AIRFLOW STUDY INSIDE AN ENCLOSURE WITH A PCM WALL AND A SOLAR COLLECTOR

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SUMMARY

The study emphasis the concept of a ventilated solar façade for air preheating with thermal inertia elements integration. A Transpired Solar Collector (TSC) is made of metal cladding with perforations, installed at a certain distance from a building wall, thus creating a cavity through which the air is circulating. The metal cladding is heated by the solar radiation from the Sun and ventilation fans create negative pressure in the cavity, extracting the solar heated air through the perforated panel. The heat transfer between the fluid and the metal is intensified depending on the flow's characteristics and other external parameters like the special geometry of the perforation used in this case. An improved solar collector with innovative geometry is investigated, optimizing the heat accumulation with Phase Change Materials integration. The present study investigates different configurations for the PCM bars inside the collector for an enhanced heat transfer.

Keywords: transpired solar collector, TSC, PCM, phase changing materials, energy efficiency, thermal energy storage, pressure and temperature distribution

1 INTRODUCTION

Considering the Energy Performance of Buildings Directive, from 2020 all the new buildings must be nZEB (nearly zero energy building) and a part of the energy consumption must be covered by systems using renewable energy sources because the buildings are responsible for 40% of the energy consumptions worldwide and more than 52% of these consumptions are because of the HVAC systems. These goals can be met only by using high performance materials, cost-effective energy efficient systems and systems based on renewable energy sources.

According to the literature, the solar air collectors acting as a part of the building envelope are a promising strategy that could be used in order to reduce the energy consumption for heating the buildings or for the fresh air needed in the buildings, for drying systems or to improve the efficiency of HVAC systems (Dymond and Kutscher 1997, Alkilani, Sopian et al. 2011). TSC are systems recommended because of their efficiency and reduced implementation/operating costs (Wang, Lei et al. 2017). Many studies conducted by researchers are emphasizing that solar collectors could reach a rise in temperature (between inlet and outlet) from 3°C to 35°C and a collector efficiency from 25% to 75% depending of the air flow, solar radiation, absorber plate, orifices type, pitch etc. (Leon and Kumar 2007, Cordeau and Barrington 2011, Croitoru, Nastase et al. 2016, Croitoru, Nastase et al. 2016).

Usually, the TSC are without thermal inertia materials integrated. According to different studies, the integration of thermal storage is essential in order to increase the operation time and efficiency of a solar air collector (Hami, Draoui et al. 2012) and also to stabilize the outlet temperature. The energy could be stored during the day and released during the night (Goyal, Tiwari et al. 1998). Thermal energy storage materials are classified as materials with: sensible heat storage, latent heat storage and chemical heat storage (Khadiran, Hussein et al. 2016). Materials with sensible heat storage are classical materials used on a large scale (concrete, water, bricks, granite etc.), materials with chemical heat storage are not used usually in the buildings due to their instability and materials with latent heat storage, also called Phase Changing Materials (PCM), have a higher storage capacity and can store 5 to 14 times more energy than classical materials (Kuznik, Virgone et al. 2011, Soares, Costa et al. 2013). PCM materials are implemented in passive systems (external walls, internal walls, floors, windows etc.) and in active systems (solar collectors, boilers, fan coils etc.) (Heier, Bales et al. 2015) and they have the potential to: reduce energy consumptions for heating (especially in low inertia buildings), reduce energy consumptions for cooling, reduce thermal loads and improve the efficiency of active systems. Usually PCM as thermal storage are implemented in the glazed solar air collectors such as Trombe walls in order to replace classic masonry to improve the efficiency and outlet temperature stability but, according to the literature studied, we didn't find a TSC with PCM integrated which acts like a solar wall (Alkilani, Sopian et al. 2011, Shukla, Nkwetta et al. 2012).

This paper's objective is to evaluate the airflow dynamics inside a TSC with and without PCM elements integrated in the system.

2 METHODS

2.1 Experimental set-up

The solar collector consists of an absorbent metal plate with lobed perforations through which the outside air is aspired into a rectangular cavity with multi-layer walls, i.e.: OSB inside, thermal insulation (4cm) and OSB on the outside. The created gap has the following dimensions: 2000x1020x280 mm. The air is collected at the top of the system through an opening of 830 x150 mm and further evacuated by an Embpapst variable speed fan (180 mm diameter). The TSC geometry can be observed in figure 1.

