Evaluation of PCM-cardboard composite materials in dynamic thermal conditions

Marta Musitelli*, Paola Garbagnoli*, Maria Vittoria Diamanti* **, Barbara Del Curto* **, MariaPia Pedeferri* **

* Politecnico di Milano, Department of Chemistry, Material and Chemical Engineering "Giulio Natta", Milan, Italy, marta.musitelli@chem.polimi.it - paola.garbagnoli@chem.polimi.it
** INSTM, National Interuniversity Consortium of Materials Science and Technology, Florence, Italy, mariavittoria.diamanti@polimi.it - barbara.delcurto@polimi.it - mariapia.pedeferri@polimi.it

ABSTRACT

In this work, composite panels developed in previous research activity, made by PCMs and cellulose fibers [1], are studied. In particular, the evaluation of PCM-based composite material in dynamic thermal conditions will be presented and its functionality will be compared with commercial panels.

A thermostatic chamber has been designed in order to simulate dynamic thermal conditions. Each panel object of the analysis has been used as part of the frontal wall of the chamber; inside the chamber, temperature profiles are tuned to simulate the real conditions of application; the temperature outside the chamber is maintained constant at room temperature.

Results have shown the heat storage capacity of PCMs and their effect on improving the thermal insulation of a cellulose-based panel. In particular, the effect on thermal profile smoothing (attenuation) and the delay in time of the maximum temperature (time lag) have been noticed.

Keywords: building envelope, insulation, PCMs, waste paper, composite panel

1 INTRODUCTION

In the European Union about 40% of global energy consumption depends on building heating and cooling systems [2]. In recent years, the use of smart materials to mitigate energy consumption in buildings, and the consequent environmental effects, has been increasingly widespread [3]. In particular, Phase Change Materials (PCMs) are used to improve thermal performance of air conditioning system and building insulation components [4]. PCMs can be used to reduce energy consumption since they are able to store and release heat, stabilizing the thermal profile inside the building. If the appropriate transition temperature is chosen, the final result is a nearly isothermal system.

The development of a new building panel has been conducted through experimental tests related with production technologies and technical performances. In this work an innovative PCM-cardboard composite material has been tested in dynamic thermal conditions. Two typical Italian climatic zones have been selected and their outdoor parameters have been reproduced for experimental tests. The work has consisted in the fabrication of a device which allows to simulate climatic and thermal changes on a building envelope, in order to test the insulating properties of the building envelope. This device ensures a good reproducibility of test parameters, which is needed to apply identical conditions to different specimens for a more reliable comparison. The innovative panel with PCMs has been compared in its thermal performance to ones available on the market.

2 MATERIALS

The composite material considered is a mixture of 50% cellulose fibers derived from waste cardboard and 50% Phase Change Materials in the form of paraffin powder (PX 28 HC, Rubitherm, Germany).

The two separated materials and the composite obtained have been examined through microscopic analysis (Leica DMLM) [5]. Optical micrographs are shown in Figure 1 together with real scale pictures. The incorporation of PCM microcapsules in paperboard results homogeneous, with a regular distribution of particles in paper matrix, moreover the microcapsules maintain their shape without damaging.

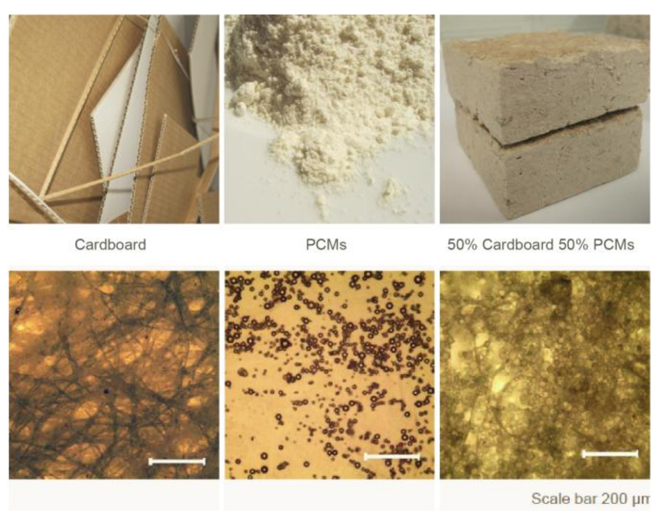

Figure 1: Material composition and optical micrographs.

