ENERGY REHABILITATION OF BUILDINGS THROUGH PHASE CHANGE MATERIALS AND CERAMIC VENTILATED FAÇADES

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ABSTRACT

In recent years, phase change materials (PCMs) have gained major relevance for their ability to take advantage of indoor/outdoor air temperature differences to store energy. This characteristic of PCMs allows to transfer stored energy to periods of energy demand, thus achieving optimum conditions of comfort and notable energy savings. The present study compared the energy consumption of a traditional façade and a ventilated façade to which large format ceramic tiles covered with PCMs were applied. For this purpose, an office building in the city of Alicante was used as a case study. Salt hydrate PCMs were attached to the slabs, and air was allowed to circulate or not circulate through night and day dampers as passive conditioning, accumulating energy. The energy performance of the building was simulated using the Lider-Calener (HULC) energy certification tool in both scenarios. The building's energy demand was calculated in its current state and with the ventilated façade with ceramic tiles and PCMs. An energy saving of 5% was obtained.

Keywords: ceramic, energy rehabilitation, phase change materials (PCM), ventilated façades.

1 INTRODUCTION

The housing sector is one of the European Union's major energy consumers: 40% of the energy produced in Europe is consumed throughout buildings' life cycle phases. For this reason, in 2010 the European Parliament approved Directive 2010/31/EU to reduce energy consumption and emissions in buildings [1]. Conforming with these European guidelines, Spain's Technical Building Code (or CTE by its Spanish acronym) was approved in 2006 to improve buildings' energy efficiency and consumption [2]–[3]. The building energy certification protocol based on the use of HULC software was approved at the same time [4].

Under these circumstances, it is necessary to consider the impact that the economic crisis and the bursting of the housing bubble have had on the Spain's construction sector. These factors have led to a drastic reduction in building construction activity, which is why many buildings are outdated. One way the governments stimulate the economy is by promoting building refurbishments, especially in the field of energy and consumption reduction. Thus, within this context of new demands for energy reduction, the present study proposes two lines of action. On the one hand, we suggest addressing energy losses and reducing consumption by intervening in façade enclosures to improve their performance by replacing joineries and by incorporating ventilated façade systems that prevent thermal bridges [5]. On the other hand, current needs in architecture to reduce energy consumption have generated new strategies based on passive energy conditioning systems in buildings. This reduces energy consumption and limits the use of traditional fossil fuels [6].

In recent years, thermal energy storage systems using phase change materials (PCM) have attracted considerable interest, since they allow adapting supply periods to energy demands. These systems present a great potential for improving energy efficiency [7]. The amount of publications on the subject of thermal storage using PCM has thus grown significantly [8].

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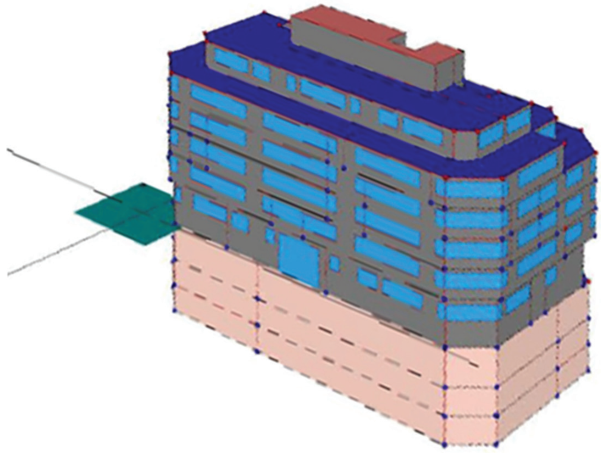

Figure 1: Model of the building drawn up with HULC software.

According to the statistics of the International Energy Agency (IEA), around 30% of energy supply is lost during its conversion, that is, due to dissipation or thermal costs [9].

This article focuses on the advantages and disadvantages of integrating and applying PCMs to buildings' energy refurbishment. A case study was conducted in Alicante city, in which annual energy demand was compared before and after incorporating new PCM construction systems. To quantify the improvements, both building models, the theoretical model and the real model, were simulated using the HULC software tool. The energy refurbishment proposal consisted in laying out the PCM on the lower face of the slabs, increasing their thermal inertia in the chamber formed by the false ceilings; controlled ventilation was added, allowing to regulate the flow of air entering from the outside. A new ventilated façade system with a porcelain stoneware ceramic finish was also incorporated.