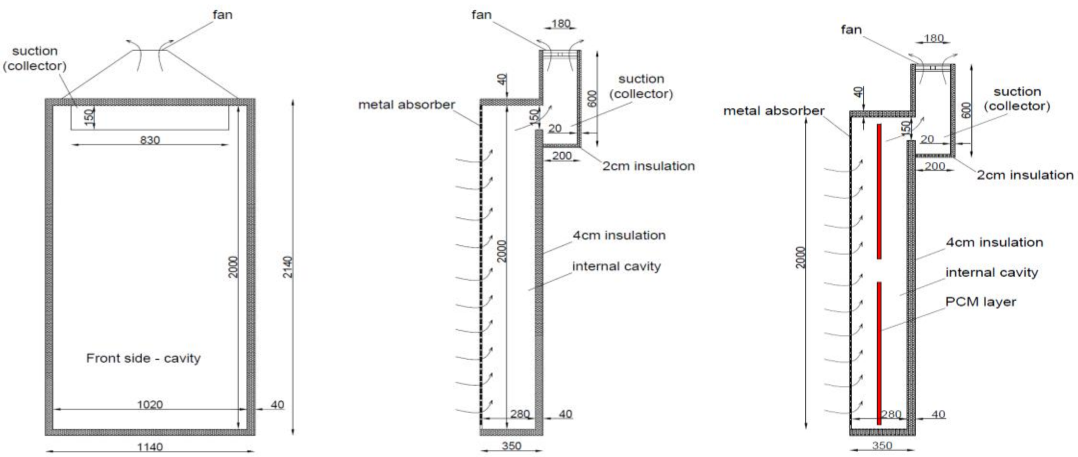

Figure 1. Solar collector geometry front and section view, without and with PCM elements

Inside the solar collector a mobile metal frame was mounted, representing the holder of the rectangular aluminium containers with embedded phase change materials. This will help to study the optimal positioning of inertial materials inside the cavity. The study was performed on one solar collector (with lobed perforations), in order to evaluate the pressure distribution in each collector in case with and without PCM bars inside. The solar collector is studied in real conditions while being mounted on the south wall of the laboratory.

2.2 Measuring method

In order to measure the temperature gradient inside the cavity, 6 K-type sensors were mounted which can be observed in figure 2a: T30, T65, T100, T135, T170 for the gradient and Tamb used in order to measure the ambient temperature. The data acquisition for air temperature inside the cavity was performed via a data logger (AHLBORN ALMEMO 2890-9) at a time interval of 5 minutes and the data were processed. The weather data were measured using a meteorological station located on the outside of the laboratory.

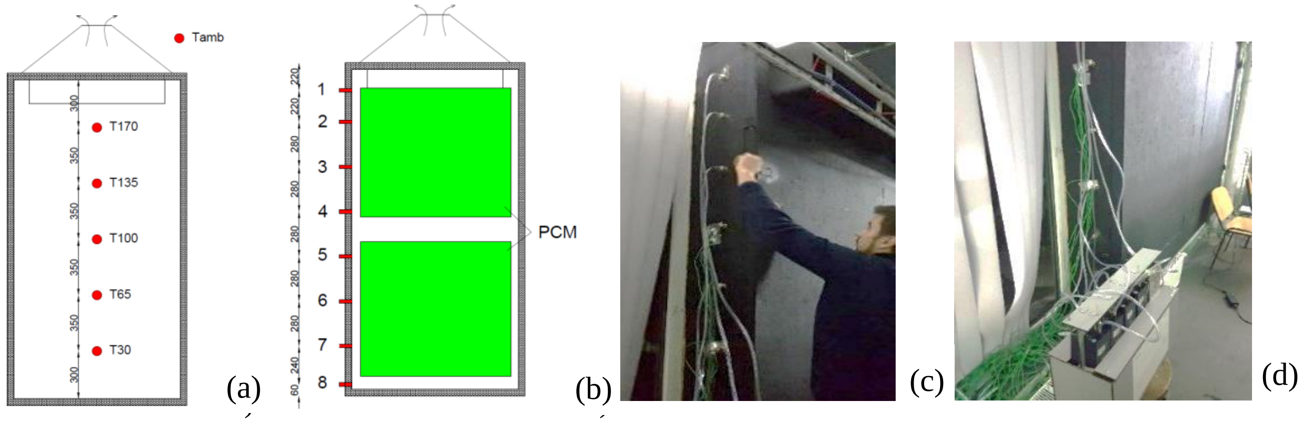

Figure 2. Position of the 5 temperature sensors inside the cavity (a), position of the 8 pressure probes (b, c) and the scanivalve connected to the 8 pressure probes (d)

