Study of energy saving in a Greek building using Phase Change Materials

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Abstract

In Greece the energy upgrading of existing and new buildings, manufactured to the highest standards of thermal insulation is a necessity according to the National regulations due to high consumption of the existing building infrastructure. In recent years, the trend in the building sector is to achieve thermal comfort conditions and to minimize the use of conventional energy. Phase Change Materials (PCMs) have high heat storage capacity so that they can absorb a lot of energy before melting or solidifying. A PCM temperature remains constant during the phase change, which is useful for keeping the subject at a uniform temperature. In this study the potential energy benefits that can arise from integrating PCMs into building components, are examined. The software adopted (TRNSYS) simulates the behavior of the building throughout the year in the climate of Greece.

1. Introduction

The building sector is one of major energy consumers and its contribution toward global energy consumption is about 40% [1]. Energy efficiency and conservation in buildings is therefore becoming one of major issues of concern to governments and societies today. The use of thermal energy storage systems is received increasing interest, which has been recognized as one of effective approaches to reducing energy consumption of buildings.

Energy storage in the walls, ceiling and floor of buildings may be enhanced by encapsulating suitable PCMs within these surfaces to capture solar energy directly and increase human comfort by decreasing the frequency of internal air temperature swings and maintaining the temperature closer to the desired temperature for a longer period of time. PCMs can be encapsulated in concrete, gypsum wallboard, ceiling and floor [2].

PCMs are ‘‘latent’’ heat storage materials that use chemical bonds to store and release heat. The thermal energy transfer occurs when a material changes from solid to liquid, or liquid to solid. This is called a change in state or phase. PCMs, having melting temperature between 20 and 32^oC, are used for thermal storage in conjunction with both passive storage and active solar storage for heating and cooling in buildings. A large number of PCMs are known to melt with a heat of fusion in the required range [3].

Most commonly used PCMs for building applications can be either encapsulated paraffin or hydrated salts [4].

For building applications (wall board, paint, insulation, tiles, flooring, roofing) PCM should have a melting point just over the room temperature, so under normal circumstances it will be retained in a solid state.

When the temperature rises, the wax melts and the PCM absorbs heat. When the temperature drops, the wax solidifies, and heat is emitted. During the phase change, the temperature remains constant. PCMs can be integrated invisibly into the most diverse of construction materials, thus lending them their impressive properties.

2. Simulation of PCMs in buildings

The main objective of this study is the integration of PCMs in building elements, in order to check improvements in their thermal performance achieving high energy savings in cooling and heating power. This is achieved by using an energy simulation tool for buildings. New type of buildings with adequate thermal mass and insulation, and prefabricates buildings are simulated and studied. Active air-conditioning (heating-cooling) was also taken into account during the simulations. PCMs used in the simulations are materials commercially available.

There are various commercial programs for the thermal simulation of buildings: EnergyPlus, TRNSYS, ESP-r, B-SIM, CLIM2000, and several others. Some studies realized with these software tools, outline the three first ones for their versatility and reliability. However, are missing modules allowing direct simulation of the effect of adding a PCM in a building wall [6].