3 EQUIPMENTS

The equipments employed for experimental tests are illustrated in Figure 2. A climatic chamber with insulating walls has been equipped with a heat source provided by a lamp. Two fans have been placed on the back wall in order to produce uniform climate conditions inside the chamber. On the opposite wall a hole has been made in order to place panels with different structures and materials to be tested. On the outer surface of each panel tested, a heat flow sensor has been placed and several thermocouples have been arranged in strategic positions in order to monitor and record temperature variations during tests.

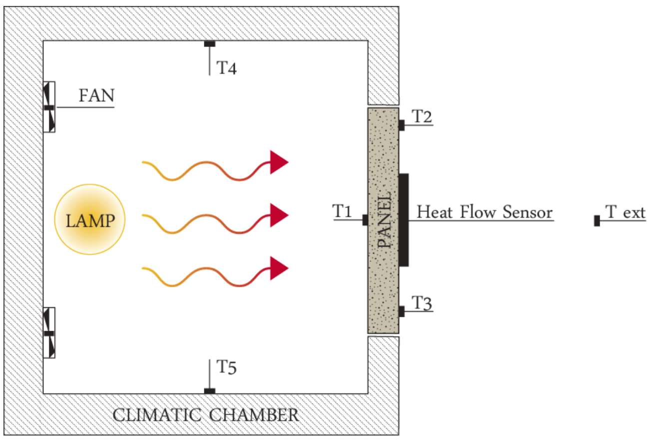

Figure 2: Equipments scheme for experimental tests.

4 EXPECTATIONS

The aim is to simulate the environmental climatic variations inside the chamber and to record the heat flows through the panel in order to compare different panels. Heat flux diagrams that will be obtained from the tests are represented in Figure 3 [6].

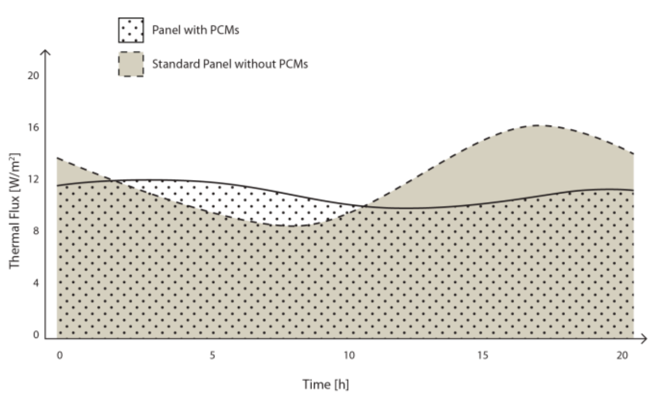

Figure 3: Theoretical heat flux diagrams obtainable with the climatic chamber tests.

The area under the curve represents the total heat which flows through the panel during the test. The integral calculation allows to evaluate the difference in thermal performance between a standard panel without PCMs (dotted line and grey filling) and a panel with PCMs (continuous line and dotted filling). The first gives a higher integral value, which means increased heat loss, while the second gives a lower integral value, which means reduced heat loss.

5 CLIMATIC REFERENCES

The climatic chamber tests involve the simulation of real climatic conditions. The choice of the temperature range to take in account during tests depends on the geolocation and on the season of use of the product.

PCMs application gives a better efficiency in summer conditions when temperatures exceed the optimal comfort values and specifically in Mediterranean climate [7]. For these reasons temperature and radiation data of specific Italian cities have been collected: Milan (northern Italy), Palermo and Catania (southern Italy) [8-9].