The airflow was controlled by a RXN-602D continuous current source and is varied between 83m^3/h and 125m^3/h. As it can be observed in figures 2b, 2c and 2d, the pressure distribution was measured by a Sangari scanivalve equipped with 8 pressure transducers with properties presented in table 1. A pressure transducer, often called a pressure transmitter, is a transducer that converts pressure into an analog electrical signal. Pressure applied to the pressure transducer produces a deflection of the diaphragm which introduces strain to the gages. The strain will produce an electrical resistance change proportional to the pressure.

Table 1. Sangari scanivalve properties

Characteristic	Value	Unit
Model	AutoTran Incorporated, 750D-012	-
Pressure range	0-124.72	Pa
Output	1-5	V
Accuracy	±0.25	%

3 RESULTS AND DISCUSSION

Initial studies were performed (Croitoru, Nastase et al. 2016, Croitoru, Nastase et al. 2016) in order to evaluate the thermal behaviour of the two different types of solar collectors, one with classical round perforations and the other one with lobed perforations.

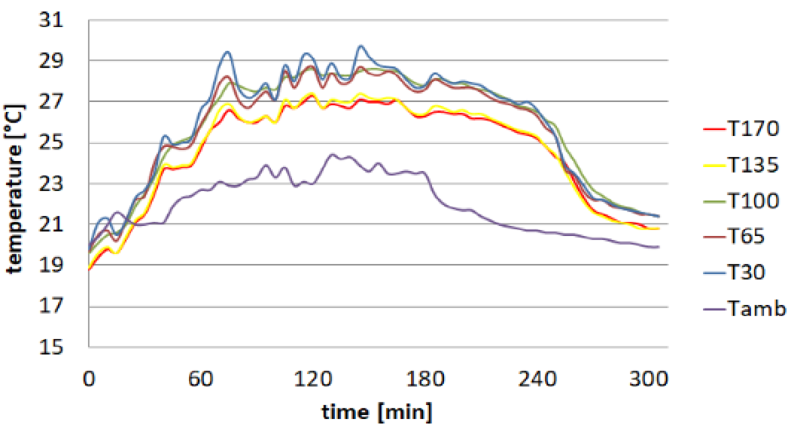

Figure 3. Temperature distribution in the cavity of the solar collector system (lobed case)

The investigations, in the case without the PCM bars, indicated that the temperature stratification, for both types of the solar collectors, is reversed, meaning that the lower temperature sensors measured higher temperatures. As it can be observed in figure 3, when the ambient temperature reaches a maximum of 24.3 °C, the temperature on the upper part of the cavity is around 26.9 °C (T170), while at lower part is around 28.9 °C (T30). One explication was that the fan influences directly the airflow inside the cavity and the air from the lower part is given more time to heat, which can decrease the collector's efficiency.

All these results lead us to the conclusion that the thermal stratification induced in the cavities of the collectors is determined by a difference of vertical pressure. This may be due to the air intake in the collector at the top and may result in the aspiration of an increased air flow through the orifices in the upper part of the absorbent metal plate, respectively a lower air flow intake through the orifices on the bottom of the absorbent metal plate.

Taking all these aspects into account, we aimed to evaluate the influence on airflow when adding the PCM bars. The study intended to estimate the pressure distribution along the cavity. For the lobed geometry type of the solar collector, two situations were tested: with and without the PCM bars inside. In Figure 4 we can observe the pressure distribution for all 8 measuring points for different airflows in the 2 cases. The PCM bars induces a more balanced distribution of pressure on the vertical.

