Two active integrated storage systems: Double skin facade and active slab with PCM

Lidia Navarro[1], Alvaro de Gracia[2], Luisa F. Cabeza[1*]

[1] GREA Innovació Concurrent, Universitat de Lleida, Edifici CREA, Pere de Cabrera s/n, 25001, Lleida, Spain. Email: lcabeza@diei.udl.cat

[2] Departament d'Enginyeria Mecanica, Universitat Rovira i Virgili, Av. Paisos Catalans 26, 43007 Tarragona, Spain

Abstract: Energy consumption in buildings has become an important part of the global energy consumed in Europe and it is mainly related to heating ventilation and air conditioning (HVAC) systems. Hence, efforts need to focus not only on improving the building envelope but also on enhancing the energy efficiency of the HVAC systems. The use of thermal energy storage (TES) in buildings has been widely studied as passive system through their incorporation in the building envelope. Lately, new applications of active TES using latent heat storage materials are becoming popular. In this paper, two innovative systems of TES integrated in the building, double skin facade and internal slab, are presented. The use of a building component as a heat storage unit and heating and cooling supply provide significant energy benefits. The potential of both technologies are presented for space heating and cooling. Moreover, some aspects found during the experimental studies are highlighted to determine required improvements and further analysis.

Keywords: thermal energy storage, phase change materials, energy savings, numerical study, reinforcement learning, building integration.

1. Introduction

Nowadays, energy policies (Directive 2010/31/EU) and building regulations are determining new limits on the energy consumption in buildings. Therefore, low energy or zero energy buildings are becoming the target to achieve by the building stock. These new policies give importance to the research and development of technologies focused on reducing the energy demand and the greenhouse gas emissions (Horizon 2020), by promoting the use of renewable energies. Development of new technologies to integrate renewables in heating ventilation and air conditioning (HVAC) or domestic hot water (DHW) systems should be provided by researchers to achieve better acceptance by architects and engineers. Moreover, the integration of these new technologies in the building design is shown as an attractive alternative to conventional systems. However, the mismatch between supply and consumption that characterize most renewable energies should be solved by a properly designed thermal energy storage system (Zhou et al. 2015).

The use of thermal energy storage (TES) in buildings has been identified as a suitable solution to reduce energy demand for heating and cooling. TES allows the use of peak load shifting strategies and enhances the introduction of renewable energies in the sector. Hence, it is claimed that the use of TES can provide energy savings, cost reduction, and CO_2 mitigation.

Latent heat storage has been widely studied (Cabeza et al. 2011, Zhou et al. 2012) for its potential in many applications for building energy management (Lim et al. 2014). Passive implementation of phase change materials (PCM) in buildings has demonstrated significant energy reduction of HVAC systems, but with some limitations such as the number of cycles during the year, as well as the charging availability during summer. For this reason, active implementation of PCM in buildings is becoming popular due to the high potential to be used as a storage unit as well as its capacity for providing heating and cooling supplies. The integration of these systems in the building is one of the aspects that researchers are taking into account to achieve a competitive technology for a future inclusion into the building sector.

In this paper two innovative active systems are presented, consisting of thermal energy storage units embedded inside two different parts of building components. A double skin facade and an internal slab were filled with PCM in order to act as a storage unit as well as a heating and cooling supply. In this paper, the potential of both technologies are presented for space heating and cooling. Moreover, some aspects found during the experimental studies are highlighted to determine required improvements and further analysis.

2. Experimental set-up

In the experimental set-up located in Puigverd de Lleida (Spain) several house-like cubicles were built to study different constructive systems and materials (Fig.1). Three of these cubicles are used to test the PCM active systems; one of them has a double skin facade with PCM, another one has an active slab as internal separation with PCM, and the third one has conventional constructive system acting as a reference. Both technologies presented in this paper are designed to cover the cooling and heating demand of a building. A structural component of the building is used as a storage unit with an active charge and discharge process for covering the energy demand of the building. The novelty of these systems is the inclusion of phase change materials (PCM) inside the storage unit in order to increase the heat storage capacity.

Fig.1. Experimental set-up located in Puigverd de Lleida, Spain.

3. Operating principle

The first technology tested was the double skin facade which acts as a solar collector during daytime in winter season (Fig.2, left). Once the PCM is melted and the solar energy is needed by the heating demand, the heat discharge period starts. The openings drive the air flowing from indoor to the facade cavity, where it is heated up by the PCM panels through its solidification and sent it back into the cubicle. On the summer mode (Fig.2, right) the PCM is solidified by the outside air which is pumped into the channel during night time. The air is cooled down by the melting process of PCM and is pumped to the inner environment providing cooling supply. The air flow from outdoors to outdoors prevents the overheating effect in the air channel when there is no more cooling available to be supplied. Moreover, night ventilation mode could be also performed to achieve a free cooling effect.