2 VENTILATED FAÇADE

The ventilated façade with external thermal insulation is a construction system developed in northern European countries to solve certain construction problems [10]. The system creates a continuous barrier that protects the thermal envelope and prevents thermal bridges that cause energy losses in the building. This type of façade enables reducing energy demands and improving comfort levels [9]. Due to its characteristics, the system has also gained importance in parts of southern Europe such as Alicante.

A key component of these systems is the exterior finishing material, which needs to meet essential characteristics such as: strength, hardness, durability, impermeability and low weight, since it is difficult and expensive to maintain. Ceramic material is thus ideal for these types of façades due to its resistance, great durability and competitive cost [5].

3 PHASE CHANGE MATERIALS (PCM)

Passive energy storage systems such as those that capture solar radiation through greenhouse effects, Canadian wells that take advantage of land energy, or thermal gaps of outdoor air over night and day cycles, are some examples of how buildings' energy efficiency can be greatly improved. PCMs constitute an energy storage system, bringing thermal inertia to construction elements. These materials are capable of accumulating energy in the form of latent heat under given conditions of air temperature, solar radiation, etc. It is relevant to apply them to architectural solutions because of the energy savings that can be derived from them. When these materials are incorporated into building envelopes, they allow to better condition indoor spaces via radiant surfaces. Thus, they provide a high level of comfort and bring about substantial reductions in annual energy demands [7].

3.1 Introduction to PCM

PCMs are materials that undergo a change of state (liquid-solid-gas) at a given temperature. The amount of heat necessary to increase the temperature of one of these materials (sensible heat) by one degree is much lower than that required in the case of latent heat. The changes produced in the different materials due to latent heat occur at a given temperature that is proper to each material [6].

The interest in this type of material lies in the fact that during the phase change, the temperature remains constant while the material absorbs energy. This means that these materials have a higher energy density than other materials. Phase change materials that pass from solid to liquid require the least amount of energy [11]. In addition, theirs volumes undergo smaller variations than in other phase change processes. This allows using them in architecture in different applications and formats.

3.2 Types of phase change materials

The most common liquid-solid phase change materials used in the temperature range of 20ºC to 80ºC are: paraffin waxes, hydrated salts, eutectic mixtures and fatty acids.

- Paraffin waxes are available for commercial use. But their latent heat (approximately 200 kJ/kg) is only half that of hydrated salts, making them less interesting to use.

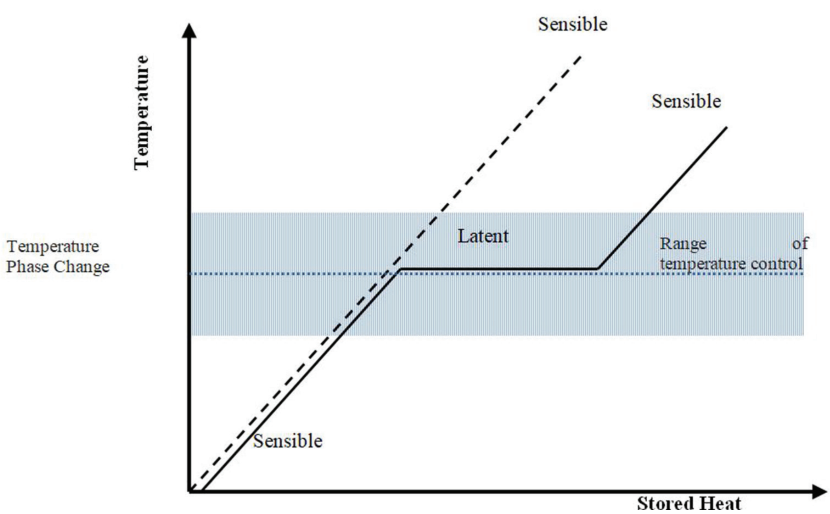

Figure 2: Operation process chart of phase change materials.