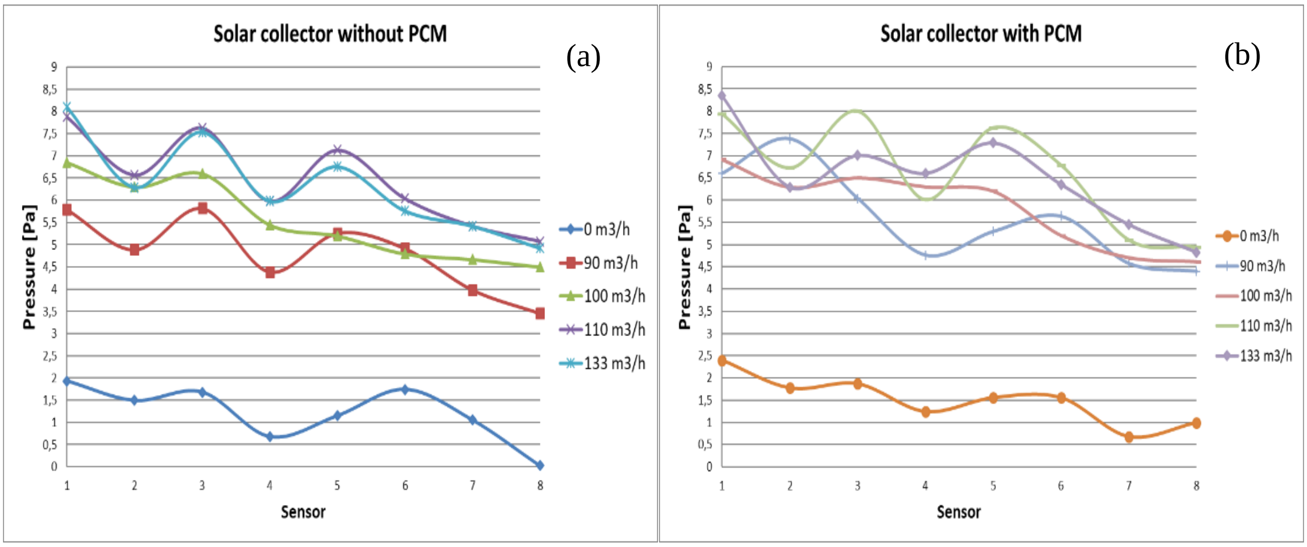

Figure 4. Pressure distribution in the cavity a) without PCM; b) with PCM

If we consider an airflow of 100 m^3/h, we have analysed the influence of natural convection. In the case of 0 m^3/h only the natural convection occurs, so subtracting the values found in this case from the values found at 100 m^3/h, we can see the forced flow due to the fan. For the case with PCM the pressure distribution is more balanced over the vertical (purple curve).

For the same situation, we have considered that the airflow distribution depends of the pressure in the zones considered. Figure 5 indicates an intensified airflow in the zone 4 and 5 for the PCM case. In this case, zones 4 and 5 point out the gap between the PCM bars, as seen in Figure 2b. However, the graphic also indicates that an important share of airflow is aspirated in zones 2-3 in the case without PCM, close to the aspiration, correlated with the stagnation zone found in the temperature distribution on the vertical. This stagnation zone is also indicated by the low pressure in zone 6-7 (Figure 6 a) purple curve). Considering that the airflow can be addressed in function of the pressure loss and a hydraulic resistance coefficient M and that this one is equal for all eight zones, than we can estimate:

$$\Delta p_n = MQ_n^2 \qquad (1)$$

$$Q = Q_1 + \ldots + Q_8 \qquad (2)$$

$$Q_n = Q_1\sqrt{\frac{\Delta p_n}{\Delta p_1}} \qquad (3)$$

where Δp_n is the pressure loss for zone „n" [Pa]

M- hydraulic resistance module [s^2m^5]

Q_n- airflow for zone „n" [m^3/h].

In order to propose a better configuration, we have evaluated also the configuration when PCM bars are placed only in the upper part, forcing the air to go through the entire collector.

