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Thermal loads inside buildings with phase change materials: Experimental results

Lidia Navarro[a], Alvaro de Garcia[a], Cristian Solé[a], Albert Castell[a],
Luisa F. Cabeza[a]*

[a]*GREA Innovació Concurrent, Edifici CREA, Universitat de Lleida, Pere de Cabrera s/n, 25001-Lleida (Spain)*

Abstract

Nowadays, European policies are promoting low energy buildings because of the high amount of energy consumption of the building sector. Phase change materials (PCM) have been studied in building implementation as a passive system to reduce the energy demand. Based in the experience obtained in the experimental set-up of Puigverd de Lleida (Spain), this paper pretends to analyze experimentally the PCM performance in a scenario with internal thermal gains. The experiments were done in three different cubicles with the same internal dimensions. The selection of the constructive systems used in these three cubicles allows the authors to evaluate the impact of using PCM in a typical Mediterranean building. A domestic heat pump for summer and an electric radiator for winter were installed to control the internal temperature of the cubicles. The results of summer period experiments show that the PCM cubicle stored the heat produced by the internal loads limiting the heat dissipation to the outer environment. Therefore, the energy consumed by the HVAC system of the PCM cubicle during the cooling period is higher than that of the other cubicles that dissipated the thermal loads according to the thermal resistance of their envelopes. Therefore, the PCM selection should take into account not only the comfort temperature but also the activity and functionality of the building.

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Keywords: thermal energy storage (TES); phase change materials (PCM); building; thermal loads; passive system

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* Corresponding author. Tel.: +34-973 003576; fax: +34-973 003575.
E-mail address: lcabeza@diei.udl.cat

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1. Introduction

Energy consumption in buildings is getting more and more importance as it represents a high amount of the global energy consumption. Nowadays, the building sector is consuming 40 % of the global energy in the European Union, and two thirds of this energy consumption is due to the HVAC systems. Hence, it is critical to reduce the energy demand of the building. The European directive on the energy performance of buildings (EPBD) suggests that all the EU member states should approve national plans and targets in order to promote the inclusion of very low and close to zero energy buildings [1].

It is well known that improvements in buildings envelope have high potential in energy demand reduction and consequently in energy savings [2]. These improvements have to be not only focused on the thermal resistance but in the thermal inertia, as well. Many researchers have increased the thermal energy storage capacity of the envelopes by using phase change materials (PCM) [3,4], which are latent heat storage materials and might provide a good solution to achieve low energy consumption standards [5]. This technology has been studied for both active [6] and passive systems, such as space heating, space cooling and domestic hot water [7]. As passive systems, PCM have been implemented and studied in many buildings applications. A precast concrete cubicle with PCM was experimentally tested by Cabeza et al. [8]. Results show that the microencapsulated paraffinic PCM inclusion in the concrete walls smoothed out the internal temperature fluctuations and delayed around 2 h the maximum peaks. Furthermore, Castell et al. [9] measured energy consumption reductions of 15% when macroencapsulated PCM (paraffin and salt hydrate) was implemented in building envelopes. However, all studies focused on the comfort temperature required and the weather conditions. None of them considered the heat produced by daily activity of the building. The contribution of these internal loads has a significant impact on the energy consumption for space heating and cooling.

Based on the experience obtained in the experimental set-up of Puigverd de Lleida (Spain), this study pretends to analyze experimentally the thermal impact of using PCM in a building with internal thermal loads. Occupancy, equipment, and lighting are examples of internal gains of an office which have influence to the comfort temperature.

The inclusion of PCM in the walls increases the storage capacity and, therefore thermal loads are supposed to be absorbed by the building envelope. The behavior of the PCM might be different in summer and winter conditions due to the heat dissipation capacity to the environment. In this study, experimental results of the summer period are presented.

2. Methodology

An experimental set-up located in Puigverd de Lleida, Spain, (Fig.1) is used to perform the experimental part of the work. The thermal behavior of three different cubicles with the same internal dimensions (2.4x2.4x2.4 meters), no windows and a metallic insulated door in the north wall, were compared.

Fig. 1. Experimental set-up of Puigverd de Lleida.

The constructive systems of these cubicles are presented below:

1. Reference cubicle (REF): it was built with traditional brick system based on two layers of bricks with an air gap and without insulation.
2. Polyurethane cubicle (PU): this cubicle was also built with traditional brick system, but with 5 cm of spray foam polyurethane in the walls and 3 cm in the roof.
3. PCM cubicle (PCM): it was built as the previous cubicle adding a PCM layer in the southern and western walls, and in the roof. The CSM panels containing RT-27 paraffin (Rubitherm) were located on the internal side of the polyurethane.

