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Research paper

Performance of a window shutter with phase change material under summer Mediterranean climate conditions

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HIGHLIGHTS

- Incorporation of phase change materials into window shutter.
- Resourcing to PCMs as a thermal regulator of indoor temperature.
- Analysis of the thermal energy storage system using PCMs.
- Experimental campaign of a window shutter incorporating PCM.

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ABSTRACT

The building sector is the largest final end-use consumer of energy in the European Union. Substantial heat losses in buildings occur through glazing areas, so it is crucial to mitigate the energy transfer between through these areas. The use of phase change materials (PCMs) is presently a technology advanced solution to improve the energy performance of building elements, particularly with window blinds or shutter protections.

This paper presents the results of an experimental campaign of a window shutter containing PCM during the summer season. The shutter prototype was applied in an outside cell test composed by two compartments (side by side) and oriented to South. It was monitored and analysed the indoor air temperatures, the outside weather conditions and the heat flux of the interior wall partition.

During the experiment, the range of the external air temperature changes from 13 °C to 25 °C and the average solar radiation recorded is 237 W m^{-2} to 306 W m^{-2}. The measured results shows that the compartment with the PCM window shutter can reveals thermal regulating capacity of the indoor temperature about 18%–22%. The maximum and minimum temperature peaks decreased 6% and 11%, respectively. Besides the improvement of the indoor temperatures, the compartment with PCM increased 45 min the time delay to achieve the minimum temperature peak and 60 min to attain the maximum temperature peak, compared to the reference compartment (without PCM).

1. Introduction

Presently, the environmental concerns and the energy efficiency are two widely compatible main research topics. According with the International Energy Agency (IEA) the buildings sector in the European Union is simply the largest final end-use consumer. The energy consumption of this sector is 470 Mtoe (million tonnes of oil equivalent) of 1194 Mtoe which represents about 40% of the total energy consumption [1]. Not considering the emissions associated with the electricity use in the building sector, the CO_2 emissions represent 12% of the total CO_2 emissions produced in 2011 [1]. Recent studies show that a good building refurbishment combined with correct operation and installation of monitoring devices with well-designed active systems, can improve the buildings energy efficiency up to 60% [1,2].

Nowadays, the building design frequently includes large translucent areas, mainly in offices and commercial buildings. However, the use of large façade glazing areas could lead to thermal and

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visual discomfort of indoor space and their occupants [3,4]. The use of phase change materials (PCMs) are currently a promising solution to improve the energy performance of building elements considering their capacity to store and release energy. This capacity contributes to minimize the maximum and minimum indoor air temperature peaks and to reduce the buildings energy demand [5–8]. The first research developments led to constructive solutions with the incorporation of PCMs, namely gypsum wallboards [9–12], masonry walls [13–17], mortar and concrete [18–23]. There are also many research works and prototypes using PCMs in translucent components, to enhance the thermal performance and the indoor comfort of buildings. Some examples of PCM incorporation into translucent solutions and/or in windows shutters systems could be found in the literature [24–32].

Diarce, Urresti, García-Romero, Delgado, Erkoreka, Escudero and Campos-Celador [30] presented an experimental and numerical study of a ventilated active facade with the incorporation of PCM in its external layer. The authors estimated that the energy efficiency of the ventilated active facade with PCM increased from 10% to 12% compared with the same model without PCM. Gowreesunker, Stankovic, Tassou and Kyriacou [24] evaluated experimentally and numerically the performance of a PCM-glazing, including the thermal and optical characterization of the PCM. The thermal testing of the PCM RT27® of their work was carried out using the T-history method and using the enthalpy method [24,33]. The main conclusions taken from this study were *i)* the optical thickness of the PCM decreases with the temperature rise, *ii)* the PCM-glazing is translucent in liquid phase and transparent in solid state and *iii)* the PCM increases the thermal mass of the solution, however this phenomenon is valid during the phase change process. Goia, Perino and Serra [27] proposed a prototype of a simple PCM glazing system. They compared, during six months, relevant thermophysical properties and thermal performance (such as temperature, heat flux, and transmitted solar irradiance) between the simple PCM glazing system and the typical double glazed unit with clear glass. They evaluated the comfort conditions using the Predicted Mean Vote (PMV) method and calculated the thermal conditions according ISO 7730 [34] and EN 15251 standards [35]. Goia, Perino and Serra [27] concluded that the indoor conditions reached by the application of the PCM increases considerably the thermal comfort comparatively to the conventional solution for the most time of the different seasons. They suggest *i)* the application of PCM with lower melting temperature for cold climates and winter season and *ii)* the application of PCM with high melting temperature for hot climates and summer.

