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Energy saving potential of a hybrid BIPV-T system integrated with heat storage material

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1. INTRODUCTION

Increasing energy consumption, shrinking resources and rising energy costs will have significant impact on our standard of living for future generations. In this situation, the development of alternative, cost effective sources of energy for residential and non-residential buildings has to be a priority. Designing energy efficient and affordable solutions integrated in buildings dealing with summer and winter climate challenges present a very ambitious target. The European Green Paper Towards a European Strategy for the Security of Energy Supply [1] has set targets to double renewables from 6% in 1996 to 12% in 2010 with further targets in the Renewable Energy Framework Directive of 20% by 2020 [2]. In addition to this, in May 2010 the recast of the Directive on Energy Performance of Building [3] set Zero Energy performance targets for all new buildings.

The integration of PV systems into buildings becomes imperative in this context. Solar energy collection and utilization systems that constitute an integral part of the building envelope or interior walls and floors save in installation and material costs. Façade-integrated photovoltaic panels may be utilized to generate electricity and useful heat [4], with possible efficiencies of nearly 70% in some cases [5]. In addition, building-integrated thermal storage, particularly phase-change materials, can be an effective means of reducing peak loads and controlling associated temperature fluctuations [6]. Recent developments that facilitate building integration include microencapsulated PCM that can be mixed with plaster and applied to interior surfaces [7] and solid-solid transition materials [6]

The present work is a part of a national Portuguese project underdevelopment that begins in May 2012 and has a duration of two years. The Project pretends to investigate advanced technological prefabricated modules integrating PV and PCM for improving the indoor thermal conditions and reducing building energy demand, through direct electricity generation, solar thermal contributions and energy storage in residential and non-residential buildings.

2. DESCRIPTION OF THE SYSTEM

The prototype is installed on a main façade of SolarXXI office building in Lisbon and since then is tested in real conditions (Figure 1 and Figure 2). The modules consist of an outer layer (PV panel) and an inner layer (gypsum wallboard incorporating PCM). In the case of BIPV-PCM (that is the case of the module integrating PCM in the gypsum board) during daytime, due to sun exposure, the PV panels absorbs the solar radiation, generating heat during conversion process, heat that is used for phase change material melting. During the nighttime, the melted PCM solidifies and delivers heat that keeps the panel warm for a prolonged period of time. The purpose of the BIPV-PCM and the expected behaviour is to keep the outside wall temperature warm (over 20ºC), to prevent heat loss through the wall.

The BIPV-PCM system is designed to be integrated with a building envelope and accumulate the thermal energy directly into the wall of the building.

The external and internal frame of the prototype has a ventilation system that can provide, if necessary, the ventilation of the inner air gap with interior ambient or exterior one. The air flow can be controlled by opening or closing the slot openings. The internal layer (plaster PCM board) is movable in order to control also the air gap width and to evaluate its influence in the overall system behavior. The system is presented in cross-section in the Figure 3.

Fig. 1, Prototype installed on the SolarXXI main façade

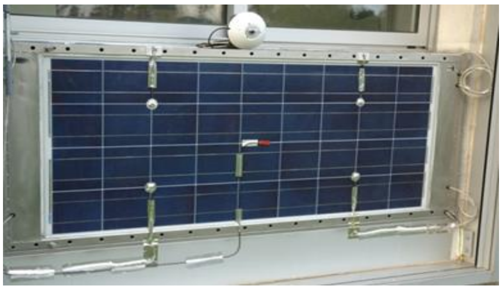

Fig. 2, BIPV-PCM system

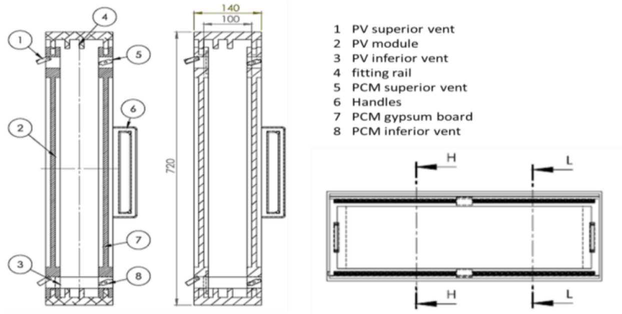

Fig. 3 Cross-section of BIPV-PC

The PCM used is incorporated in the gypsum board Alba®balance plasterboards type. The PCM gypsum board is integrated in the BIPV-PCM system adjacent to the interior room. The outer layer of the system is a PV polycrystalline module with a peak power, Pmax, of about 120 Wp. The air gap formed between two layers (internal-PCM gypsum board and external-PV module) is about 10 cm width.

The properties of each layer are resumed in the Table 1.

Table 1. Materials properties.