All cubicles have a heat pump and an electrical oil radiator to perform experiments with controlled comfort temperatures. The experiments with thermal loads were carried out with an infrared radiator HJM mod.301 (Fig.2), in which different loads can be performed (300, 600, 1000 W) to simulate different levels of activity and occupancy. These loads were programmed with an office profile (9-14 h and 16-19 h), and experiments were performed for free floating and controlled temperature conditions during summer period. The internal gains due to the occupancy, equipments and activity of the building are based on the ASHRAE standards [10]. The considered case is an office with one person, a computer with screen and the lighting, obtaining a total value of about 300 W.

Fig. 2. Infrared heater HJM mod. 301

In order to measure and analyze the thermal behavior of these cubicles the following data was registered with an interval of 5 min:

- Internal wall temperatures (east, west, north, south, roof and floor) and also external south wall temperature.
- Internal ambient temperature and humidity (at a height of 1.5 m).
- Heat flux at the ceiling inside surface.
- Electrical energy consumption of the heat pump or the electrical radiator.

All these cubicles are instrumented with Pt-100 DIN B sensors, calibrated with a maximum error of ±0,3 ºC. The internal ambient conditions (temperature and humidity) are measured with ELEKTRONIK EE21 with an accuracy of ±2% and the heat flux with HUKSFLUX HFP01 sensors with an accuracy of ±5%. An energy counter (Circutor MK-30-LCD) is used to register the energy consumption of the heat pump (Fujitsu Inverter ASHA07LCC) and the electrical oil radiator (Technofont TF).

In addition, the outer weather conditions were registered measuring the global solar radiation, the external ambient temperature, the outer humidity, and the wind velocity.

Two different experiments were carried out in the experimental set-up:

- Internal loads with office profile. No heating or cooling systems were used during these experiments, therefore the temperatures had free oscillation, and it is the so-called free floating experiment. The inner environment temperatures of the cubicles were compared.
- Internal loads with office profile and controlled temperature. Heat pumps and electrical oil radiators were used during summer and winter, respectively, to set the internal temperature of the cubicles.

3. Results and discussion

3.1. Thermal loads with office profile in free floating conditions

In Fig.3 the thermal evolution of the different inner environment temperatures during the experiments under free floating is presented. As it was expected, the reference cubicle had higher temperature fluctuations (27.5 ºC to 24 ºC) than the other cubicles with insulation in its envelope (28 ºC to 26 ºC). This fact means that the reference cubicle can release easily the heat accumulated during the office working schedule to the outer environment in the night periods. The cubicles dissipated the thermal loads according to the thermal transmittance of their envelopes (Table 1) [11]. The polyurethane cubicles have the same U-value, therefore they have similar thermal profiles.

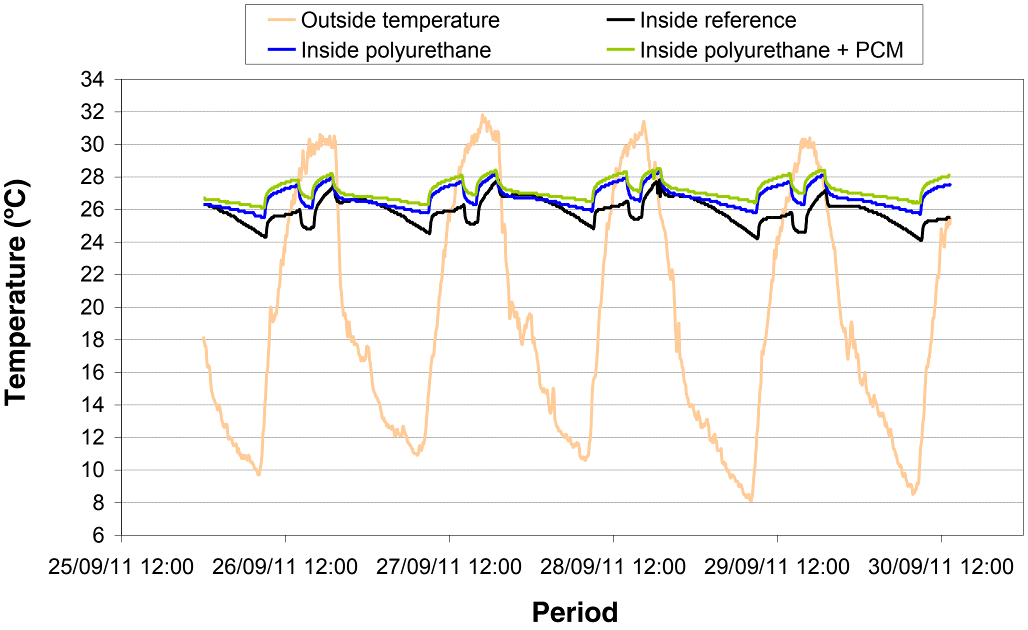

Fig. 3. Free floating with internal loads (office profile): inside and outside temperatures

