaCl ₂ .6H ₂ O / 33,3% MgCl ₂ .6H ₂ O	25	127
47% Ca(NO ₃) ₂ .4H ₂ O / 53% Mg(NO ₃) ₂ .6H ₂ O	30	136
60% Na(CH ₃ COO).3H ₂ O / 40% CO(NH ₂) ₂	30	200

Energy stored in a PCM product depends on the melt temperature range of the PCM and on the latent capacity per unit area of the product. The melting temperature range should be chosen, based on the objective of its application, whether is to save energy during cooling or heating.

Over the years different techniques to integrate PCM into the building materials have been studied. These techniques included mainly immersion and encapsulation.

In the immersion process the porous building material is dipped into the hot melt PCM, which is absorbed by capillarity. This is easy to perform but PCM may interact with the structure, changing the properties of the materials matrix by reacting with it or by leakage.

Encapsulation of the PCM in tubes, pouches, spheres or panels is an effective way of containing the material, however, macro-capsules heat transfer rates decrease due to low heat transfer coefficients during freezing, preventing the system to fully discharge. More, this method requires protection of the containers from destruction during integration.

Micro-encapsulation allows easy integration of the PCM into conventional porous materials, preventing the interaction of the PCM with the matrix, good stability and larger heat transfer surface, affecting however mechanical strength of the elements.

For wallboards for example, direct incorporation at the mixing stage is preferred because little additional process equipment and labour is required, however, if no contention mechanisms are used, leakage may be a problem. Nevertheless, PCM wallboard and conventional wallboard characteristics present flexural comparable strengths, around 15% difference in thermal conductivities depending on the PCM used and its amount and excellent fire resistance. For radiant floor applications shape-stabilized PCM plates are most common.

Major concerns with safety codes and flammability requirements imposed to construction materials lead to the development of techniques to prevent fire hazards. Adding fire retardants in materials composition is usually an effective measure. Examples include, non-flammable surface materials such aluminium foil or rigid PVC film for plasterboards and brominated hexadecane and octadecane combined with antimony oxide for other applications, since it self extinguishes.

3 THERMAL STORAGE MATERIALS PERFORMANCE

The incorporation of PCM in different materials for several applications has been studied. Due to widespread application, most of these researches focus on wallboards, concrete blocks and shape stabilized PCM plates for radiant under floor heating.

Peippo et al. (1991) showed that a house with 120 m² in Madison, Wisconsin (43°N), could save up to 4 GJ a year (or 15% of the annual energy cost). They have also concluded that the optimal diurnal heat storage occurs with a melt temperature 1–3 °C above average room temperature.

Feldman et al. (1995) studied the performance of gypsum wallboard, for cooling storage at night, impregnated by immersion with 22-25%-wt (2 kg/m²) PCM with a melting range of 22-26 °C. Wallboard presented good stability with thermal properties remaining unchanged after cycling. Researchers concluded that within a temperature interval of 3.5 °C, the total storage capacity of the PCM wallboard was 381 kJ/kg, which was 12 times higher than the storage capacity of the wallboard alone.

Thermal performance of a full-scale outdoor test room with inside lining made of gypsum wallboard containing 25%-wt. PCM, with a temperature transition range of 16-21 °C, was investigated by Athienitis et al. (1997). Results showed a maximum temperature of 21 °C registered in the wallboard containing PCM against 27 °C in regular wallboard. Freezing process was observed to last up to 7-11 hours. With a total wallboard area of 20 m², a 10 MJ increase in heat transfer was measured, corresponding to approximately 15% of the total heat load

The thermal dynamics of gypsum-PCM wallboard not directly illuminated by sunlight were studied by Neeper (2000). In this study daily variation of room temperature was between 20 °C and 26°C with an average around 21.5 °C. The wallboard was 12.7 mm thick, containing 10% and 20% PCM, with a latent heat capacity of 192 kJ/m² and 427 kJ/m² respectively. From his studies Neeper concluded that a design value for wallboard energy storage was in the range of 300-400 kJ/m², which is very important data when calculating heating or cooling needs.

Another wallboard thermal performance study was carried by Kissock et al. (1998). The wallboard was imbued with 30-wt% with commercial paraffin PCM (K18). In the simulations conducted, solar radiation, ambient temperature and interior temperatures in the test cells were continuously monitored for 14 days. Results indicated that peak temperature in the phase change test cell were up to 10 °C less than in the control test cell during sunny days.