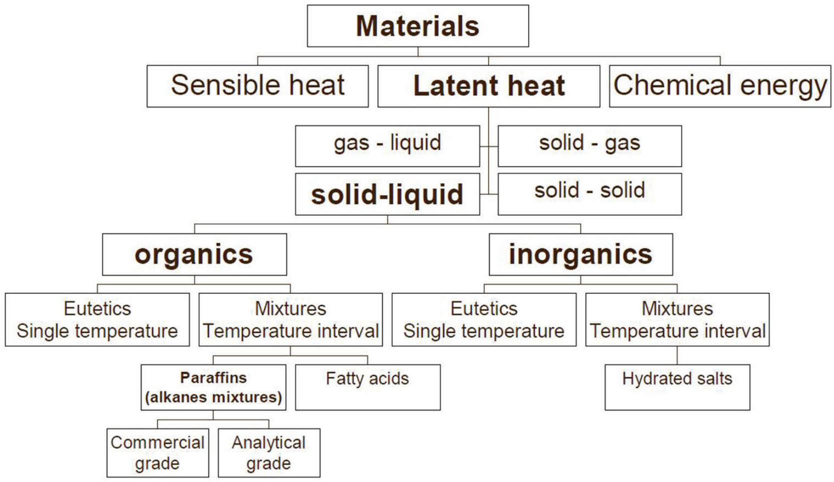

Figure 3: Classification of substances used for thermal storage.

- Hydrated salts are cheaper than paraffin waxes. They have the disadvantage of offering a low melting temperature and presenting higher corrosion when in contact with metals.
- Eutectic mixtures are formed by two components that, when joined, have a melting point (solidification) that is below that of the compounds individually, causing both elements to solidify at eutectic temperature. An example of these eutectic mixtures is salt bonding with ice.
- Fatty acids, like paraffin waxes, have a latent heat value of approximately 200 kJ/kg, but a higher commercial cost.
- Organic compounds do not present subcooling problems and are more stable than inorganic compounds [11]. Organic materials such as: waxes, fats and their esters have been recommended as heat accumulators, since their latent heat of fusion is 120 kJ/kg, their density 800 kg/m^3, their thermal conductivity 0.20 W/m·K and the specific heat is from 1500 J/kg·K.

3.3 Final considerations regarding PCMs

The use of PCMs for energy storage has increased rapidly in recent years. New products based on PCMs have appeared in the field of architecture. Applications of these products have been proven to be viable in other areas. New PCMs are being developed with determined characteristics and physical properties suitable for specific applications such as the temperature control of pharmaceutical products or of the human body [6].

Several studies have demonstrated how radiant floor heating and passive cooling by convection using energy storage systems based on PCMs function correctly in the construction field [9]. Results obtained by researchers on PCMs in a Mediterranean environment led us to opt for inorganic hydrated salts as they are inexpensive and offer a large heat storage capacity per volume unit [8]. Although organic substances are more stable and their temperature is closer to operating temperatures, they have the setback of presenting low thermal conductivity [11].

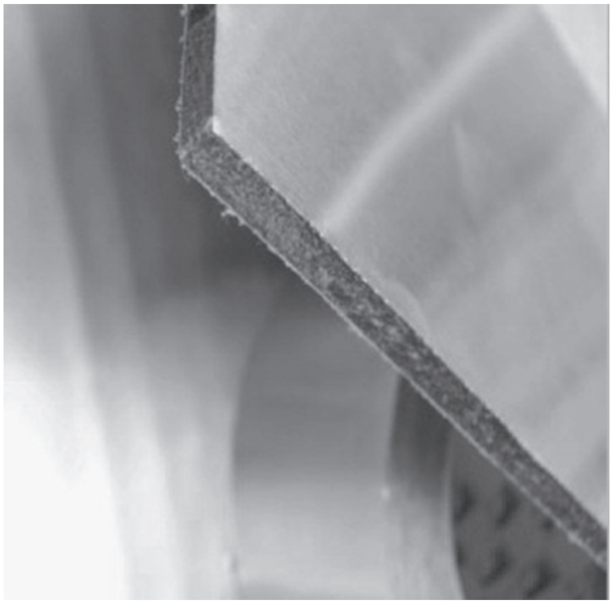

Figure 4: Paraffin wallboard [12].

Figure 5: PCM used in this work, hydrated salts SP 21EK by Rubitherm (Source: Rubitherm).