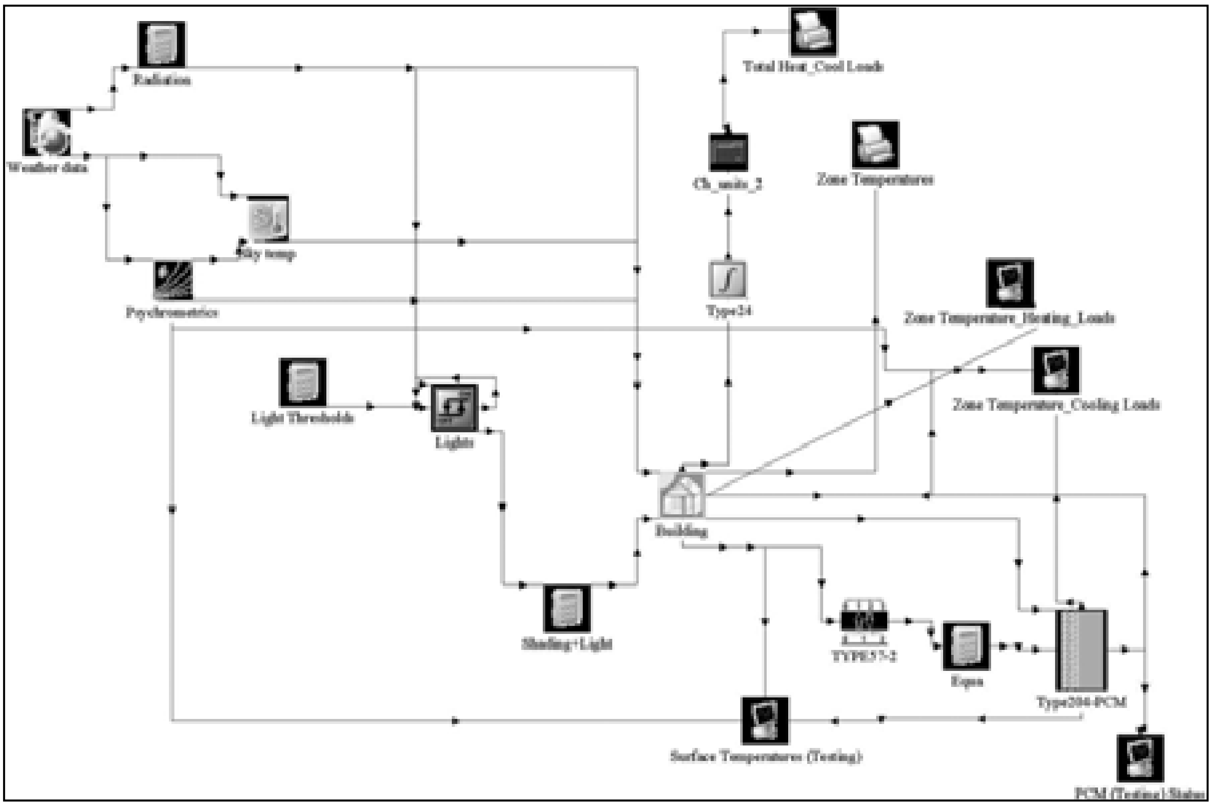

Fig. 1. Layout of the simulation

"Type 204", simulates the real process of heat flow in the PCM. The heat transfer equations are solved in three dimensions for various situations while the PCM is simulated using the effective heat capacity method [7]. The model was modified to operate in the TRNSYS 16.1 environment and validated with experimental data [8]. "Type 204", was chosen for the purposes of this study as it has been verified with experimental data. The schematic layout of the simulation is presented in the flow chart (Fig. 1).

To develop a realistic model of a construction the Renewable and Sustainable Energy Systems laboratory (6x10x3m) was used. Future objective of this work is to integrate real PCM wallboards in this construction in order to validate our results (Fig. 2).