Table 1. U-value calculations [9]

	U-value (W/m^{2}K)	
	Theoretical	**Experimental**
REF	1.21	1.04
PU	0.38	0.30
PU + RT-27	0.38	0.30

The daily behavior of the polyurethane and the PCM cubicle is analyzed (Fig.4). It can be observed that the inner temperature of the PCM cubicle is always slightly higher. Even though both cubicles start at the same temperature, during night the internal temperatures decrease depending on the heat dissipation capacity of each constructive system. The thermal reduction is slower in the PCM cubicle since it has stored more heat (latent). At the beginning of the following daily cycle, the PCM cubicle temperature is around 0.5 ºC higher than the PU cubicle. The heat loads have not been released outdoors as it happens in the PU cubicle. Therefore, the PCM cubicle temperature is higher than the PU cubicle during the entire office schedule.

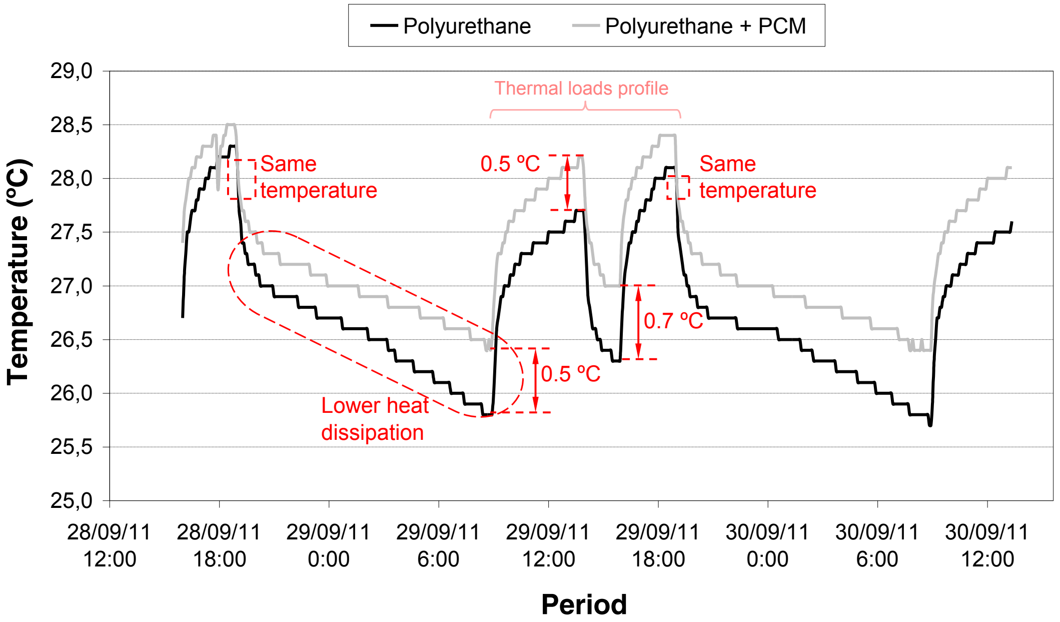

Fig. 4. Free floating with internal loads (office profile): PU and PU + PCM during a day

3.2. Thermal loads with office profile and controlled temperature (24 ºC)

The first controlled temperature experiment was done with a set point of 24 ºC. In Fig.5 the energy consumption between all cubicles is compared. As it was expected, the reference cubicle has the highest consumption. On the other hand, the PCM cubicle has consumed more than the PU one. In this experiment, the set point temperature (24 ºC) is below the PCM melting point. Consequently the RT-27 is storing heat to achieve its phase change, and even though the heat pump is cooling, the PCM walls and roof are releasing heat to the internal ambient at the phase change temperature.

3.3. Thermal loads with office profile and controlled temperature (26 ºC)

A second experiment was done with controlled temperature at 26 ºC and the electrical energy consumed by the HVAC systems is shown in Fig.3. It can be seen that the use of 5 cm of PU in the envelopes reduces 50% of the energy consumption of the cubicles. The PU and PCM cubicles consumption is nearly the same but the PCM one is still consuming more than the one without, although the difference between them has been reduced. The RT-27 phase change peak is over the set point (26 ºC), therefore the PCM can not use all its storage potential.