4 CASE STUDY

The headquarters of the National Organization for the Blind in Spain (ONCE by its Spanish acronym) in Alicante was chosen as a case study. The building uses a ventilated façade. The construction system is unique among the construction techniques prevailing in the area, which mostly use a traditional double-skin façade system with a chamber. Figure 7 illustrates

Figure 6: Image of the building.

the absence of thermal bridges in the façade thanks to the ventilated façade system, but also the presence of heat loss due to joineries with no thermal breaks.

The case study building is located in a widened area with street alignment, at 43, Avenida de Aguilera in Alicante city. The building was built in the year 2000 and consists in a seven-storey isolated block. It has four main façades with chamfered corners, resulting in eight façade planes, and is mainly used as an office building.

4.1 Composition of the existing enclosures

The exterior façade enclosure, from the exterior to the interior, is composed of: a finishing layer of natural granite stone plates of e = 2.5 cm, a ventilated air chamber of e = 6.0 cm, a galvanised steel metal substructure, an insulation thermal layer e = 4.0 cm, a plastering of cement mortar e = 1.5 cm, an interior sheet formed by hollow ceramic double brick e = 9.0 cm, a plastering and plaster finish of e = 1.5cm and an acrylic paint coating.

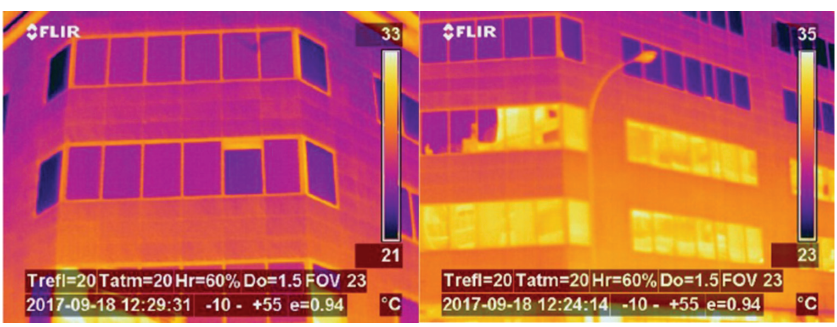

Figure 7: Thermal images of the ventilated façade. 18 September at 12:30 p.m.

5 ANALYSIS AND RESULTS OF THE PROPOSED SOLUTION

5.1 Description of the alternative solution

This work aims at innovating in the field of construction solutions to achieve the proposed objectives: passive conditioning, a ventilated façade using ceramic material and energy improvement. The general design was based on taking advantage of the PCMs' energy storage capacity and integrating the PCMs into the case study's joint refurbishment solution, arranging these materials in the false ceiling beneath each floor's slabs. In addition, new reflective thermal insulation was incorporated, improving the enclosure's performance, while decreasing thermal transmittance thanks to a thickness of only 3.0 cm (Fig. 8) [14]. We suggest replacing the existing aluminium window frames with high thermal transmittance by aluminium frames with a thermal bridge break based on a double-glazed sheet with an inner chamber since, as illustrated in the thermographs (Fig. 7), they are critical regarding energy loss.

5.2 Description of the passive conditioning system using PCM

A chamber communicating the building's opposite façades was proposed: it acts as an internal ventilated conduit in the false ceilings. Automated doors were placed on the façades to control the opening and closing of this conduit. The PCM sheets were placed in this chamber and acted as energy storage. The accumulated energy is gradually released to the upper slab in the form of heat both by conduction and by radiation [14]. The theoretical operation of the PCM conditioning system is detailed below based on four different scenarios.