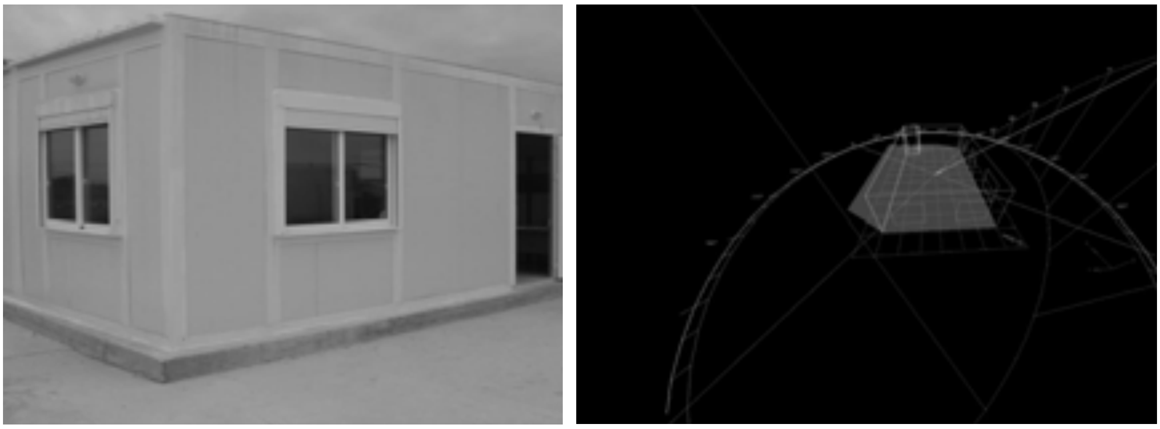

Fig. 2. Renewable and Sustainable Energy Systems laboratory, Technical University of Crete

The model building was created using the building multizone simulation of TRNSYS Type 56, which consists of two zones with identical characteristics in terms of structure, orientation and functional features. The only difference is that the second zone is used to integrate PCM.

In both zones a heating and cooling system was taken into account so that the temperature could be maintained between 20°C (below which the heating system is activated) and 26°C (above which the cooling system is activated).

This temperature range is to ensure thermal comfort for building users. The load (cooling or heating) required for the two areas depends mainly on the following parameters:

- ambient temperature
- direct and indirect solar radiation absorbed by the structure of the building
- total loads generated within each area by users and appliances
- type of construction (insulation, thermal mass, etc.).

2.1 Prefabricated buildings

Prefabricated buildings are constructions with a very low thermal mass; however, they are often used in Greece because of their low cost and the ease and speed of implementation.

The absence of appreciable thermal mass can lead to large temperature fluctuations resulting in a lack of thermal comfort conditions. Thermal comfort conditions can be achieved by mechanical air conditioning systems but the energy consumption cost is very high. It is therefore important to explore methods to achieve energy saving in such constructions.

The material used, for the first set of simulations was Micronal PCM SmartBoard™ 23/26 a plasterboard (2.0x1.25x0.015 m) which contains 3kg/m^2 PCM (26% w/w) with a latent heat capacity of 330kJ/m^2. The melting temperature range is 23-26 °C. [5]

In order to check the results with another commercially available insulation system [9] a third zone was added in the model with the following characteristics:

- extra roof tile (5 cm, tile adhesive material 2 cm) for the ceiling
- extra boards of extruded polystyrene (5 cm, tile adhesive material 2 cm) and plaster for the outwalls.

The results of the simulations are presented in figures 3 and 4.

Table 1. Construction features (prefabricated buildings)

	Zone 1	**Zone 2 (Construction with PCM)**
Walls /ceiling	galvanized steel sheet 1.5 cm	galvanized steel sheet 1.5 cm
	insulation (polyurethane foam) 4 cm	insulation (polyurethane foam) 4 cm
	galvanized steel sheet 1.5 cm	galvanized steel sheet 1.5 cm
	-	wall board with PCM 3 cm
Floor	floor tile 5 mm	floor tile 5 mm
	tile adhesive material 5 mm	tile adhesive material 5 mm
	concrete 24 cm	concrete 24 cm
	concrete 10 cm	concrete 10 cm
Heating / Cooling	ON	ON
Internal Gains	office (*)	office (*)
	Gains	Hours/day
*Office	occupants: 3 (light work)	09:00 – 20:00
	lightening: (20% convective heat- 10W/m^2)	18:00 – 20:00
	number of PCs: 3	09:00 – 20:00

