INTERIOR COMFORT REGULATION WITH GYPSUM PLASTERS

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ABSTRACT

In this work, the performance of a manually applied thin layer of a multilayer gypsum plaster system, for interior lining of walls and ceilings, incorporating phase change materials (PCM), is investigated. The study aims the development of a passive solar storage system that can be combined with both active heating and cooling storage systems and equipments.

Mechanical and thermal tests were carried in laboratory, in two test cells and in residential buildings. Results so far showed that the gypsum plaster with 20%-wt. PCM reduces up to 45-50% flexural and compressive strengths, but the specifications of the European standard for these materials are fulfil.

On what concerns thermal properties, the use of gypsum-PCM plaster reduces the maximum room temperature up to 5 ºC with a time delay of 3 hours and increases the minimum room temperature up to 1.5 ºC with a time delay of 2 hours. Besides, it also reduces room relative humidity up to 10%. Power savings of 0.44 $W/m^2_{wall}.m^2_{floor}$ were estimated, with higher potential for lower temperatures, according to tests carried in a Passy's test cell during the cooling season.

INTRODUCTION

One of the main causes of energy's consumption increase in buildings is related with higher comfort needs by the users. In developed countries, lightweight construction has been used as a way to reduce the environmental impact of natural resources exploitation for building materials use. However, most of the comfort needs have been satisfied by the use of air conditioning apparatus. Due to continuous increase of fuels and energy price, companies in countries such as Japan, have already applied extreme measures such as the non use of ties in their office buildings.

The importance of energy's consumption and CO_2 emissions reduction, has led, in the last twenty years, to several research programs that aim energy conservation by thermal storage, through new materials and building techniques. Focusing on materials development, one of the major fields of study has been phase change materials (PCM) that have been used both for solar passive storage, integrated in construction materials and as cooling or heating medium in active systems such as air conditioners.

Integration of these materials in wallboards as an attempt to develop new lightweight materials but with high thermal mass is a wide field of study. These materials thermal capacity is so high that a wallboard 15 mm thick may be compared with 9 mm thick concrete, depending on the PCM nature and content.

In Portugal, high thermal mass buildings are still very common, as part of the construction method mainly for dwellings. These buildings are usually plastered with gypsum due to the material's good hygrometric, thermal and acoustic properties. However, temperature fluctuations can be high mainly during the heating season. Therefore the idea of incorporating PCM in the finishing plaster layer of a multilayer system seemed a way to save indoor energy.

By choosing the adequate phase transition temperature of the PCM, one can, to some extent, thermo regulate indoor environment, contributing not only to a decrease on energy consumption but also to peak shift the heating loads to periods when energy is less expensive.

Zhou et al. [1] performed a simulation of a direct gain passive solar house in Beijing that incorporated PCM plates as walls and ceiling interior lining. In their study, during the heating season, an external heat source was used in order to maintain indoor temperatures above 18 ºC. Results showed that up to 47% energy could be saved during the peak hours with a total of 12% energy saved during winter.

Chen et al. [2] conducted a simulation with gypsum wallboards, 30 mm thick, a phase change temperature of 23 ºC and an enthalpy of 60 kJ/kg and showed that up 17% energy could be saved during the heating season. For this study, the wallboards were applied in the north wall of an ordinary room and indoor room temperature was set at 20 ºC.

Schossig et al. [3] conducted a study where they used gypsum plaster for interior lining in lightweight (gypsum plasterboard, wooden slats with insulation and 14 cm thick polyurethane foam) test buildings facing south. In this study, two different plaster systems were tested: a 40%-wt. PCM, 6 mm thick plaster and a 20%-wt. PCM, 15 mm thick plaster. Results showed a 4 ºC difference in the maximum temperature, with a time delay of 1 hour.

One inconvenient of Schossig's work [3] is the amount of PCM necessary for the plastering system, since PCM is a very expensive material, and as seen for the results, at least 20%-wt. PCM in a 15 mm thick plaster layer (1000 kg of plaster per 76 m^2 of plastered area) must be used in order to produce significant results.

METHOD

The experimental programme for the complete research work was planned to evaluate both mechanical and thermal properties of the material and also to economically assess its viability, by quantifying active heating and cooling energy savings, both in thermal test cells and in a full scale residential building. The programme was divided into three main stages.