A combined system for space heating and hot water was investigated by Ip (2000). Water heated by a solar panel is used to charge the PCM of an under floor panel, through which the mat of water tubes circulate. Considering a solar radiation of 9.8 MJ/m² with a total system efficiency of 25%-50%, applied in a two storey 3 bedroom house with 100 m², a heating load of 1.6 MJ/m² and a collector with 6 m², Ip estimated energy savings of around 6%-12.5%.

More recently Schossig et al. (2004) studied the behaviour of PCM gypsum plaster in full-size lightweight test rooms. Gypsum plasterboard was mounted on wooden slats with 14 cm thick polyurethane foam insulation. Two different gypsum plasters were used: a 40 %-wt. PCM 6 mm thick and a 20 %-wt. PCM 15 mm thick. The PCM melting temperature range was 24-27 °C.

Results of this experiment demonstrated that, for the 6 mm plaster, maximum room temperature with PCM was reached 1 hour later and was 4 °C lower. More, during three weeks, the reference room temperature was above 28 °C during 50 hours while in the PCM test room was only around 5 hours. One important feature of this work was the use of Venetian blinds and night ventilation to achieve full discharge of the PCM.

Gypsum plasters incorporating PCM have also been study and investigate in Minho University, in order to develop a new multilayer plastering system. Commercial gypsum plaster (Monteiro, 2005) has been mixed with 25%-wt. micro-encapsulated PCM with a melting temperature around 20 °C, by direct incorporation and compared with the same conventional plaster. Figures 1 and 2 present some of the results achieved.

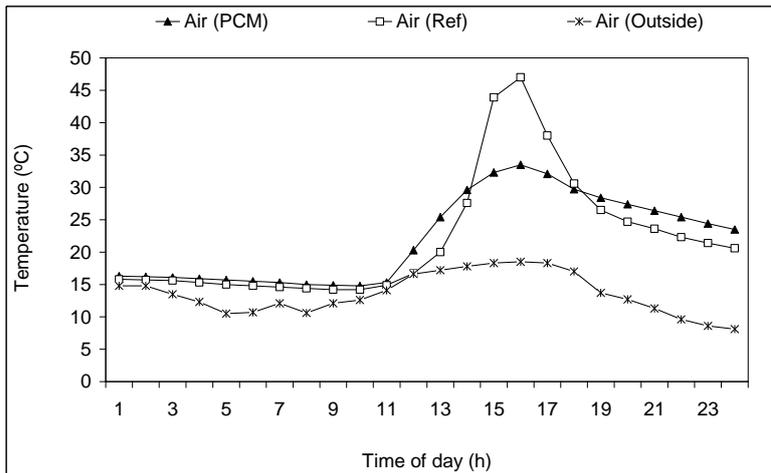


Figure 1. Air temperature profiles for the two test rooms in the hottest day (Monteiro, 2005).

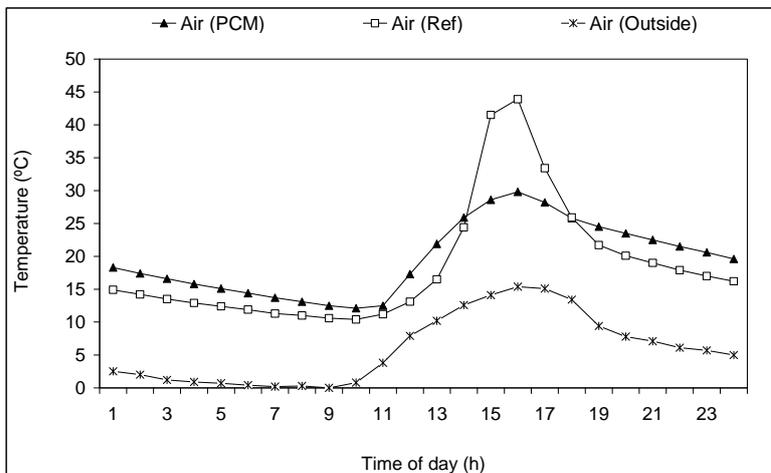


Figure 2. Air temperature profiles for the two test rooms in the coldest day (Monteiro, 2005).

Results, obtained during winter, indicate a reduction of 29% in the maximum temperature for the hottest day, while in the coldest this reduction was of 32%. For the minimum temperature increases of 4% and 14% in the hottest and in the coldest day, respectively, were observed.

These results led to conclude that PCM with a melting range around 20 °C are suitable for thermal performance in winter, when heating loads are higher, effectively regulating interior thermal comfort parameters.