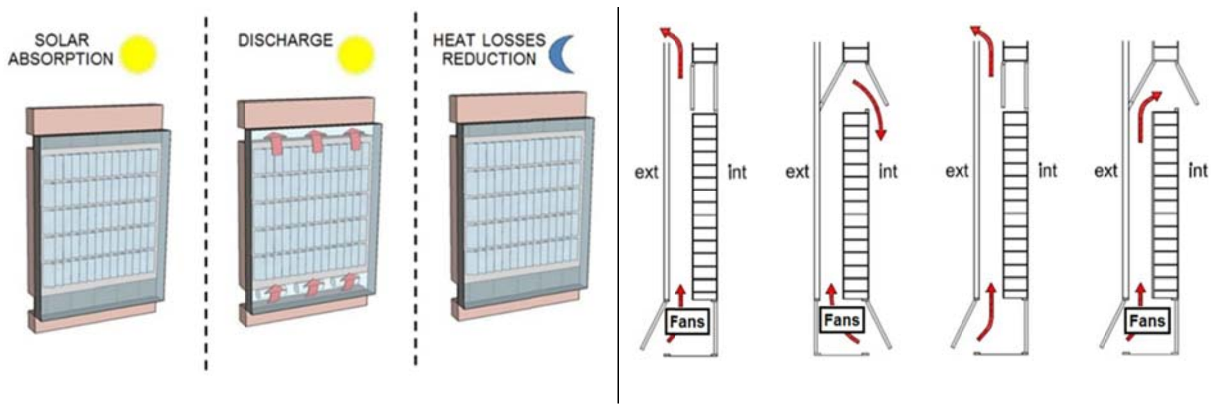

Fig.2. Operating principle double skin facade; left winter, right summer.

The following technology tested was the active slab located in the internal horizontal separation between two storeys. In winter season, the active slab (Fig.3.a) is charged during daytime through the injection of hot air from a solar air collector. The thermal energy is stored inside the slab until a heating demand is needed. The air of the internal ambient is pumped through the hollows of the slab and the heat exchange with the PCM provides the heat needed to cover the demand totally or partially. On the other hand, regarding the operational mode during the summer period (Fig.3.b), outside cool temperature at night is used to cool down the concrete slab and to solidify the PCM by the circulation of outdoors air through the hollows. During daytime, the inner air of the cubicle is pumped through the slab getting a cooling supply and covering part or the whole cooling load.

Both technologies, double skin facade and active slab, are driven by a control system to manage the different sequences and operation of heating and cooling modes.

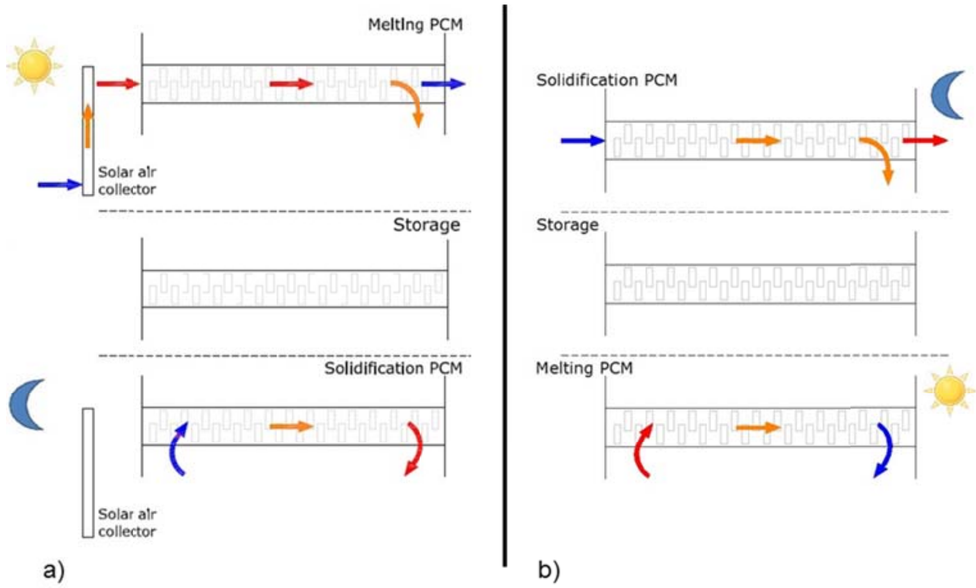

Fig.3. Operating principle active slab: (a) winter, and (b) summer.

