DYNAMIC THERMAL RESPONSE OF COMPOSITE MATERIALS

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Abstract

Dynamic thermal responses of building envelopes must be taken into account during the design phase of buildings, otherwise several construction systems can be underestimated and wrongly discarded. The evaluation and measurement of transient thermal parameters of multilayered samples are difficult due to the irregular morphology of the used materials and the difficulty in providing well controlled environment. New equipment has been constructed to measure those thermal responses of small samples in well controlled environmental conditions.

Moreover, the use of phase change materials has become important recently in the building sector because it increases the thermal mass of the envelope and hence smoothes the temperature oscillations and reduces the energy consumption of heating and cooling. The equipment developed will be used to test the improvement in the thermal response of a building envelope due to the incorporation of PCM.

Keywords: Dynamic thermal response, multilayered wall, energy savings, PCM, experimental study

1. Introduction

Thermal and energetic optimization in the building sector depends strongly in the selection of the materials and the design of the constructive system for each envelope, depending on the energetic demands of the building. Therefore, it is very important to specify during the design phase of the building, the thermal properties of the different possible construction systems and materials (thermal resistance, heat storage capacity, dynamic thermal response...).

In order to compare the thermal behaviour of the different construction systems, thermal transmittance in steady-state, also known as U-value (Çengel 1998), is widely considered as the key design parameter and it is usually regulated by law. However, thermal inertia is not considered in this parameter and hence, not considered in many national building codes.

Several studies have been done to evaluate the thermal resistance of different envelopes. Peng and Wu (2008) compared different methods for measuring in situ the thermal resistance of a building envelope (synthetic temperature method, surface temperature method and frequency response method). Even though the three of them show good accuracy, the frequency response method is recommended since it does not need heat flux measurements, which are always difficult to measure accurately. Moreover, Cabeza et al. (2010) tested in 4 different real house-like cubicles the thermal resistance of 3 envelopes with different insulation materials (polyurethane, mineral wool and polystyrene).

Nevertheless, De Gracia et al. (2011a) used the house-like cubicles to prove experimentally that the real performance of the different constructive systems not only depends on the thermal transmittance in steady state, but on its thermal inertia and hence its dynamic performance. In this work, an alveolar brick construction system (without insulation) was compared against a traditional Mediterranean brick system combined with insulation. Even though the insulated envelope presented a much lower U-value than the alveolar construction, these differences are not reflected in the measured energy consumptions, where the alveolar cubicles only consume 2% and 13% more than the insulated ones, for winter and summer periods, respectively. It was concluded that to analyze the thermal performance of a building envelope transient parameters must be taken into account.

The use of phase change materials (PCM) in buildings to increase the thermal mass of the envelope, and the research around this topic has grown significantly in the last years (Cabeza et al. 2011, Khudhair and Farid 2004). The improvement due to the use of PCM was experimentally evaluated for different constructive systems, such as timber construction (Farid and Behzadi 2010), concrete based envelopes (Cabeza et al. 2007) and typical Mediterranean brick construction system (Castell et al. 2010). These experimental set-ups constructed in Spain and New Zealand provide good information about real response of buildings and they offer a good testing procedure for any material used in construction. However, they are expensive and not very flexible.

In addition, in order to achieve a good performance in the solidification and melting process of a PCM used in a building envelope, all other used materials and the multilayered envelope itself must be well characterized. Hence, steady and transient parameters of the construction systems must be analyzed. The equipment described in this paper is a simple tool for testing the steady and transient thermal response of real constructive systems including those containing PCM. This equipment has been already used to measure the thermal transmittance of steady-state and the heat storage capacity of multilayer constructive systems containing PCM (de Gracia et al. 2011). In this paper, the equipment will be used to analyze the dynamic thermal response of different samples.

2. Materials and method

2.1. Experimental set-up

The equipment (Figure 1) was constructed from a wooden box having dimension of 50 cm x 50 cm x 118 cm and it is divided into 2 identical sections which simulates the interior and exterior conditions of a building envelope. The sample to be tested is placed between these two sections with its four edges well insulated. The upper section of the box is provided with a copper heating coil connected to a programmable water bath, capable of simulating daily variation of ambient temperature while the lower section is provided with a copper cooling coil connected to a constant water bath to simulate indoor temperature.