One of the drawbacks of Monteiro's work, was the non conformity of the gypsum plaster with the requirements of the new EN 13279-1 (CEN 2005), namely, in what concerns to mechanical properties of the gypsum-PCM mortar. This new European standard (CEN 2005) sets at least 1 MPa for flexural strength and 2 MPa for compressive strength.

4 EXPERIMENTAL WORK

The first part of the experimental work consisted in the development and evaluation of the gypsum mortars mechanical properties (flexural, compressive and adhesive strengths), while the second consists in the comparison between the thermal performances of two rooms plastered with and without PCM. The final goal is to predict the amount of energy that can be saved by incorporating the PCM, while maintaining comfort parameters in the room.

Three different compositions (F3, F4 and F5) of finishing layer gypsum plaster, in which 25%-wt. PCM was directly incorporated at the time of mixture, were evaluated. The amount of PCM incorporated was defined, based in the mentioned references and in preliminary mechanical tests (Silva et al. 2006). The PCM, a technical grade hexadecane paraffin wax, microencapsulated in a melamine-formaldehyde resin, with an average particle size distribution of 20-30 μm , presented a melting temperature around 20 °C and a latent heat of fusion of 140 kJ/kg.

Flexural and compressive tests were carried in 40 x 40 x 160 mm³ specimens while adhesive strengths were tested directly in plastered pilot scale brick walls, according with EN 13279-2 standard (CEN 2004).

5 RESULTS

Figures 3 and 4 present the results obtained for mechanical properties testing carried, in order to select the appropriate finishing plaster for thermal testing.

The analysis of the experimental results led to conclude that the incorporation of PCM in the mortar reduces significantly the mechanical properties of the final plaster. Nevertheless, through the research work carried out the three different compositions could be established, in order to fulfil the requirements of standard EN 13279-1 (CEN 2005).

It was also concluded that the ideal mixing water content, both for workability and mechanical properties is around 70% for the other three (F3, F4 and F5). The EN 13279-1 doesn't set any requirement standard for adhesion between plaster layers in test walls, this property showed good results, both with and without paint, despite the different fracture patterns.

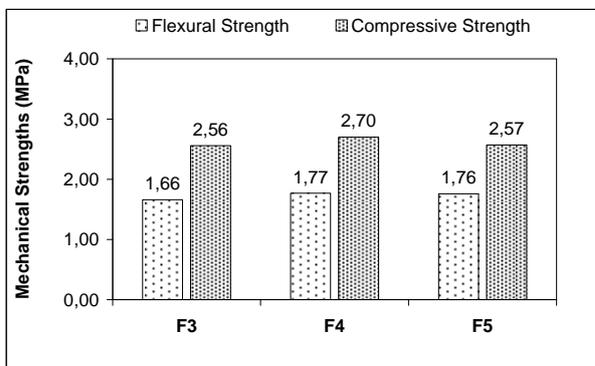


Figure 3. Mechanical properties of modified compositions incorporating 25% PCM.

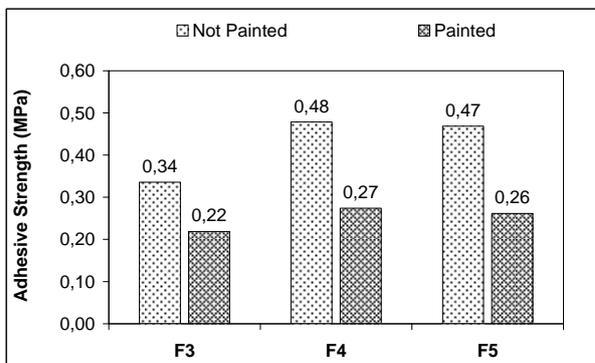


Figure 4. Adhesive strengths of modified compositions incorporating 25% PCM.

6 CONCLUSIONS

The incorporation of PCM in buildings is an effective way of improving thermal performance by energy storage in construction elements. It can be used for passive solar heating by integrating mainly the walls, maximizing solar radiation gains, in active heating systems combined with solar collectors or electricity through radiant floor and also in cooling systems with night ventilation.

Studies have demonstrated that PCM can contribute to minimize temperature fluctuations inside buildings, regulating thermal comfort parameters, while shifting heating or cooling peak loads to off peak electricity periods.

In order to compare the performance in terms of energy consumption and heat fluxes of two rooms, one containing a PCM material and the other the conventional material, identical temperature histories must be established. Careful experimental design is required to demonstrate quantitative energy savings and to emulate buildings performance; glazing and temperature history, insulation and ventilation should be similar to the real building.

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