Material	Density (Kg/m^3)	Specific heat ($J/Kg\ K$)	Thermal conductivity ($W/m\ K$)	Specification
PV	2330	677	148	PV and PCM absorptivity and emissivity is 0.9
Air	1.205	1007	0.0257	Kinematic viscosity is 15.11 x 10^{-5} m^2/s
PCM	1000	1800	0.27	Latent heat of PCM is 210 KJ/m^2

3. EXPERIMENTAL SET-UP

The installed prototype is completely monitored in all surfaces and in the inner air gap, in order to understand the thermal behavior of the system. Interior and exterior air temperatures are also monitored as well as the solar global radiation. For measuring of the surface temperature of each layer of the prototype, thermal sensors type PT 100 (2mm*2,3mm) has been used, 4 sensors in each surface. In the same time in order to have a more precise surface temperature measure, a Self Adhesive Patch sensor has been considered, one in each surface. The heat flux measurements are planned also, using Hukseflux sensor HFP01-05. Inside the air gap three PT100 sensors are placed in three different levels as it can be observed in Figure 3. The exterior and interior ambient temperature are also measured using PT100 sensors and the solar radiation is measured using Hukseflux SR11 sensor. The map of sensors is presented in Figure 4 and Table 2.

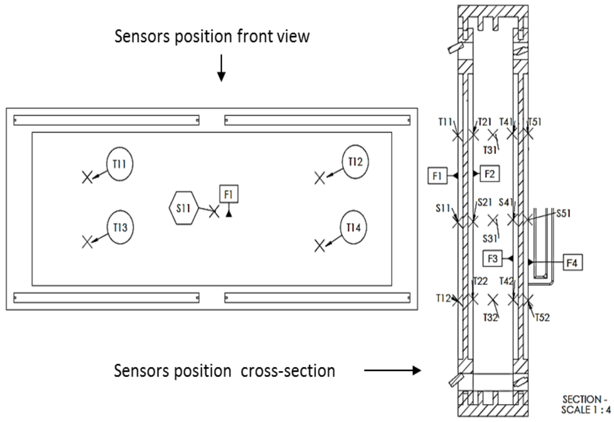

Fig. 4, Cross-section set-up and sensors positions

Table 2. Sensors identification and positions.

PCM surface facing room	PCM surface facing air gap	Air gap between PCM and PV	PV facing air gap	PV outside
PT100 2x2,3mm	PT100 2x2,3mm	PT100 2x2,3mm	PT100 2x2,3mm	PT100 2x2,3mm
T51	T41	T31	T21	T11
T52	T42	T32	T22	T12
T53	T43	T33	T24	T13
T54	T44	T34	T25	T14
Patch PT100	Patch PT100		Patch PT100	Patch PT100
S51	S41		S21	S11
Hukseflux HFP01-05	Hukseflux HFP01-05		Hukseflux HFP01-05	
F5	F4		F2	

4. MEASUREMENT CAMPAING AND RESULTS

The installation has been done in January 2013 and the sensors installation has been concluded in first part of February 2013. In this manner the first experimental results has been obtained in the second part of February. Interior and exterior temperature as well as the solar radiation measurements is presented in the Figure 5. As it can be easily observed only three days in February have been characterized of winter specific sunny conditions, so the better climatic conditions for experimental campaign with the clear sky, values of solar radiation reaching almost 900W/m2, maximum of outside temperature of about 12ºC and the minimum values between 4 to 6ºC.

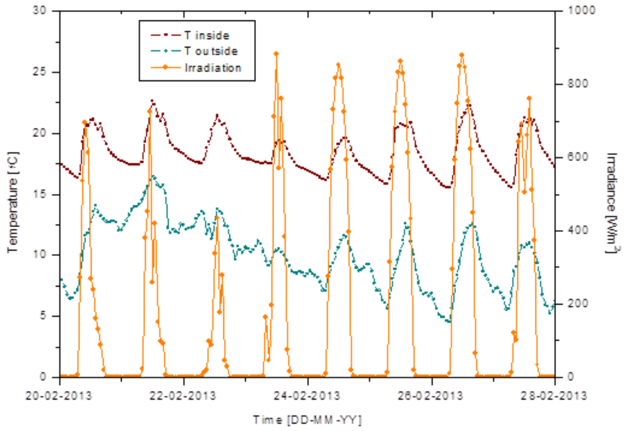

Fig. 5. Exterior, interior temperature and solar radiation measurements February 2013.

For the present study an analysis of thermal performance of the BIPV-PCM system has been proposed, for two days with slightly different climatic conditions, in order to estimate the behavior of the system, PCM and inside room temperature for two different outside ambient conditions.