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 ºC and a latent heat of fusion of 140 kJ/kg.

The *first experimental stage* was the evaluation of the mechanical properties of the gypsum-PCM mixture (Figure 1). A commercial gypsum plaster, referred as MA, was primarily evaluated with the purpose of defining the PCM content and the water/plaster ratio in order to fulfil the new EN 13279-1 [4]. Since MA did not fulfil the standards, a second set of gypsum plasters, based in MA and referred as F3, F4 and F5, were developed and their flexural and compressive strengths were tested in specimens according with the EN 13279-2 [5]. Bond strength between plaster layers, in both painted and non-painted surfaces, was also evaluated in pilot scale walls. The final PCM content was set in 20%-wt. of the final plaster and the water/plaster ratio was set in 0.65.

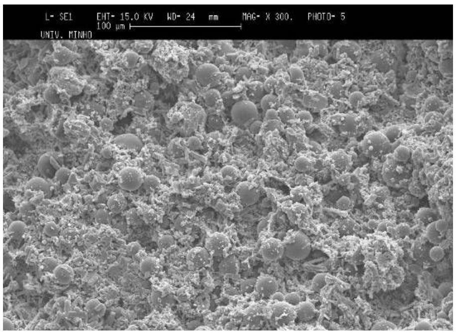

Figure 1: SEM picture of the PCM microcapsules inside the gypsum matrix.

The *second stage of the experimental campaign* consisted in the comparison between the thermal performance of two rooms, in a Passy's test cell, of the selected plaster and the commercial MA. The mentioned cell (Figure 2), located at the Building Physics and Technology Laboratories of Civil Engineering Department at the University of Minho in Guimarães, north to south oriented, is 4.24 m length, 2.58 m wide and 3 m high and presents the following constructive characteristics: *south façade* made of a hollow polycarbonate sheet (10 mm thick) mounted in a wood frame (2.83 m high and 2.03 m wide) and glass door (55 cm wide) mounted in a wood frame; *inner north wall* made of cement bonded particle board (12 mm thick) and expanded polystyrene (10 cm thick). In this wall, two particleboard doors (2.20 m high and 59 cm wide) allow access to the room; *inner west wall* made of adobe bricks and expanded polystyrene (20 cm thick); *inner east wall* made of mortar layer (2 cm), hollow brick (11 cm), mortar layer (2 cm) and expanded polystyrene (20 cm thick); *floor* made of cement bonded particle board (12 mm thick), air box (10 cm), of cement bonded particle board (19 mm thick) and expanded polystyrene (25 cm thick); *roof* made of particleboard (5 cm thick), cement bonded particle board (12 mm thick) and expanded polystyrene (30 cm thick).

A hollow ceramic brick (11 cm thick) wall was built, dividing the cell in two rooms (east and west). To allow plastering, instrumentation and maintenance of the east room, an aperture was left (this opening was then closed with a double layer of expanded polystyrene 5 cm thick plates and polyurethane foam). Each surface of the wall was then covered with projection gypsum plaster. After 24 hours, three very thin layers of finishing plaster were manually applied in both façades. In the West façade gypsum-PCM mixture was used as solution in study (Figure 2), while in the East façade gypsum plaster was used as Reference solution. Table 1 presents the characteristics of both systems.

Property	**Reference Solution**	**Studied Solution**
Internal cell dimensions (L x W x H in m)	4.10 x 2.50 x 2.60	
Plastered area (m^2)	9.74	
Gypsum plaster used (kg)	10	7.5
PCM used (kg)	---	1.9
Plaster specific consumption (kg/m^2)	1.03	0.77
PCM specific consumption (kg/m^2)	---	0.20
Storage capacity (Wh/m^2)	---	**7.6**

Table 1: Test cell system characteristics.

Figure 2: West room of the Passy's test cell – Gypsum-PCM façade.

Both rooms were instrumented with temperature and relative humidity sensors and thermocouples were installed in the different plaster layers and walls surface. Monitoring was carried between the 21st July and the 8th August, 2007.

The *third stage of the research work*, still undergoing, involves testing and comparing the thermal performance of the gypsum-PCM solution with the conventional plastering system MA, in full scale residential buildings. For this stage, we selected two houses (Reference and PCM) and two rooms in each house (Figure 3). Within each house, one of the rooms faces east while the other faces west. Both walls and ceilings were plastered. Table 2 presents the characteristics of both systems.

a) *b)*

Figure 3: Selected Reference and PCM rooms in the a) West façade and in the b) East façade.