4. Results

Both technologies were tested under real weather conditions and coupled to a real demand house-like cubicle where the thermal performance of the systems were analysed. In addition, a reference house-like cubicle was used to compare the double skin facade and the active slab with a conventional heating and cooling system.

4.1. Double skin facade

During the summer tests, the high potential of the night free cooling effect was demonstrated for reducing the cooling loads. The cold storage capacity of the systems is very sensitive to the outer night temperature, being limited under severe summer conditions. In the case of the double skin facade the system prevents successfully the overheating effect that could be found in the air channel (de Gracia et al. 2013a).

The use of the double skin facade with PCM during winter period has demonstrated the potential as a heat storage unit and heating supply (Fig.4). Under mild winter conditions the system is able to cover almost all the heating demand of the house-like cubicle. Moreover, under severe winter conditions when compared to a conventional heating system, the double skin facade registered significant energy savings even without using mechanical ventilation in the air cavity (de Gracia et al. 2013a).

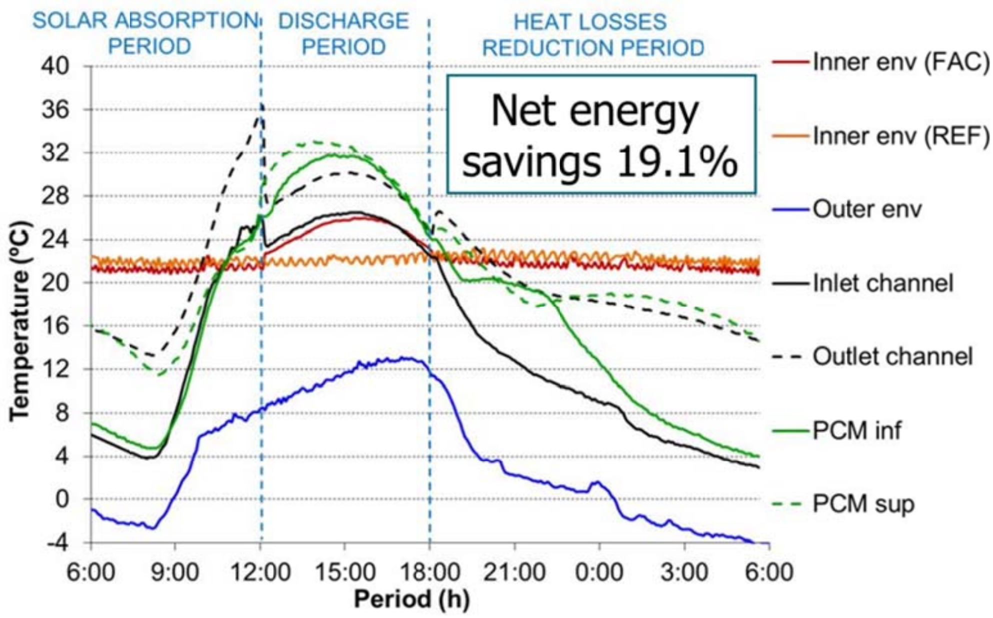

Fig.4. Thermal profiles of PCM, air flow, and inner and outer environment during winter period in the double skin facade.

4.2. Active slab

The use of an internal component of the building to integrate the storage unit was proposed to overcome the heat losses to the outer environment registered in the double skin facade. Therefore, the active slab was designed to use the internal horizontal separation of buildings to store energy and provide space heating and cooling (Navarro et al. 2015).

During the summer experimental campaign, the free cooling potential of the active slab was observed to provide some energy benefits by cooling down the internal ambient during night time. Despite the energy benefits provided by the cold storage sequence, no net energy savings were achieved, since PCM was not able to be solidified under the Mediterranean continental summer conditions (Navarro et al. 2016a).

The active slab design has the necessity to install a solar air collector to melt the PCM during the winter mode. The winter experimental campaign performed in the set-up demonstrated the potential of the active slab to store and supply heat s (Navarro et al. 2016b). Moreover, the technology was compared to a conventional heating system and significant energy savings, around 60%, were achieved (Fig.5).