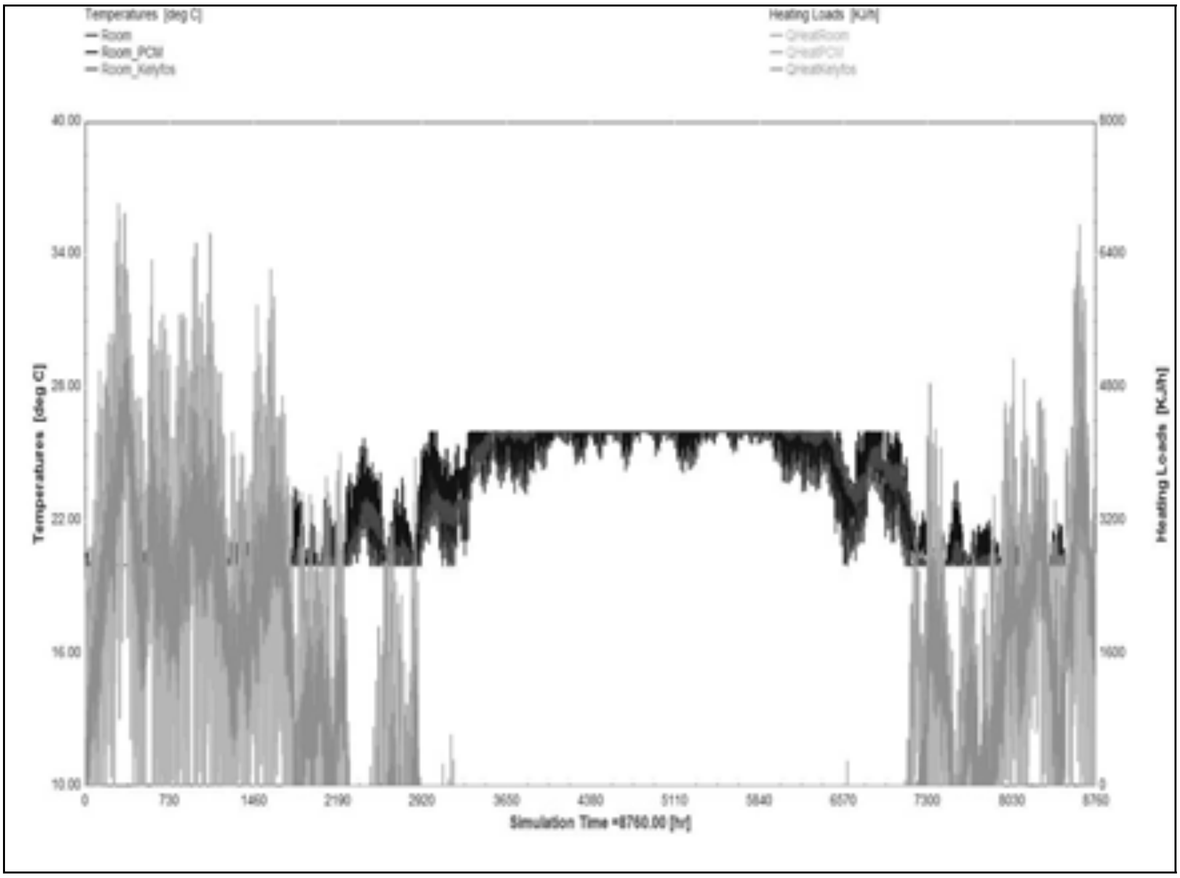

Fig. 3. Indoor temperature change in three zones- cooling and heating system enabled, interior heating loads required

