Solar absorption in a ventilated facade with PCM. Experimental results

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Abstract

The paper investigates experimentally the thermal performance of a ventilated double skin facade (DSF) with phase change material (PCM) in its air channel, during the heating season in the Mediterranean climate. Two identical house-like cubicles located in Puigverd de Lleida (Spain) were monitored during winter 2012, and in one of them, a ventilated facade with PCM was located in the south wall. The ventilated facade can operate under mechanical or natural ventilation mode and its thermal control depends on the weather conditions and the energetic demand of the building. The experimental results conclude that even though the use of the ventilated facade with PCM improves significantly the thermal behaviour of the whole building (working as a heat supplier in free floating tests, and reducing significantly the electrical consumption of the HVAC systems), these improvements might be increased if a thermal control is used.

1. Introduction

The high potential of building envelopes in the energy demand reduction and consequently in electrical energy savings has been widely proved [1-3]. The main effort in this topic was focused in increasing the
thermal resistance of the envelopes by improving the insulation [4]. However, a lot of research has also evaluated its thermal energy storage capacity. Within this context, many latent heat storage applications in buildings have been studied [5-7], since the use of phase change materials (PCM) in envelopes smoothes the daily temperature fluctuations and can absorb solar radiation and internal thermal loads [8].

Moreover, the use of ventilated double skin facades (DSF) in the building sector has recently become more popular. Those facades, if well designed, can efficiently reduce the overall HVAC energy consumption of buildings by absorbing part of the solar radiation during winter and preventing overheating during warm periods [9]. Those constructive systems are based on a special type of envelope, where a second skin, usually a transparent glazing, is placed in front of a regular building facade. The air space in between (the channel) can be mechanically or naturally ventilated to improve the thermal performance of the building [10]. The ventilated facades can operate under different modes (Trombe wall, internal and / or external ventilation) depending on the air flow path, as shown in Figure 1.

![Image](image_url)

**Fig. 1. Different operational modes of a ventilated DSF**

In this study, the use of PCM is combined with the ventilated facade constructive system, so it can absorb solar radiation during winter and hence reduce the heating load of the whole building. Moreover, the PCM can be used as a cold storage system during summer. Macro-encapsulated PCM panels were installed inside the air chamber of a ventilated facade, and its thermal performance is experimentally studied and compared against a conventional constructive system.

2. Experimental set-up

Two real cubicles with the same inner dimensions (2.4 x 2.4 x 5.1 m) were monitored in the experimental set-up located in Puigverd de Lleida, Spain. The constructive system used in the walls of
both cubicles is based on alveolar bricks (30 x 19 x 29 cm) with an external cement mortar and inner plaster coating. The only difference between the two cubicles is that one of them has a ventilated facade with PCM inside its air chamber in the south wall (Figure 2). A metallic structure is used to build the ventilated facade with an air cavity 15 cm thick, which corresponds to 0.36 m² of channel area. The inner layer is based on the alveolar brick constructive system while the outer envelope is made by a glass layer.

![Fig. 2. Reference and ventilated facade cubicle](image)

The ventilated facade has an effective solar absorption area of 6.4 m² and it is equipped with three fans (FCL 133 Airtecnics) in the air channel inlet to provide mechanical ventilation to the air chamber when needed. Moreover, in order to control the operational mode of the facade, six gates were installed at the different openings of the channel. Hence, the air can flow through the facade from the outer or inner environment, or operate as a Trombe wall. Those gates are controlled by ST450N linear spindle actuators. A system to control the fans and gates is programmed using a Microchip 18F45J10.

The PCM used in this application was the macro-encapsulated salts hydrate SP-22 from Rubitherm. A total of 112 PCM panels are distributed over the facade creating 14 air flow channels as shown in Figure 2. The use of this thin air flow channels maximizes the heat transfer area between the air flow and the PCM.

Both cubicles were fully instrumented and data is registered at five minutes intervals to evaluate their thermal performance. Surface and ambient temperatures were measured using Pt-100. Moreover the ventilated facade is equipped with air temperature, velocity and pressure sensors (KIMO CTV 210 and KIMO CP 200). Furthermore, the experimental set-up offers the possibility to perform two kinds of inner conditions: free floating temperature and fixed controlled temperature. Both cubicles are provided by two heat pumps (Fujitsu Inverter ASHA07LCC), located at different heights (3 and 5 m).
3. Methodology

In this paper, the thermal performance of the ventilated facade is experimentally tested under different weather conditions (severe and mild Mediterranean winter), in free floating conditions. The different tests under severe winter conditions were performed from the 9th to the 22nd of February, which were clear sunny days (global solar radiation peaks of 1200 W/m²) with an outer temperature oscillating from around 12°C to -4°C. On the other hand, the mild winter conditions experiments were tested from the 1st to the 29th of March, with similar solar radiation than in the previous experiments (global solar radiation peaks of 1100 W/m²) but with outer temperatures varying from 24°C to 4°C.

The sequence of operation of the experiments is shown in Figure 3. The ventilated facade acts as a solar collector during the solar absorption period. Once the PCM is melted and the solar energy is needed by the heating demand, the heat discharge period starts and the openings drive the air flowing from the inner environment to the facade cavity, which is heated up by the PCM panels and delivered to the inner environment later. This discharge period is performed until no more thermal energy is needed or can be provided by the facade; hereafter the system closes all the openings, acting as a Trombe wall, to minimize the heat losses to the environment.