The present paper analyses and shows the thermal performance of a window shutter with PCM incorporation, applied in an experimental chamber during the summer period in a Mediterranean Climate. The measured indoor air temperatures in the test cell (for the reference and PCM compartment) was evaluated and compared.

2. Experimental techniques

The details of the research experiment and the main results are presented in the next sections.

2.1. System description

2.1.1. Chamber description

The test cell is located at the University of Aveiro, Aveiro – Portugal and the translucent façade is oriented to the south. It was chosen this orientation since large glazed areas oriented to south are challenging in terms of discomfort, leading to asymmetry of the indoor thermal conditions in winter and overheating in summer. The outdoor test cell (Fig. 1) used in this experiment was built by COMOD Portuguese Company and is the model CLIP 05. The external dimensions are 7 × 2.35 × 2.58 m (length × width × height) and the internal floor area is 5.17 m^2. The main cell structure was built using galvanized steel profiles of 2 mm thickness and the floor supports 250 kg m^{-2} maximum load. The test cell envelope in contact with the external conditions is composed by 4 cm sandwich panels (insulation material – polyurethane foam) and the roof is composed by sandwich panel that has 8 cm of fibre glass with water vapour barrier. The cell is divided into two internal compartments (with the same dimensions) with an internal partition sandwich panel, also with 4 cm of insulation material. It was applied additionally 4 cm of XPS insulation material on each side of the partition wall to improve the thermal insulation between compartments and to decrease the energy transference. The floor structure is composed by the structural metal profiles and by an insulation layer of 18 mm – "*Phenolic Frame*" (insulation material and vinyl finish). Ventilation plays an important role that influences the indoor thermal performance, so to guarantee that the test cell boundary conditions are equivalent, a blower door test was carried out in both compartments to assure that the infiltration rate is similar.

As shown in Fig. 1 the front façade is composed by four double glazing windows panes (5-12-5 mm) with a dimension of 1.8 × 2.28 m. The window shutter system is located behind the double glazing layer. The details of the composition of the system are presented in Fig. 2, where it could be seen the window shutter position and the composition of the overall system.

The geometry and the imposed conditions of both internal compartments are very similar; the difference between them is the composition of the windows blades: *i)* the reference compartment has an internal window shutter composed with aluminium hollowed blades; *ii)* the PCM compartment has a window shutter composed by the same hollowed blades with paraffin PCM RT28HC®.

2.1.2. PCM RT28HC®

The PCM chose and used in the present work is the organic paraffin RT28HC® provided by Rubitherm® GmbH. The main physical and thermal properties of the PCM are given by the supplier are presented in Table 1.

The selected PCM is chemically inert and does not suffer any supercooling effect. The thermal behaviour of the heat storage and release process is done at a nearly constant temperature and is stable throughout long and repetitive cycles (good life cycle assessment). Other important chemical property is the chain length of the PCM structure that improves the thermal behaviour and the heat capacity of the PCM.

2.1.3. Aluminium hollowed blades filled with PCM

The selected material for the shutter blades was aluminium. It is one of the most used materials (window shutters) in Portugal and the thermal properties (mainly the thermal conductivity) of the Aluminium enhances the PCM charging and discharging process. The main thermal and physical properties of the aluminium are presented in Table 2.

The sealing of the PCM into the aluminium hollowed blades (Fig. 3) was a first challenge. The waterproofness and air tightness of the blades filled with PCM were tested individually for different sealing solutions.

Blade sealing needs to fulfil three main technical features: *i)* mechanical resistance; *ii)* airtightness and water seal; and *iii)* thermal resistance (up to 70 °C). Many experiments were done to guarantee the mentioned features using different sealing solutions, such as the use of liquid metal, mounting glue, high temperature