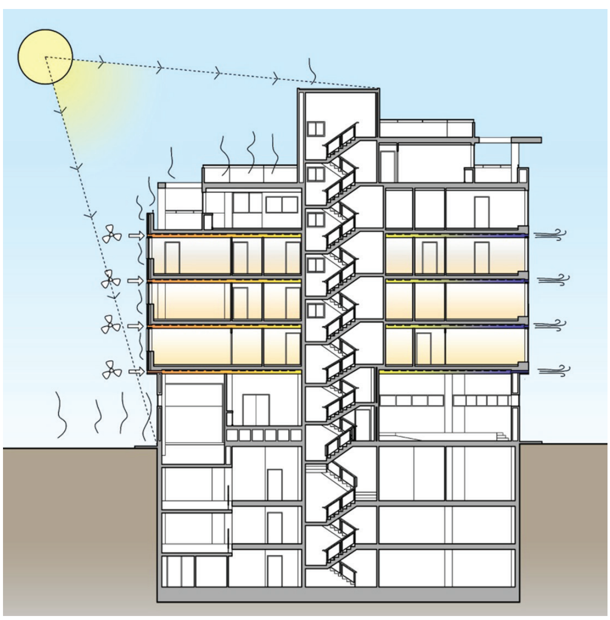

Figure 8: Comparative construction detail of the existing façade solution and the proposal using PCM.

5.3 System operation throughout the year

5.3.1 Winter

In the winter regime, an operating air temperature of 21ºC [15], was taken into account inside the building, as Alicante city's maximum and minimum temperatures recorded in the winter period are 15.9ºC and 6.0ºC, respectively [16]. In addition, two cases were differentiated: diurnal and nocturnal cycles. During the day in winter, the system's PCM sheets capture outside air heat. This air accesses the chamber through the openings in the south façade. This façade is heated by solar radiation, raising the temperature of the air around it. In this case, both chamber doors are opened, those facing North and those facing South. The north façade openings may be closed to keep the hot air longer inside the chamber. The fans placed in the south façade can also be activated (if necessary) to improve the ventilation in the false ceilings. The PCM progressively increases in temperature, storing it in the form of energy [7]. The PCM plates heat the lower face of the floor by radiation and the air by convection when the system requires it. Under nocturnal winter conditions, the PCM plates gradually transfer the energy stored during the day in the form of heat to the lower face of the floor [17], the slabs acting as a radiant floor. This heat transfer takes place directly by conduction and indirectly by radiation [8]. The doors of the chamber must remain closed on both façades during the process.

5.3.2 Summer

In summer, an operating indoor air temperature of 23ºC was taken into account as Alicante city's average maximum and minimum temperatures registered in summer are 31.6ºC and 20.6ºC, respectively. Two scenarios were considered: the day and night cycles [16]. During the day in summer, interior room temperatures are reduced, creating a flow of energy through the floor stored by the PCM via radiation (PCM-slab). For this, the doors are kept shut during the day, to avoid letting in hot air from the outside. There is thus no ventilation in the chamber. At night, the PCM plates are set to be cooled, that is, energy is to be transferred by convection from the phase change material stored during the day to the air [17]. To do this, the false ceiling chamber doors are opened creating natural ventilation during the night.

5.4 Façade proposal

The proposed solution (Fig. 8) brings an improvement to the joineries, as it integrates hinged joineries with thermal bridge breaks and double glazing with an air chamber. New reflective thermal insulation, 3 cm thick MULTITHERMIC 19 layers of WÜRTH® is proposed. The reduced insulation thickness allows for a bigger chamber and consequently, a larger air flow can circulate.

The major energy improvement measure to reduce annual energy demand consists in reducing *U* thermal transmittance of the enclosures making up the building's thermal

Table 1: Interior design conditions according to RITE (Spanish Regulation of Thermal Installations in buildings).

Season	**Operating temperature ºC**	**Relative humidity %**
Summer	23–25	45–60
Winter	21–23	40–50

Table 2: Values of *U* thermal transmittance according to HULC (elaborated by the author).

	Values of *U* thermal transmittance.		
Enclosures	**U_{exist} (W/m²·K)**	**U_{prop} (W/m²·K)**	**Reduction (%)**
Façade	0.72	0.53	26.30
Roof	0.24	0.24	0.00
Joineries	5.70	2.84	46.70

envelope. The reduction of the enclosure's transmittance value is shown in Table 2 and is expressed in percentages [14].