In Figure 4 the radiation and temperature trends in Milan during August 2012 are represented [8]. It can be seen that when solar radiation starts (black dotted line), at 6 a.m., temperature starts to raise (red line). The highest radiation value, at 1 p.m., doesn't correspond in time with the highest temperature, which is 32,5°C at 4 p.m.

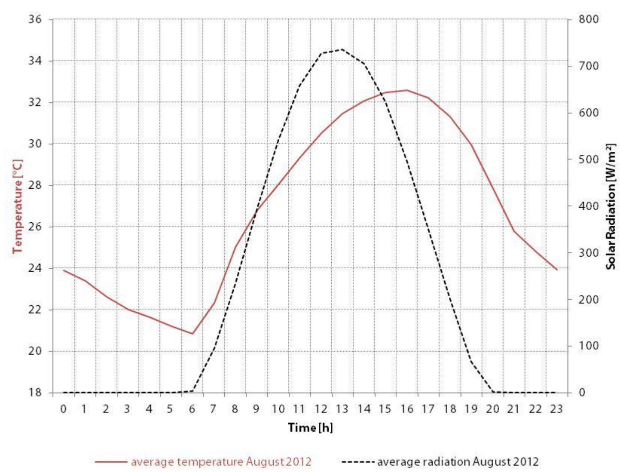

Figure 4: Averages of temperature and solar radiation in August 2012, in Milano.

In Figure 5 the radiation and temperature trends in Palermo during August 2012 are represented [9]. It can be seen that solar radiation starts at 5 a.m., one hour later than Milan, because of the latitude. The highest radiation value, at 12 a.m., corresponds in time with the highest temperature, which is 31,5°C.

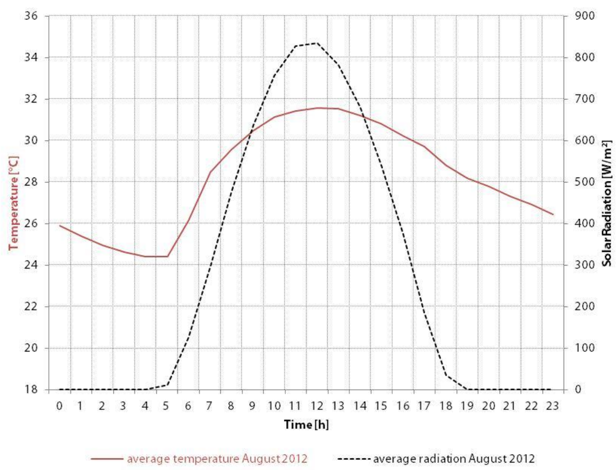

Figure 5: Averages of temperature and solar radiation in August 2012, in Palermo.

In Figure 6 the radiation and temperature trends in Catania during August 2012 are represented [9]. As in the case of Palermo, solar radiation starts at 5 a.m. and the highest radiation value, at 12 a.m., corresponds in time with the highest temperature, which is 32°C.

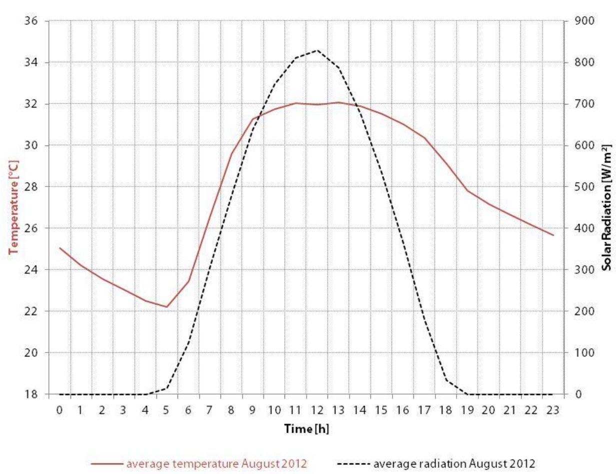

Figure 6: Averages of temperature and solar radiation in August 2012, in Catania.