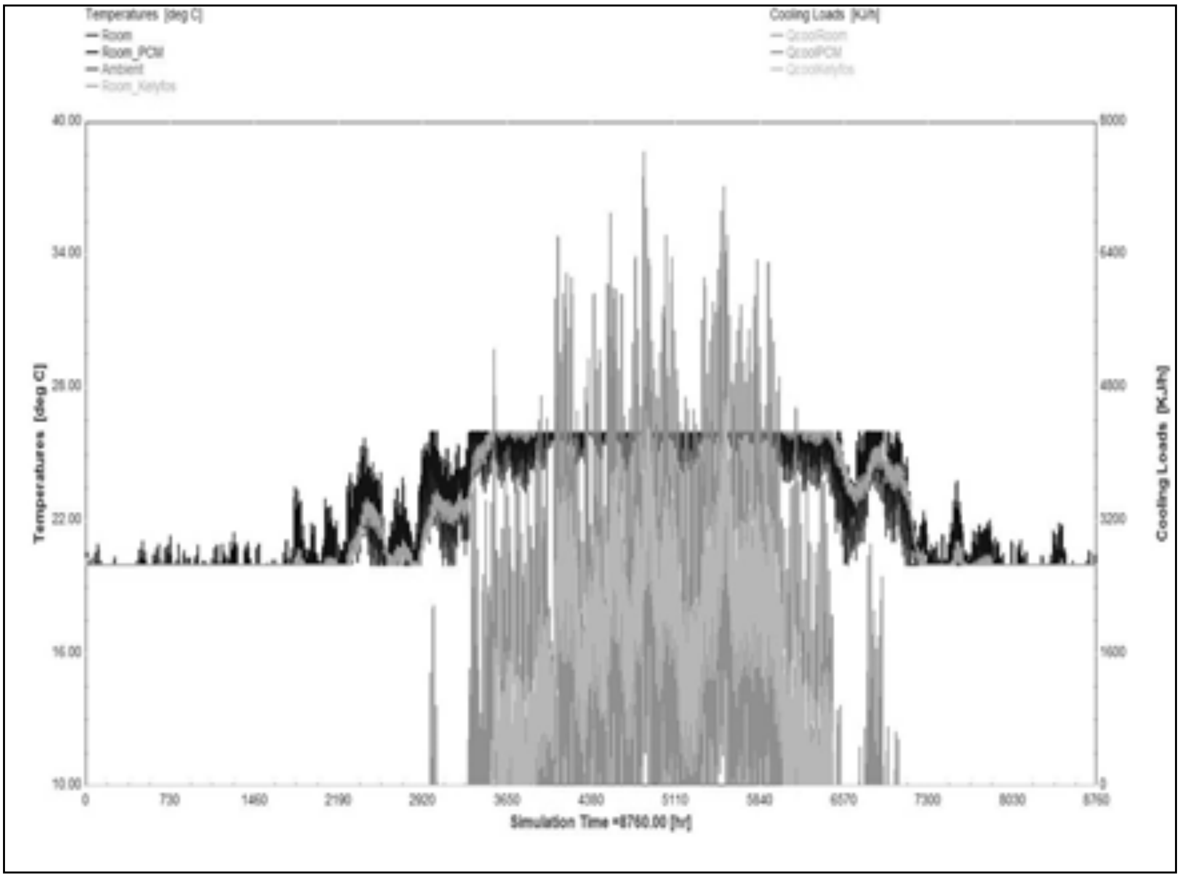

Fig. 4. Indoor temperature change in three zones- cooling and heating system enabled, interior cooling loads required

The integration of PCM wallboards resulted in a significant reduction in the heating energy required. This reduction (53%) can be achieved in a conventional, fully insulated construction. The construction with the PCM seems to be marginally more effective (2.3%) than the Kelyfos system.

Yet it is completely different in the case of the required cooling loads, as the integration of PCM does not improve the efficiency of the building and the best performance is achieved by the construction with the Kelyfos system.

However, applying night ventilation in the room with the PCM wallboards, can reduce the required cooling loads by 8.3%. Ventilation forces the PCM to discharge at least partially, and allows it to store part of the next day's cooling load. The reduction is than comparable to the one achieved with the Kelyfos system (8.9%).