During these free floating experiments no HVAC system is used, hence the thermal response of the building is evaluated by its inner temperature. This experiment is presented in the mechanically ventilated mode for severe and mild winter weather conditions. During the experiments under severe winter conditions, the system discharges the absorbed solar heat from 12:00 to 18:00, while during the mild winter test, the discharge period is programmed from 18:00 to 23:00 h. Hence, different operational modes can be tested, such as consuming the heat while absorbing or storing it for later uses.

Fig. 3. Sequence of operation of the ventilated facade
4. Results

4.1 Free floating under severe winter conditions (FF SW)

The severe winter experiment was performed from the 9th to the 12th of February 2012. During these four days an outer temperature oscillating from 8 to -4°C and a total solar heat incident to a vertical surface of 99.6 MJ/m² were registered, giving a total solar heat of 159.37 MJ/day incident to the facade. This absorbed heat was pumped to the inner environment of the cubicle from 12:00 to 18:00 by using the fans at a fixed volume flow rate of 2600 m³/h. The heat injected from the facade to the inner environment was 57.2 MJ/day, hence the system had an absorbed solar heat pumping efficiency of the absorbed solar heat of 36 %. The solar heat not pumped to the inner environment regards to heat losses to the environment and the reflection of solar radiation occurring in the outer skin.

The inner temperatures of both cubicles are presented in Figure 4. The inner temperature of the reference cubicle dropped daily following the oscillation of the outer temperature, while the use of the ventilated facade with PCM increased every day the inner temperature from 9 to 18 °C.

Fig. 4. Inner temperature evolution during the free floating test under severe winter conditions
The thermal profiles of the PCM and the air flow are presented in Figure 5 altogether with the inner and outer environmental temperatures of the ventilated facade cubicle during the 12th of February. The system did not use the whole available latent heat, stored in the PCM, since after the discharge (18.00 h) the PCM in the upper part of the facade was just starting its melting process. Hence, the discharge might be prolonged in order to take advantage of the latent heat. This indicates the necessity of using a thermal control system which might be programmed depending on the energy demand, production and storage.

The PCM and air flow temperature dropped to values close to 0ºC during the night time. However, the temperatures of the whole ventilated facade increased fast with the solar radiation, achieving its maximum just before the discharge. A vertical thermal gradient was measured in the air flow during the solar absorption period (12 ºC) indicating an important air stratification in the air channel.

It is important to highlight that the system was still absorbing solar radiation during the discharge period, when working under these operational mode, and this is why the PCM and air flow temperatures increased until 15:00 even though part of the solar heat was being injected to the inner environment.

![Figure 5. Thermal profiles of PCM, air flow, and inner and outer environment during 12th of February](image-url)
4.2 Free floating under mild winter conditions (FF MW)

The free floating experiment under mild winter weather conditions was tested the 16th and 17th of March 2012 and it is shown in Figure 6. The solar radiation incident to the facade during these two days was 163.2 MJ/day. The system discharged this solar heat from 18:00 to 23:00, injecting 31.6 MJ/day to the inner environment, having an absorbed solar heat pumping efficiency of 19.4%. It can be seen that the pumping efficiency of the absorbed solar heat was reduced in comparison to the previous experiment (FF under severe conditions). This occurred because in the experiment described in Figure 4 the heat was being discharged at the same time as was being absorbed. On the other hand, in the experiment presented in Figure 6 the absorbed solar energy was stored for later uses and hence exposed during more time to heat losses to the environment. The measurements under these climatic conditions proved that the ventilated facade improved strongly the thermal performance of the cubicle making the use of HVAC system almost not necessary, since the inner temperature was nearly all the time inside the thermal comfort range.

Furthermore, Figure 7 also shows that the latent heat was only partially used and the discharge process might be prolonged three more hours.

Fig. 6. Inner and outer temperature evolution during the free floating test under mild winter conditions
5. Conclusions

The thermal behavior of a ventilated facade with macro-encapsulated PCM in its air cavity was experimentally evaluated during winter period and it is presented in this paper. The experimental set-up consisted of two identical house-like cubicles (2.4 x 2.4 x 5.1 m inner dimensions). The only difference between the two cubicles was that in one of them a ventilated facade with macro-encapsulated PCM (SP 22) inside its air chamber was placed in the south wall. With this constructive system, the ventilated facade acts as a solar collector during the solar absorption period, until the solar energy is demanded and can be discharged to the inner environment.

In the experiments carried out, the thermal performance of the whole building was improved by the use of this ventilated facade under free floating conditions. While the inner temperature of the reference cubicle dropped daily due to the oscillation of the outer temperature, the use of the ventilated facade with PCM made the temperature increase every day from 9 to 18ºC under severe winter conditions, and made almost not necessary the use of HVAC system during the mild winter period.

Moreover, the use of SP-22 as PCM provided almost no thermal benefits in this system, since its phase change temperature during the solidification process was very low (20ºC) to be used in this facade, and only in some operational modes, a part of the stored latent heat was injected to the inner environment.
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