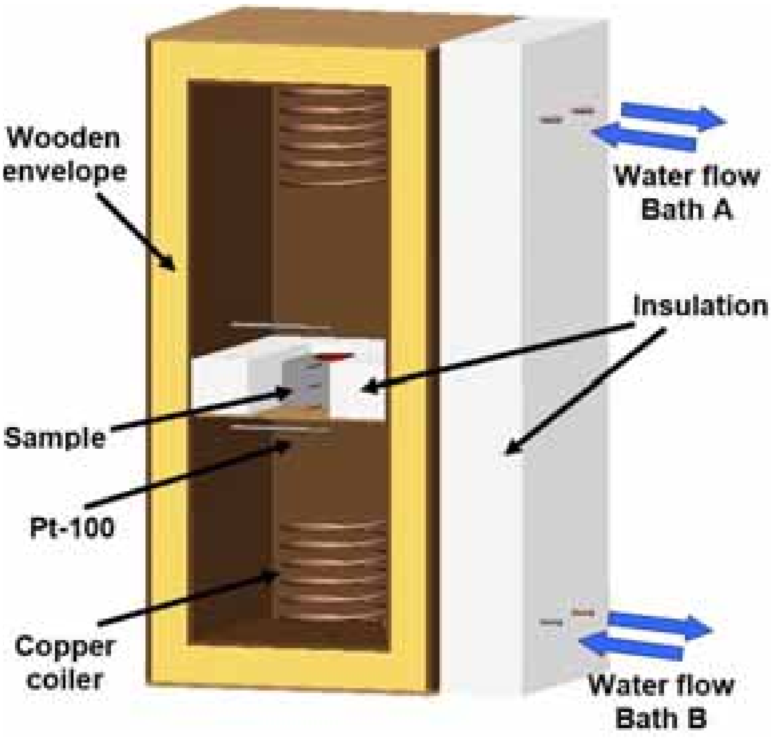

Figure 1. Sketch of the new equipment

The sensor distributions in the equipment is shown in Figure 2. The temperature of these two environments as well as the surfaces and centre temperatures of the sample are measured using temperature sensors (thermocouples type T in the sample and Pt-100 in the environments). Two heat flux sensors are fixed at the sample surfaces to measure input and output heat fluxes. The tested samples have the dimensions of 19cm x 19 cm with varying thickness (depending on the construction materials to be tested).

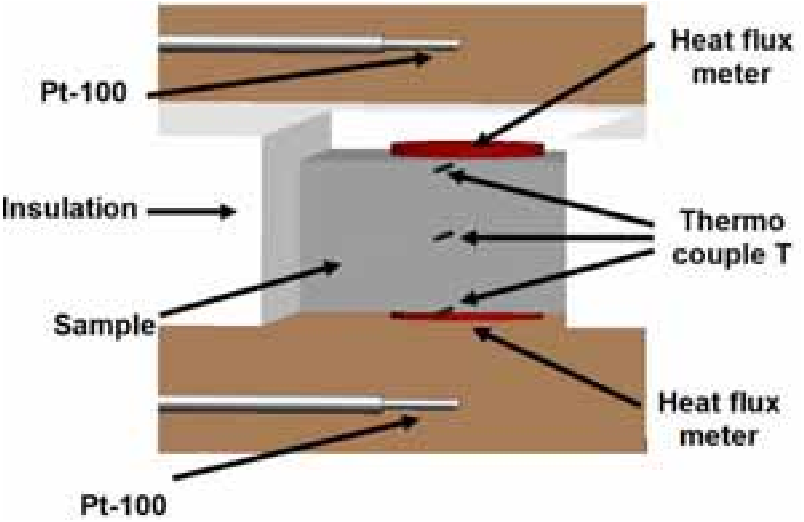

Figure 2. Sensor distribution in the sample

2.2. Materials

This paper analyzes the effect in the dynamic behaviour due to the impregnation with PCM of a conventional gypsum board. Two different multilayered samples have been tested being both composed of 1.8 cm thick pine wood panel (k=0.12 W/m·K) glued to a 1.2 cm thick gypsum board (k=0.17 W/m·K). The wood panel acts as a structural support and insulating layer while the gypsum board acts as inner surface. The second sample has impregnated PCM (13.5% w/w). The tested samples are described in Table 1.