2.2 Modern design buildings

Two simple modern design buildings were also simulated. The construction characteristics of the two zones are presented in Table 2. The two zones are identical with the only difference being the replacement of the internal plaster with a special plaster containing PCM (20% w/w). The material is a microencapsulated PCM called Maxit Clima (BASF) with a melting point of 26ºC, and a thermal capacity of 18 kJ/kg in the temperature range 23-26 ^{o}C. [5]

The thickness of the plaster with PCM layer, was initially considered equal to the conventional internal plaster replaced (1.5 cm).

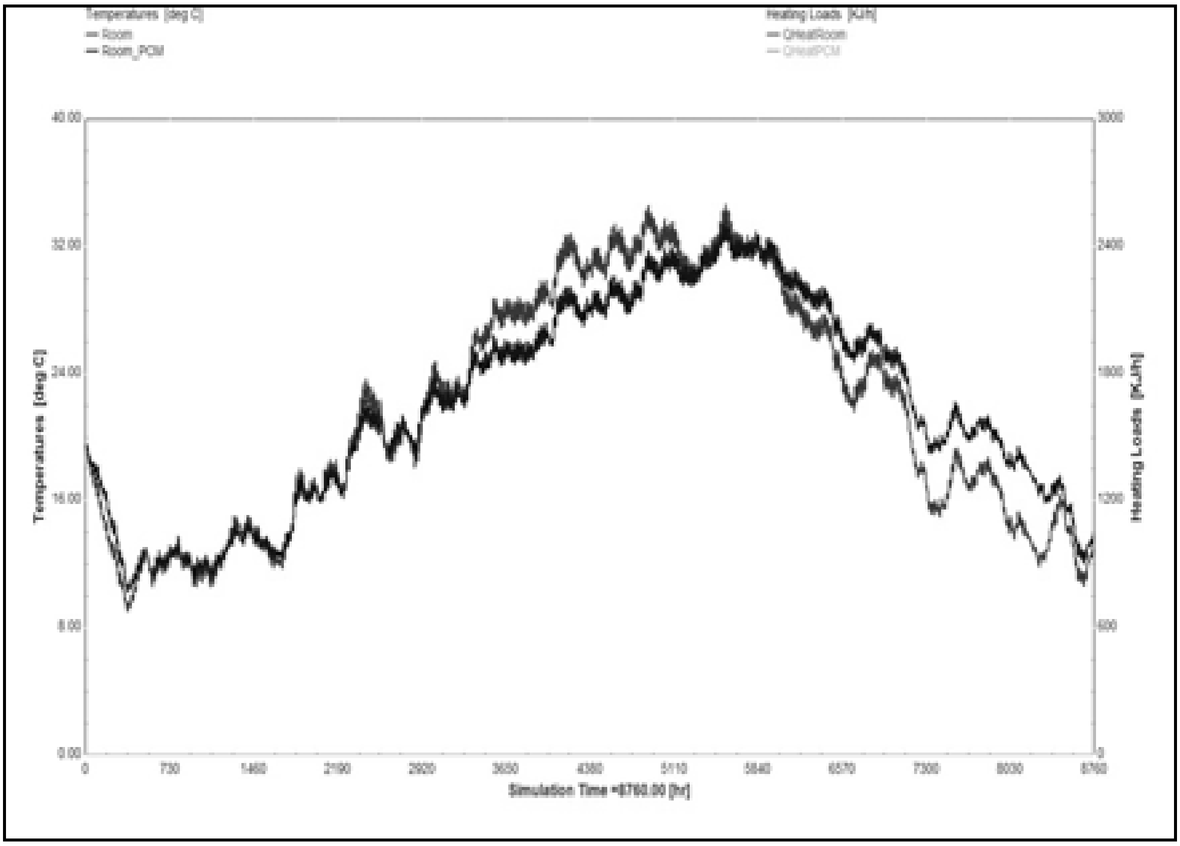

Fig. 5. Indoor air temperature change in 2 zones

Figure 5 presents the air temperature change in both zones with no internal gains and the cooling/heating system is off.