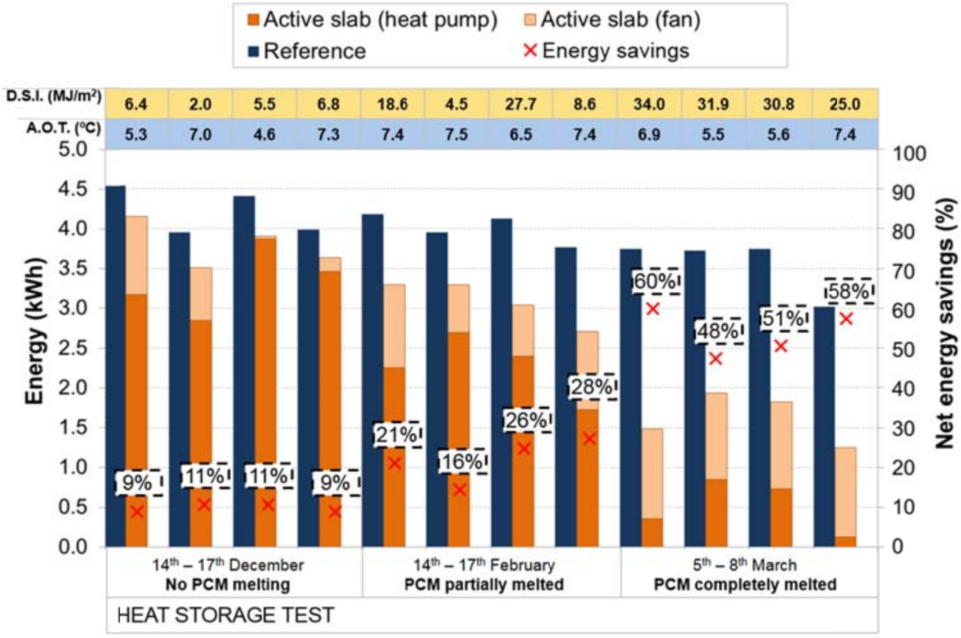

Fig.5. Electrical energy consumption of the heat pumps of the reference and active slab cubicle during winter period. D.S.I (Daily Solar Irradiance), A.O.T.(Average Outside Temperature).

4.3. Discussion

The experimental studies presented should be treated as a demonstration of the high potential of both technologies to reduce the heating and cooling energy consumption of the conventional HVAC systems.

Different aspects were observed during the experimentation that provide the authors guidelines of where the systems needs improvement. First of all, both systems presented dependence on the weather conditions, which affects the performance of the whole technology and drastically influence the energy benefits that are achieved. However, it was demonstrated through an experimentally validated numerical tool (de Gracia et al. 2015a) that the thermal performance of these systems varies depending on the weather conditions where are applied. In the study of de Gracia et al. 2015a, the double skin facade was tested by means of a numerical model in several locations representative of different climates all over the world. The energy benefits observed in other climates different from the one tested experimentally shows that the potential of the technology for cooling purposes is relevant only in climates with high daily thermal oscillations.

In addition, the control system plays an important role in the performance of the double skin facade and the active slab. This fact highlights the importance of the control algorithm behind these new active storage units. Different charging strategies resulted in significant differences in the energy benefits achieved by both systems. An optimization of the management of the charge, discharge and storage processes based on artificial intelligence algorithms, are key factors for the future development of these technologies. The implementation of weather forecast, energy demand profiles of the building, and electricity cost profiles in the control algorithm could optimize the performance of these systems.

The high investment cost of these systems makes mandatory an appropriate control to maximize the energy benefits during its operation. A first step was done in the double skin facade technology through an experimentally validated numerical tool used to study the effect of different control strategies on the performance of the system (de Gracia et al. 2015b). Three different tested control strategies are optimized based on cost savings, energy reduction and CO_2 mitigation. The results obtained showed the improvement in the performance of the system by using an appropriate control strategy, and how optimizing based on one output can influence the other two benefits claimed by TES systems.

5. Conclusions

The research related to two innovative technologies for space heating and cooling are presented in this paper, the double skin facade and active slab. The integration of phase change materials in the components of the building provides the possibility to use a part of the building as an active storage unit and a heating and cooling supply.

The potential of both technologies is demonstrated through the experimental study performed in the facility located at Puigverd de Lleida, Spain. The double skin facade and the active slab were tested experimentally under real weather conditions coupled to a house-like cubicle demand. During the summer tests, the high potential of the night free cooling effect was demonstrated in both systems for reducing the cooling loads. In both cases, double skin facade and active slab, the cold storage capacity of the systems is very sensitive to the outer night temperature, being limited under Mediterranean continental climate summer conditions. In the case of the double skin facade the system prevents successfully the overheating effect that could be found in the air channel.

In addition, during winter tests the use of the ventilated facade with PCM reduces the electrical energy consumption of the installed heating system even without using mechanical ventilation in the air cavity. The active slab system registered also significant energy savings compared to a conventional system that highlight its potential.

The integration of active TES systems in buildings is considered a relevant aspect to take into account in building designs, to achieve better acceptance of these new technologies in the building sector. However, the complexity of these systems requires an effort not just on their building integration, but also in the design of their control strategies to achieve their maximum energy benefits and justify the high required cost investments.

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