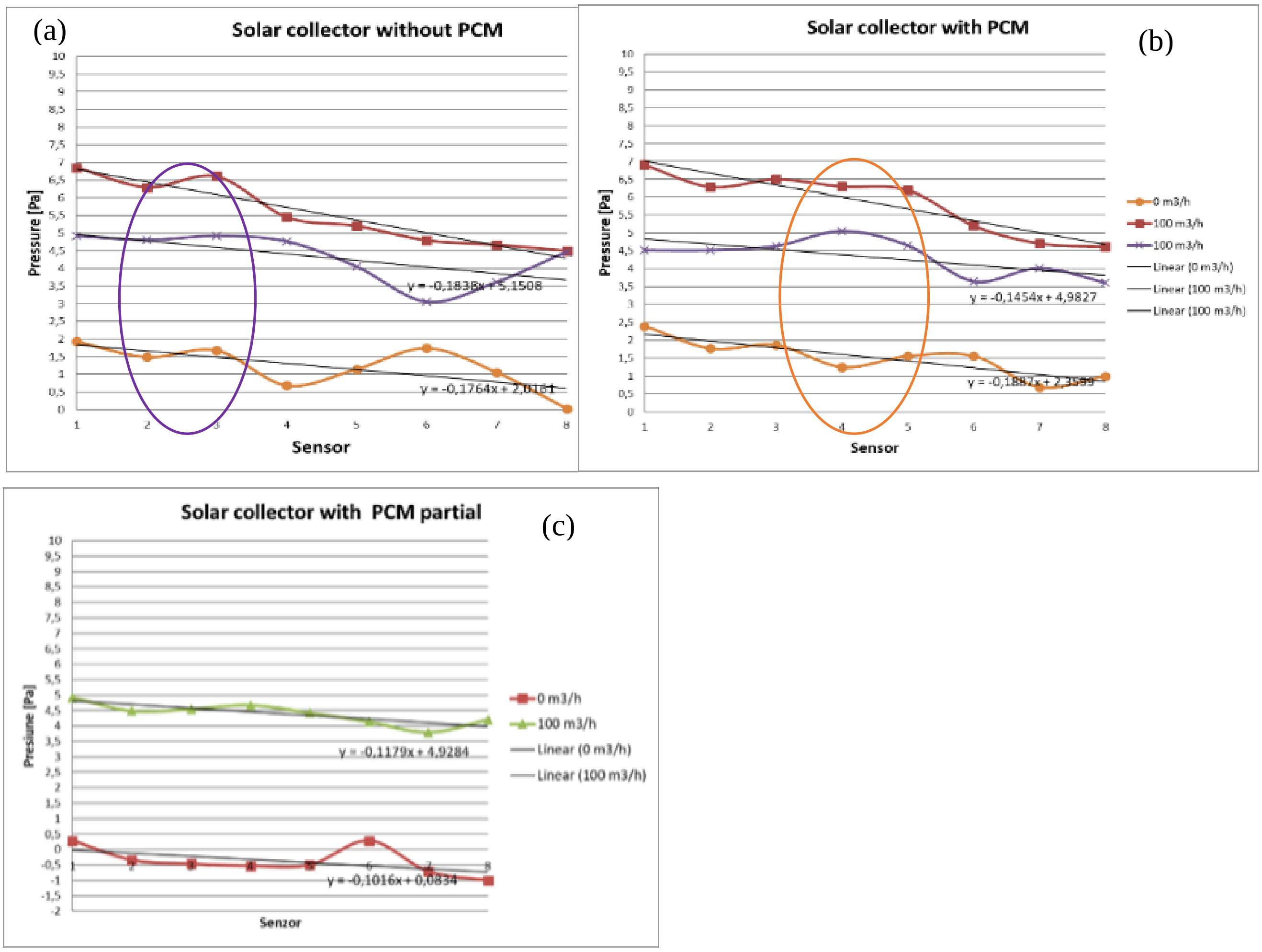

Figure 5. Pressure distribution in the cavity for 100 m³/h (considering also the natural convection effect): a) without PCM; b) with PCM; c) partial filling with PCM

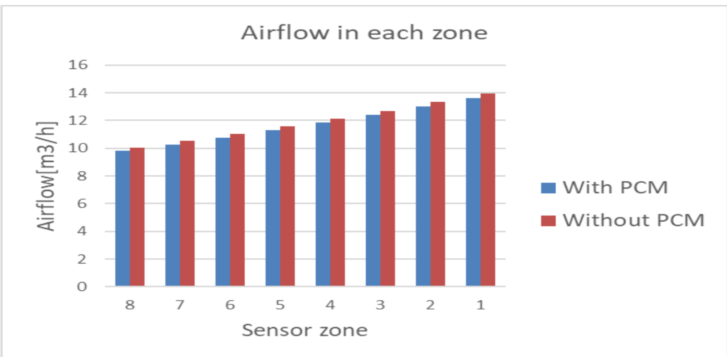

Figure 6. Airflow distribution calculated in function of the characteristic pressure loss in each zone

4 CONCLUSIONS

We can observe that the configuration of the PCM bars inside the solar collector is highly related to the airflow pattern. It is necessary that the airflow will have a uniform distribution over the whole collector, so supplementary obstacles need to be integrated.

A solar collector can be easily integrated in the building façade and reduce the energy consumption for air pre-heating using passive methods.

ACKNOWLEDGEMENTS

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