The 22th of December is one winter day that presents a low solar radiation with big fluctuations during the day time from very low values of about $80W/m^2$ to $900W/m^2$. Was a very cloudy day and the maximum outside temperature was around 10ºC, as it can be observed in the Figure 6. All surfaces temperature of the whole system presents a very high variation, especially on the inner part of PV module and the air gap temperature. The air gap temperature as highly influenced by the PV temperature presents values between 20-25ºC during the daytime. For other hand the PCM gypsum board presents a more "stable" configuration, as is expected, maintain the surface facing the room at a value of about 20ºC during daytime and 16ºC during the night. The inside room temperature presents also a constant configuration, showing that, even on a cloudy day and an outside ambient temperature of approximately 11ºC, the temperature values are around 20ºC during most of the day time and 18ºC during the night. It is known that the general behavior of the room is influenced by other factors and the building itself. Even so, the PCM gypsum board surface temperature shown that there are no heat losses through the BIPV-PCM system

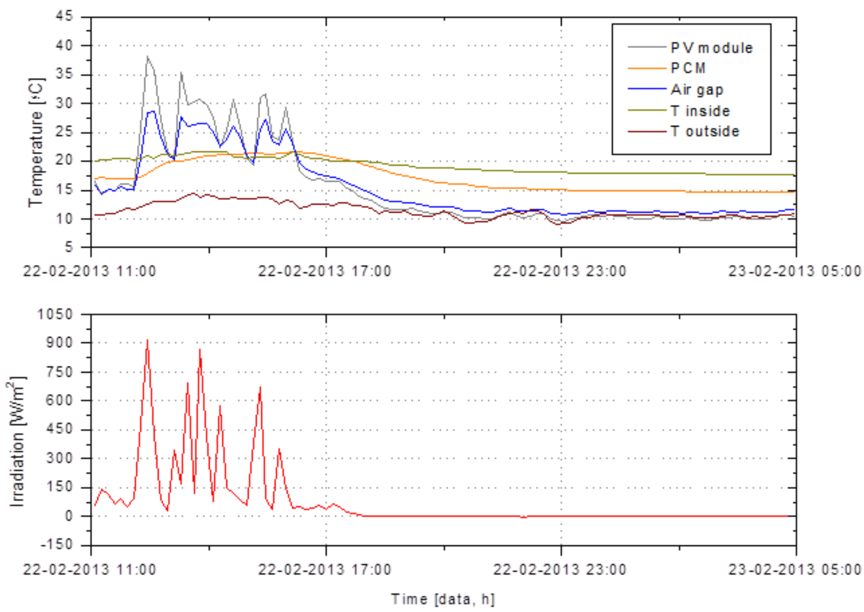

Fig. 6. Temperature and irradiation values, 22th of February 2013.

Looking at the Figure 7, it can be observed the temperatures profiles through the system cross section at some hours of the 22th of February. It can be noticed that the greatest temperature differences at different period of the day, are shown by the PV module, of about 18ºC between the temperature at 12 am and 8 pm and the smaller ones are shown by the PCM of about 4ºC from 12 am to 8 pm.

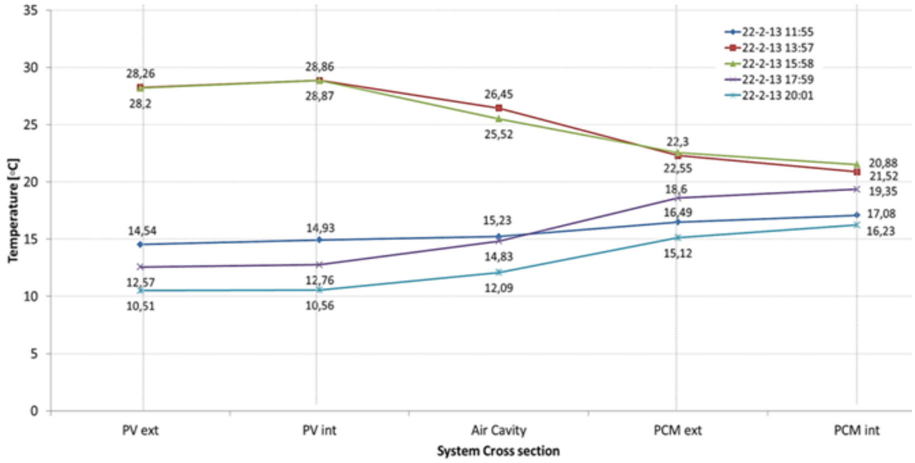

Fig. 7. Cross section temperatures at different hours, 22th of February 2013

Taking now a look on the experimental data measured on 25th of February 2013, it can be observed that the outside ambient temperatures are different (Figure 8). Was a very sunny day with the irradiation rich values of 900W/m^2, the outside temperature of about 10ºC. The thermal behavior of the BIPV-PCM shown a more regular path comparison with the results from 22th of February. In this case the PV module rich a maximum temperature of 58ºC in the pick hour of the day (between 12h and 15h), the air gap present a maximum temperature of 48ºC, the PCM gypsum board a maximum temperature of 29ºC and the inside room temperature shown a quite constant temperature of 20ºC. The temperature profiles of PV module and air gap present a more dynamic behavior, a higher difference between the maximum and minimum values of 56ºC for PV and 45ºC air gap. The PCM layer and the inside room temperature present more constant profiles, with a temperature difference between maximum and minimum values of about 18ºC for PCM and 5ºC for inside room temperature