Property	Reference (MA)		Studied (PCM)	
	East Room	*West Room*	*East Room*	*West Room*
Room area (m^2)	17	21.5	17	21.5
Total plastered area (m^2)	54	62	54	62
Gypsum plaster used (kg)	60		40	
PCM used (kg)	---	---	10	
Plaster specific consumption (kg/m^2)	0.52		0.35	
PCM specific consumption (kg/m^2)	---	---	0.086	
Storage capacity (Wh/m^2)	---	---	**3.3**	

Table 2: Residential building system characteristics.

The four rooms were instrumented as shown in Figure 4, with thermocouples in the walls, ceiling and double glass window surface. Outside and room temperatures are also monitored.

Figure 4: Schematic view of instrumentation placed (reference west room).

The first set of measurements ran between the 11th December, 2007 and the 11th January, 2008 and consisted in outside and internal temperature monitoring dependant only on solar gains. All doors were sealed with expanded polystyrene (5 mm thick) and polyurethane foam and no ventilation were provided.

RESULTS

The influence of the PCM content in the gypsum plaster was evaluated and is shown in Figure 5. Different percentages of PCM were incorporated in the gypsum plaster, leading clearly to a decrease in mechanical resistances.

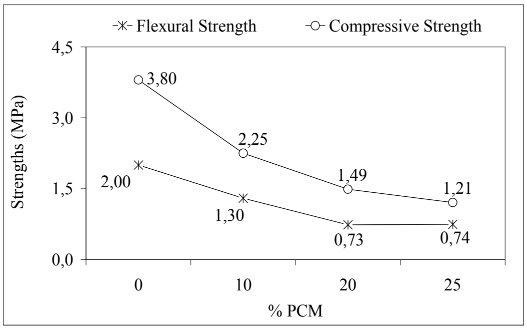

Figure 5: Variation of mechanical strengths of MA with PCM incorporation.

Based in MA, the set of F3, F4 and F5 plasters were tested incorporating 20%-wt. PCM and mixed with a water/plaster ratio of 0.65. Figures 6 and 7 present the results of mechanical properties tests carried.

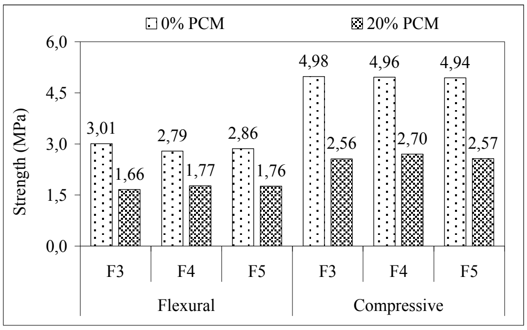

Figure 6: Variation of mechanical strengths of MA with PCM incorporation.

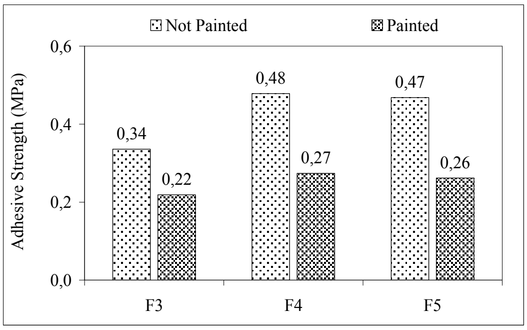

Figure 7: Bond strength between plaster layers.

After selection of F4 due to better mechanical properties and low production cost, thermal performance of both gypsum-PCM plaster and conventional plaster were evaluated in a Passy's test cell as referred above. In Figures 8 and 9, comparison between room temperatures, dependant only on solar gains, and relative humidity is presented, for a period of three days between which either the coldest or the warmest day were registered.