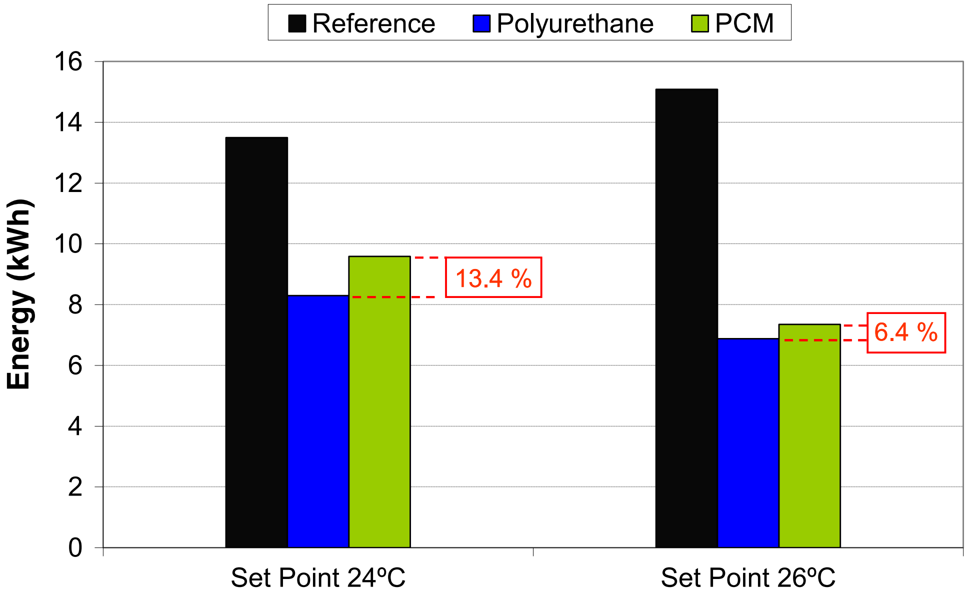

Fig. 5. Accumulated energy consumption for experiments with a set point of 24 ºC and 26 ºC

In the controlled temperature experiments the PCM is storing isothermally (at 27ºC) the heat coming from the outer environment and the heat produced by the inner loads. This heat is keeping the internal temperature high and it has to be balanced by the heat pump, consuming more energy to achieve an internal temperature of 24 ºC or 26 ºC.

In Table 2 the energy consumption values of the controlled temperature experiments are shown. In the first experiment (24 ºC), the PU + PCM cubicle is consuming 13.43 % more energy than the one without, while in the experiment with a set point of 26 ºC this percentage is reduced to 6.39 %.

The difference between the comfort temperature and the PCM melting point is directly related to the energy consumption. A higher difference between both temperatures results in higher energy consumptions. For this reason, it is important to choose the appropriate PCM for its implementation, depending on the scenario and conditions of the building [1].

Table 2. Energy consumption values

	Energy consumption (kWh)	Energy difference[1] (%)
Set point of 24 ºC		
Reference	13.50	38.54
Polyurethane (PU)	8.29	-
Polyurethane (PU) + PCM	9.58	13.43
Set point of 26 ºC		
Reference	15.08	50.31
Polyurethane (PU)	6.88	-
Polyurethane (PU) + PCM	7.35	6.39

[1] Referenced to the polyurethane cubicle.

4. Conclusions

In this paper the effect of adding macro-encapsulated PCM in conventional constructive system used in buildings with internal thermal loads was experimentally tested. The internal heat gains simulate the occupancy profile of an office. During the summer period, experiments under free floating conditions and controlled temperature with HVAC system were performed.

In the free floating experiments with internal gains, the PCM is storing the heat and maintaining the temperature higher than in the other cubicles, reducing the thermal comfort of the building. This fact means that PCM has low dissipation of these thermal loads.

Furthermore, in the controlled temperature experiments, the difference in the energy consumption between the PCM and the PU cubicle is lower with set point of 26 ºC (6.4%) than at 24 ºC (13.5 %). In both cases, the energy consumption of the PCM cubicle is higher than the PU one because of the reduced heat dissipation.

It is demonstrated that the difference between the PCM melting point and the set point is directly related to the energy consumption, and it is critical in cases with significant internal thermal loads, especially in summer conditions. Therefore, the selection of the PCM is very important not just for the comfort temperature but for the activity and functionality of the building. Also, the results from the experiments show the need of night ventilation to discharge the PCM during night, otherwise the energy consumption increases.

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