Tab. 1: Composition of analyzed samples

	Sample 1	**Sample 2**
Pine wood	297.3 g	258.8 g
Gypsum board	325 g	329 g
PCM	---	94.6 g
Glue	14 g	14 g
Total	636.3 g	696.4 g

2.3. Methodology

The effect of increasing the thermal mass of the sample by the addition of PCM was studied evaluating the dynamic thermal response of both samples under periodic thermal variations. In the experiment, the sample was placed with the gypsum surface facing the lower environment, simulating a roof separating the outer (upper cavity) and the inner environmental conditions (lower cavity). The temperature at the upper cavity was driven by a programmable water bath which will create high temperature daily oscillation between 42 ºC and 15 ºC in the upper cavity during 48 hours in order to simulate outdoor environment. The water bath B will not be used during this experiment; hence the lower cavity will stay in free floating conditions (room temperature). The thermal response of the sample was evaluated during the last 24 hours of experiment by analyzing the delay between peaks of the inner and outer temperature and heat fluxes, and by evaluating the dampening of the temperature wave calculating the thermal stability coefficient (TSC) (Neila and Bedova 1997), which will be calculated as the ratio between the inner and outer thermal amplitudes.

$$TSC = \frac{Tmax_{in} - Tmin_{in}}{Tmax_{out} - Tmin_{out}} \qquad \text{(eq. 1)}$$

3. Results and discussion

The dynamic thermal response of the samples under an outer temperature daily oscillation between 42 ºC and 15 ºC was evaluated. The surface temperature evolution through time of the tested samples during the 2-day period of the experiment is shown in Figure 3. As it was previously said, in order to analyze the transient behaviour of the constructive system, only the second day of experiment will be considered (the first day is used as a warm up period). Phase change processes can be easily seen in the temperature profiles of both days (melting from 5 to 10 h and solidification from 17 to 20 h).

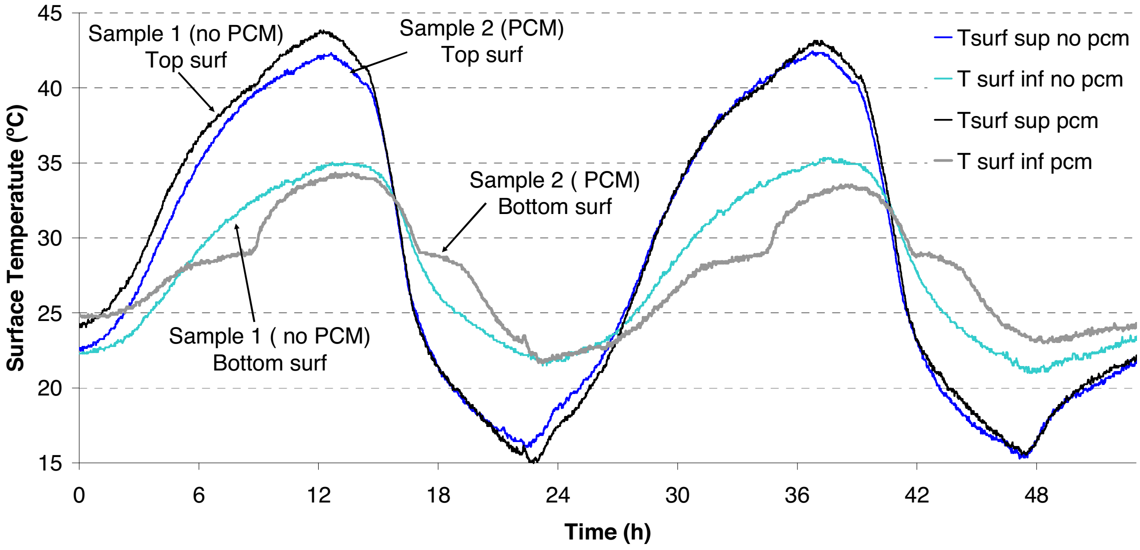

Figure 3. Dynamic response of the surface temperatures

Table 2 presents the highest and lowest temperature values of both cavities during the second day of experiment. It was measured that the thermal stability coefficient decreases from 0.51 to 0.39 just because of the addition of the PCM (13.6 % wt). The delay in the inner temperature peak was significantly higher in the sample with PCM (more than 1 hour).