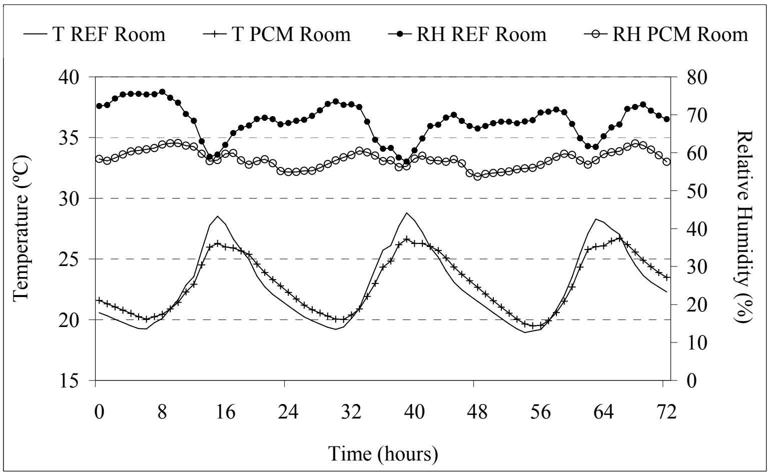

Figure 8: Temperature and relative humidity profiles for the period hosting the coldest day (9.6ºC<T_{out}<25.8ºC).

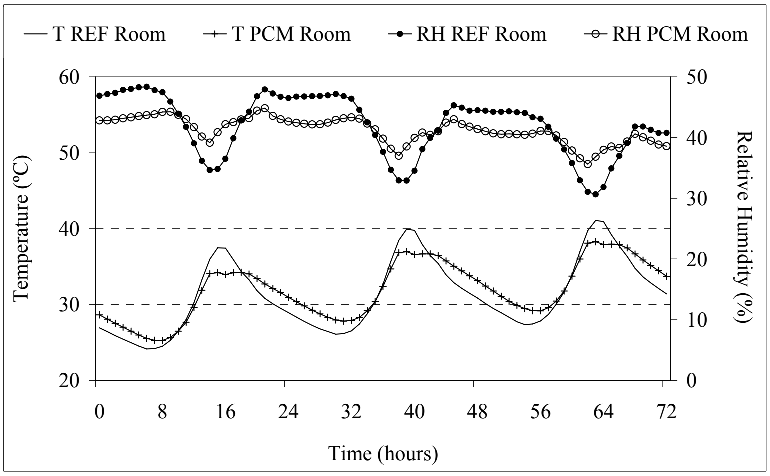

Figure 9: Temperature and relative humidity profiles for the period hosting the warmest day (14.9ºC<T_{out}<36.8ºC).

For the period represented in Figures 8 and 9, the maximum and minimum measured temperatures are shown in Table 3. For the whole monitored period, the most important feature of the measurements, is presented in Table 4, where both temperature and time measured amplitudes are shown.

	Outside	Reference Room	PCM Room	Reference Wall	PCM Wall
T_{Max} (ºC)	36.8	42.2	38.1	39.2	37.5
T_{Min} (ºC)	9.0	19.1	19.2	19.2	19.6

Table 3: Maximum and minimum registered temperatures during the monitored period.

	Temperature / Time Delay	
	Maximum	*Minimum*
ΔT (ºC)	-4.9	1.4
Δt (h)	3	2

Table 4: Maximum and minimum temperature amplitudes and time delays between Reference and PCM rooms.

Assuming equal heat loss through the envelope for both rooms and neglecting conductive heat transfer through the wall, the heat fluxes between the wall surface and the room were determined according to Equation 1:

$$Q = U.A.\Delta T = \frac{\Delta T}{R} \quad (1)$$

Where,

U is the Overall Heat Transfer Coefficient, in $W/m^2.ºC$;

A is the Heat Transfer Surface, in m^2;

ΔT is the Temperature difference between room medium and wall surface, in ºC;

R, is the Horizontal Thermal Resistance through walls, in.

In this case, R = 0.13 $m^2.ºC/W$ defined by RCCTE, the Portuguese Regulation for Buildings Thermal Behaviour Characteristics [6]. Results are shown in Table 5.

ΔQ_T (W)	ΔQ_h (W)	ΔQ_{Wall} (W/m^2_{Wall})	ΔQ_{Floor} (W/m^2_{Floor})	$\Delta Q_{Wall.Floor}$ ($W/m^2_{Wall}.m^2_{Floor}$)
24788	21.3	2.2	4.3	0.44

Table 5: Calculated heat flux differences.

Where,

ΔQ is the heat flux, from wall surface to the room, difference between PCM and reference room;

T refers the total monitored period;

h refers to one hour;

Wall refers per wall area;

Floor refers per floor area;

Wall.Floor refers per wall and floor area.