6 EXPERIMENTAL SETTINGS

By using the climatic information described it has been possible to set the experimental equipments in order to obtain reasonable temperature trends inside the climatic chamber.

Preliminary tests have been done evaluating the temperature inside the chamber once the light bulb has been turned on. Temperatures have been recorded on the inner surface of the panel (thermocouple position is indicated as T1 in Figure 2) and results are presented in Figure 7.

Two different electrical powers have been employed: 25 W light bulb (red line) and 22 W light bulb (green line).

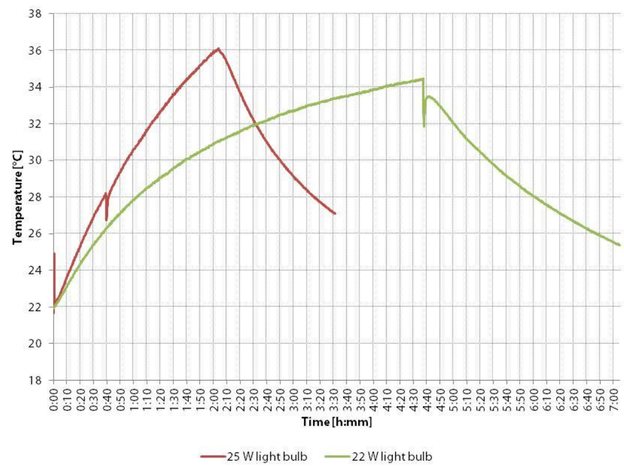

Figure 7: Temperatures variation inside the climatic chamber by turning on and off the light bulb.

Preliminary tests have shown that it is possible to simulate the real summer temperature range inside the climatic chamber with the use of light bulbs as heat source. Depending on the power of the lamp it is possible to adjust the temperature variation rate.

Starting from 22°C (room temperature) it is possible to reach 32°C in 1 hour and 15 minutes using a 25 W bulb (red line) or in 2 hours and 30 minutes using a 22 W bulb (green line). In this way, laboratory tests time can be reasonably reduced compared to the 7 or 9 hours of heating observed in real climate to raise the temperature from 22°C to 32°C (as seen in Figures 4 – 5 – 6).

Once the lamp is switched off, the temperature decreases, as happens in real conditions when solar radiation starts to get down. Thus, the temperature inside the climatic chamber can be controlled by switching on and off the light bulb at a specific time.

7 PRELIMINARY RESULTS

First dynamic thermal tests have been done comparing the new composite panel developed and a standard perlite panel commonly used in building insulation (provided by PIZ S.r.l.). Both panels have been placed on the opening of a climatic chamber. The test consists in reproducing the temperature increase which takes place in the morning hours. Once the device is activated, the temperature inside the heater (indicated as T1 in Figure 2) and the temperature on the outer surface of the panel (average between T2 and T3 as indicated in Figure 2) are recorded using a system of thermocouples (National Instrument System acquisition NI cDAQ 9172). The recorded data are shown in Figure 8.