The proposed intervention also considers replacing the stone finishing material with a double ceramic sheet of great durability and strength together with an internal mesh reinforcement [5]. The inner sheet of the enclosure is solved with a light sheet using rectangular stainless-steel profiles, laminated with gypsum board cladding and a paint finishing. Furthermore, to carry out the passive conditioning strategy, gaps are opened in the enclosure at the height of the lower false ceilings. Automated opening and closing doors are inserted. In the south façade, jet fans will be installed to allow adequate air circulation through the chamber and correct air distribution. This false ceiling chamber houses the aluminium panel plates containing the PCM, Rubitherm SP 21EK Hydrate Salt (Fig. 9). The properties of this material allow it to act as a radiant device by heating the air in the false ceiling in winter and cooling it in summer. In this way, it is possible to modulate the operating comfort temperature in the rooms below. Installing adjustable and automated vertical slats protect the window openings from the sun's rays along their route during the day. As for the interior, a false ceiling with a ceramic finish is proposed and, to avoid leaks in the chamber system, we suggest sealing using EPDM compression strips and EPS bands. This is complemented by a technical floor that incorporates the building's necessary installations.

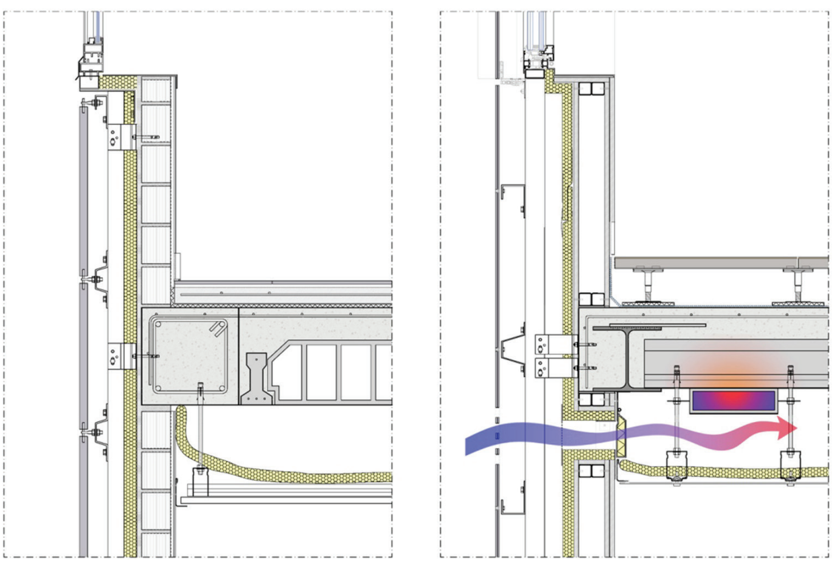

Figure 9: Operation process chart of the passive air conditioning system.

Table 3: Results of the energy demands of booth drawn up using HULC.

HULC Model	Energy demands Annual	Winter	Summer	Reduction compared to the CTE reference building
	(KWh/m^2·year)			(%)
Existing building	46.66	21.40	25.26	3.05
Proposed building	42.32	17.42	24.90	12.07
CTE reference building	48.13	16.34	31.79	-

6 CONCLUSIONS

Studies show that the use of ventilated façades on the east coast of Spain can reduce the overall environmental impact by 7.7%, based on a building's useful life of 50 years and the system's environmental amortization period of 30 years.

PCMs have shown to be fruitful in the field of architecture and are currently gaining ground. PCMs are used as a thermal storage system (TSS): they accumulate energy for use at different times, allowing to balance energy supply and demand, achieving an efficient use of the produced energy while taking advantage of thermal surpluses. Savings at peak times is another advantage of incorporating PCMs in buildings. Incorporating these materials to complement cold or heat production equipment allows compensating moments of high demand, increasing efficiency. The construction solution proposed in this paper is based on using PCM panels mainly as a thermal storage system, laid out in false ceilings and functioning as heat exchangers. The chamber's ventilation air flow can be controlled according to need.

Based on the studied ratios of energy gains per day of refrigeration supply compared to that of similar prior studies, the consumption of cooling energy for each building floor can be estimated to be 0.087 MJ/day·m^2, considering that 10 panels of 0.12 dm^3 were installed per m^2. That is, a saving of approximately 0.90 KWh/ m^2·year is achieved. Therefore, a 12.0% saving of combined heating and cooling demand is made.

The cost of the PCM materials, the openings produced in the building and its refurbishment means that the system's amortization period extends over time. Recent studies on the functioning of PCMs have shown that investing in this type of intervention is risky and the cost is high, sometimes so much so that it is not profitable or of interest to property developers.

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