Results from experimental work carried *in-situ* in residential buildings are not yet available. However, the first important feature is presented in Figure 10, where room temperatures were monitored.

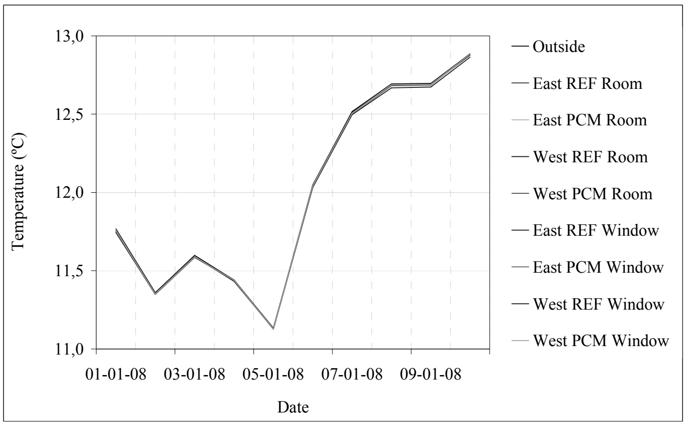

Figure 10: In-situ interior and window temperature profiles.

DISCUSSION

The incorporation of PCM in gypsum plaster decreases significantly its mechanical properties. Only 10%-wt. PCM represents a 35% to 40% loss, both in flexural and compressive strengths. An overall decrease between 60% and 70% was registered for MA when incorporating 20%-wt. PCM.

From previous work [7], 20%-wt. PCM in the final plaster was used for a water/plaster ratio of 65%. Since EN 13279-1 [4] sets flexural and compressive strengths for these plasters in 1 MPa and 2 MPa respectively, F3, F4 and F5 were then developed and evaluated. Again when compared to the results without PCM, significantly strengths loss, around 40% to 50% was registered but when compared to MA, increases of 40% in flexural and 58% in compressive strengths were achieved.

Another important property for this type of plaster is adhesion between layers which can be characterized by bond strength testing. Tests between F3, F4 and F5 and a commercial projection plaster, were performed in pilot scale walls showing good results in what concerns the standards (over 0.1 MPa) in both painted and non-painted surfaces.

From the results obtained in the test cell was possible to verify that PCM has a benefit effect in room environment, decreasing maximum temperature up to 5ºC and increasing minimum temperature up to 1.5ºC. More, the registered minimum and maximum temperatures in the PCM side, where observed with a time delay of 2 and 3 hours respectively, after reference side peaks been achieved. This data is very important due to the potential of peak shifting energy consumptions to periods when energy's less expensive.

Considering the heat flux, from wall surface to the room, difference between PCM and reference room calculated per wall and floor area presented in Table 5, and taking as an example a room between 12 to 16 m^2, the possible cooling power savings with this system would be around 15% (valid only for the period analyzed). Considering a fan or AC supply of 1000 W and 0.1143 €/kWh (Portuguese energy price), up to almost 2 c€/h could be saved.

Another important feature of the system is shown in Figures 8 and 9, where the relative humidity of both spaces is compared. Not only has the PCM side presented, in general, lower RH for both colder and warmer temperatures but also its variation is narrower (RH between 35-45% *versus* 30-50% during the hottest period and 53-62% *versus* 57-76% during the coldest period). This data is important attending that for higher RH, higher condensation problems may occur.

The first stage of experimental work carried *in-situ* in residential buildings was monitoring room temperatures depending only on passive solar gains. From Figure 10 is clear that no difference was so far verified between Reference and PCM rooms. The low winter solar gains and consequently PCM room temperatures below PCM fusion temperature (around 20 ºC), inhibit the PCM to change its state, from solid to liquid, therefore regulating temperature. More, no differences were registered between East and West rooms or between windows facing East and West, again showing no sufficient solar gains.

The second stage of the *in-situ* campaign consists in the introduction of an external heat source in both PCM and Reference rooms, in order to promote PCM fusion and that way evaluate the thermal behaviour of both solutions. The installation of energy meters side by side with the already installed thermocouples, will also allow temperature and energy consumption control and comparison.

ACKNOWLEDGEMENTS

The research work presented in this paper is 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.

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