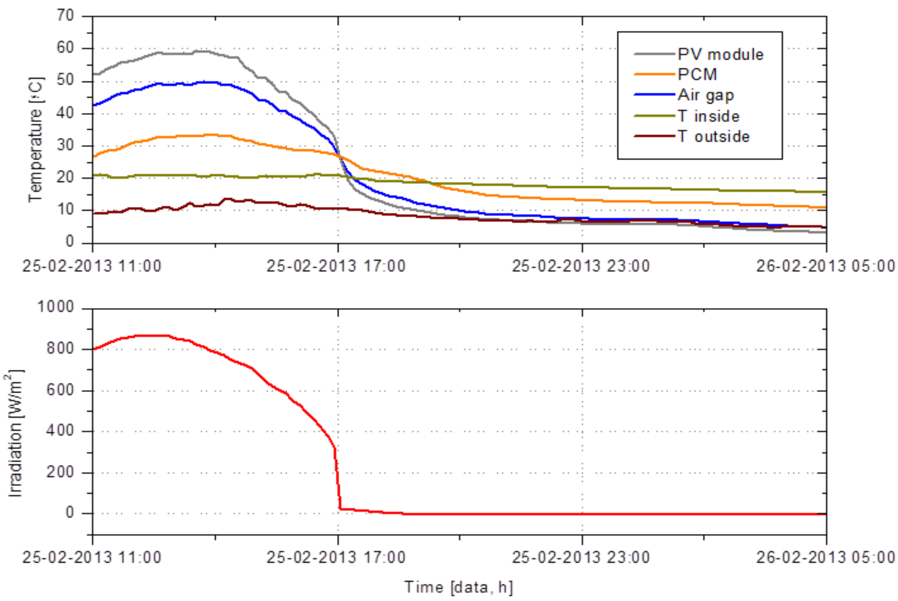

Fig. 9. Temperature and irradiation values, 25th of February 2013.

Fig. 9 presents the cross section temperatures for the 25th of February 2013. The temperature profiles present a quite similar path comparison with the ones from 22th of February 2013. The higher temperature differences at different hours of the day presents the PV module and the air gap, the PCM presents again a smaller difference in temperature at different hours of the day.

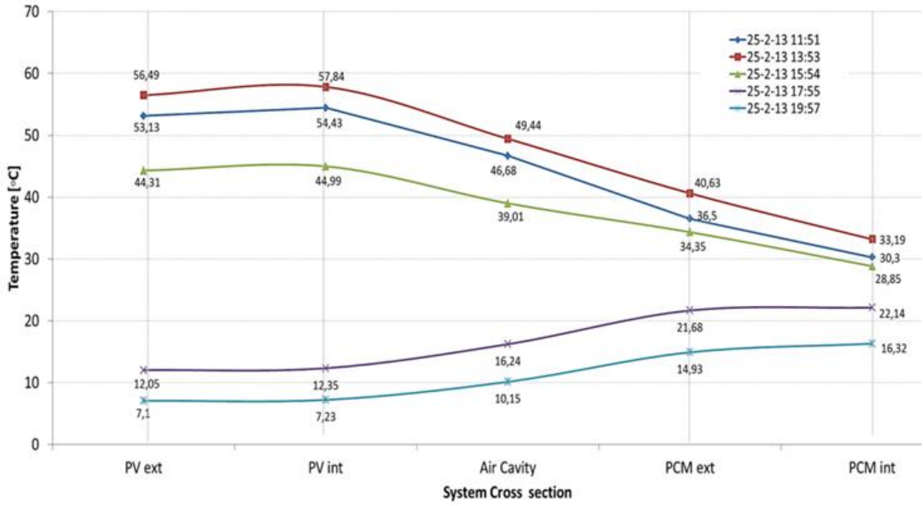

Fig. 9. Cross section temperatures at different hours, 22th of February 2013.

5. CONCLUSIONS

The present study was focused on the experimental thermal analysis of a BIPV-PCM system integrated on the Solar XXI office building main façade, building located in Lisbon.

The study was focused on the measurements results of two different days, with different climatic conditions, during the February 2013. For both cases the thermal behavior of the BIPV-PCM system presents a highest temperature difference at different hours and between the maximum and minimum values at the PV module and in the air gap and a more constant temperature at PCM gypsum board and inside room. Even, on a day with low irradiation, cloudy, the PCM facing the room presents temperatures of about 20ºC during daytime.

ACKNOWLEDGMENT

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