Tab. 2: Measured values to calculate the Thermal Stability Coefficient

		Sample 1	Sample 2
T upper env (outdoors)	T max	42.83 ºC	42.33ºC
	T min	15.45 ºC	15.76 ºC
T lower env (indoors)	T max	35.23 ºC	33.53 ºC
	T min	21.18 ºC	23.09 ºC
TSC		0.51	0.39

Instead of comparing the delay of inner and outer temperature peaks, the time lag between the outer temperature and the inner heat flux peaks (thermal lag) is usually evaluated. Figure 4 presents the thermal lag of the two samples under daily temperature oscillation. As in Figure 3, the phase change can be easily observed in the inner heat flux curve, reducing the peak loads in a 22% and delaying the response from 0.49 to 1.03 hours.

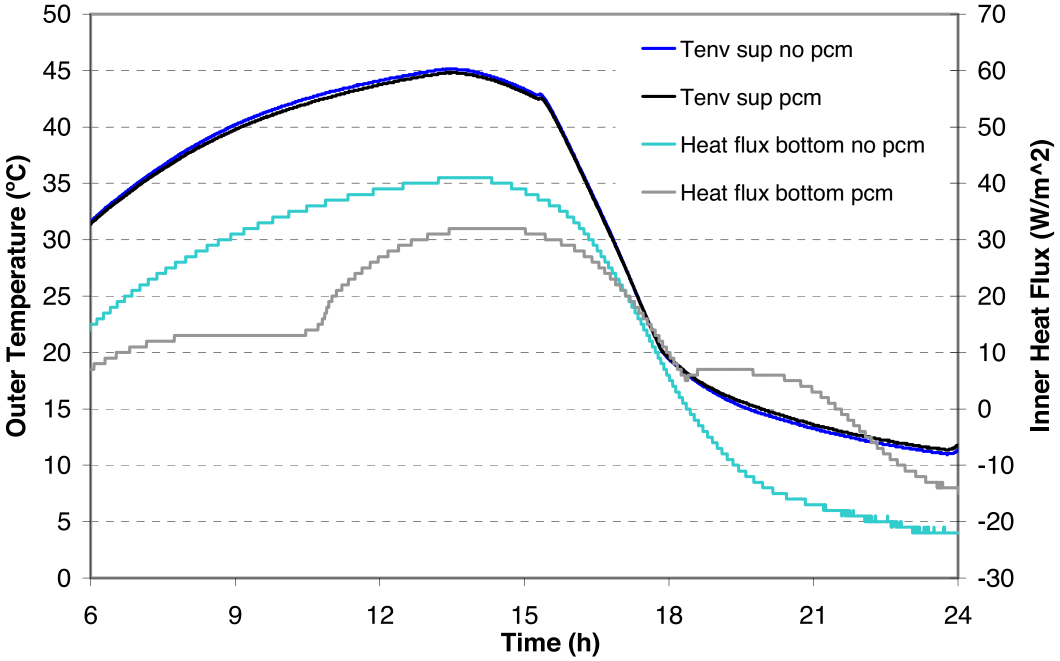

Figure 4. Thermal lag of both samples

4. Conclusions

A new equipment able to measure the dynamic thermal responses of multilayered samples, including those containing PCM, is presented in this paper.

The effect in the dynamic characteristics of adding PCM in common gypsum board is discussed and measured using this equipment. Samples of wood + gypsum board (with and without PCM) were tested under temperature daily oscillation conditions simulating the thermal performance of a roof system.

The measured results demonstrate that the addition of impregnated PCM in the gypsum board (13 % w/w) increases significantly the thermal mass of the constructive system. The dynamic thermal performance of the envelope is improved, since the thermal stability coefficient of a daily variation decreased from 0.51 to 0.39 and the thermal lag between outer temperature and inner heat flux peaks of the envelope increased from 0.49 to 1.03 hours.

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