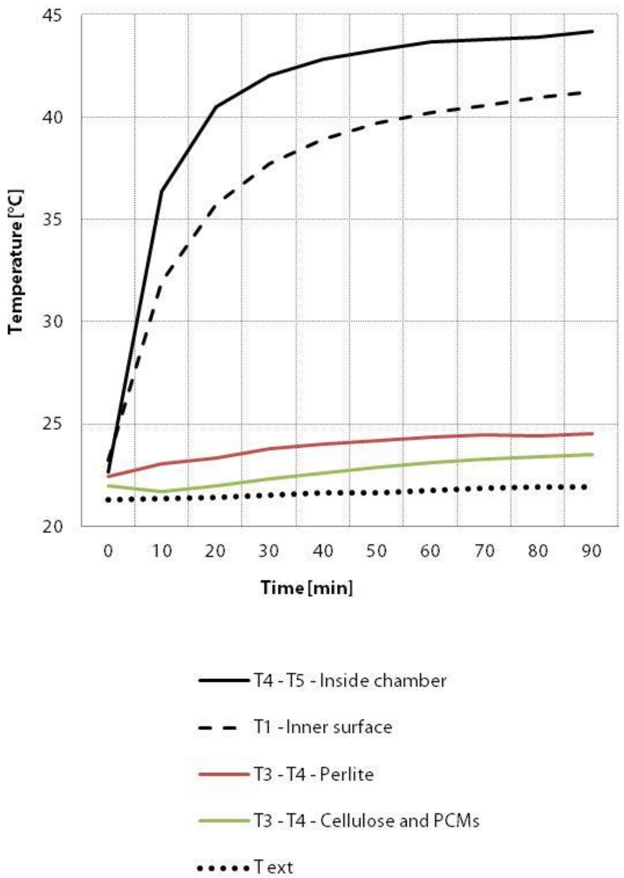

Figure 8: Comparison test between Perlite and Cellulose with PCMs panels in a climatic chamber.

The inner surface temperature (T1) changes from 22 °C to 35 °C. This range of values allows the activation of PCMs at 28 °C and the cellulose panel begins to absorb energy preventing the heat transfer outside the chamber.

The outer surface temperature on the cellulose and PCMs panel (green curve) increases by 1 degree every 30 minutes and reaches the maximum temperature of 24 °C in 90 minutes.

The outer surface temperature on the perlite panel (red curve) without PCMs show a rapid increase in temperature and reaches the maximum temperature of 24 °C in 40 minutes.

8 CONCLUSIONS

Thanks to the equipments setting, it has been possible to validate the effectiveness of the climatic chamber realized. Using the described instruments it is possible to reproduce the real temperature conditions in order to simulate the operating conditions of a building insulating panel.

A preliminary thermal test realized has shown the proper functioning of PCMs added inside a cellulose matrix: they help to achieve a delay of temperature rise outside the chamber.

The future works of this research will consist in testing the innovative panel made by cellulose fibers and PCMs through the use of the chamber and heat flux meter equipments. In order to carry out reasonable tests on these smart materials, it has been necessary to realize a device which works in a dynamic thermal way as close as possible to the real operating conditions.

9 ACKNOWLEDGEMENTS

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REFERENCES

[1] P. Garbagnoli, M. Musitelli, B. Del Curto, M.P. Pedeferri “Development of cellulose panels with porous structure for sustainable building insulation”. Proceedings of International Conference ICCBM, WASET, Paris, November 2012.

[2] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast). Official Journal European Community, 2010.

[3] Sylvia Leydecker, Marius Kölbel, Sascha Peters, Nano Materials in Architecture, Interior Architecture and Design, Birkhauser, Berlin 2008.

[4] L. F. Cabeza, A. Castell, C. Barreneche, A. De Gracia, A. I. Fernández, “Materials used as PCM in thermal energy storage in buildings: A review”, Renewable and Sustainable Energy Reviews 15, (2011) 1675–1695.

[5] Melone, L. Altomare, L. Cigada, A. De Nardo, L. “Phase change material cellulosic composites for the cold storage of perishable products: From material preparation to computational evaluation” Applied Energy 89 (2012) 339-346.

[6] Paolo Principi, Roberto Fioretti, “Thermal analysis of the application of pcm and low emissivity coating in hollow bricks”, Energy and Buildings 51 (2012) 131–142.

[7] Brunoro Silvia, “Efficienza energetica in clima mediterraneo. Soluzioni tecniche d’involucro per la riduzione del surriscaldamento estivo”, INARCOS n.702, September 2007.

[8] Data provided by: Servizio Meteorologico Regionale - ARPA Lombardia.

[9] Data provided by: Regione Siciliana - SIAS - Servizio Informativo Agrometeorologico Siciliano.