Table 2. Construction features (modern design buildings)

	Zone 1	Zone 2 (Construction with PCM)
Walls	plaster 1.5cm	plaster 1.5cm
	Insulation 10cm	insulation 10cm
	brick 24cm	brick 24cm
	conventional plaster 3.0cm	Plaster Maxit Clima 3.0 cm
Ceiling	insulation 10 cm	insulation 10 cm
	concrete 24cm	concrete 24cm
	plaster 3 cm	plaster Maxit Clima 3 cm
Floor	floor tile 5mm	floor tile 5mm
	tile adhesive material 5mm	tile adhesive material 5mm
	concrete 24 cm	concrete 24 cm
	insulation 10 cm	insulation 10 cm
Internal Gains	office (*)	office(*)
	Gains	Hours/day
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The influence of the PCM is considerable as it minimizes the decrease of the temperature during winter and the increase during summer. Zone 2 delays to reach the maximum temperature during summer. It is however clear that only the inclusion of the PCM is not sufficient to achieve thermal comfort conditions for users, as the temperature exceeds 32°C in summer and falls to 10°C during winter in both zones.

When using active air conditioning the reduction of the cooling and heating load is 12% and 25% respectively in the PCM zone (zone 2). Furthermore, a significant reduction in the required installed heating and cooling system capacity (12.5% and 4% respectively) is observed.

To study the effect of the thickness of the layer "plaster with PCM" in the required heating and cooling load the simulations were repeated for a layer equal to 2, 3, 4, 5, 6.5 and 7.5 cm. Table 3 summarizes the results of simulations for all the above layers.

Table 3. The effect of the thickness of the plaster-PCM layer to the heating and cooling loads

Plaster -PCM layer (cm)	Required Loads (% reduction)		System Dimensioning (%reduction)	
	Change in Heating Loads	Change in Cooling Loads	Heating System	Cooling System
1.5	24.8	11.9	12.5	4.0
2.0	29.2	17.7	18.0	4.1
3.0	47.3	21.8	24.9	4.2
4.0	47.4	35.4	24.9	4.2
5.0	47.5	42.7	25.0	4.2
6.5	47.9	59.6	25.1	4.3
7.5	48.1	63.2	25.1	4.3

Regarding the required heating loads, adding extra layers of PCM does not improve substantially the performance of the building. When the plaster-PCM layer is doubled (3.0 to 6.5cm) the required heating load is reduced by 0.6%.

As for the required cooling loads, adding PCM prevents the temperature of the building to exceed 26°C. However, since the PCM is charged, high temperature prevent its discharge and as a result the improvement observed is negligible.

The simulation was then repeated for 3 cm plaster with PCM but internal gains (office) were added this time. The results are summarized in table 4.

Table 4. Reduction (% of the initial) of the required loads

Plaster-PCM layer	Reduction (% of the initial) of the required heating loads	Reduction (% of the initial) of the required cooling loads
	Office	Office
3.0 cm	62.9 (31.9)	0.7 (0.3)

Zone 2 responds significantly better during winter and autumn. The required energy for heating is greatly reduced due to the internal gains.

Just the inclusion of PCM in plaster does not seem to have the expected results, as the PCM is charged very quickly and the gains in the overall energy demand and the dimensioning of the cooling system appear negligible improvement. Moreover, the plaster-PCM layer, increases the cooling needs during autumn and the interior temperature of the construction cannot remain in the thermal comfort conditions for users.

In order to improve the efficiency of the PCM, concerning the cooling loads, night ventilation can be used during night. This method depends on the climatic characteristics of the studied area. Table

5 summarizes several of the results when using a layer of plaster - PCM 3.0 and 6.0 cm and night ventilation. The reduction (% of the initial) of the required cooling loads using a plaster - PCM layer of 3.0 and 6.0 cm and night ventilation was 15.5 (2.8) and 19.6 (3.1) respectively.

3. Conclusions

Integrating the appropriate PCM in different construction elements can improve the energy efficiency of a building providing a more comfortable environment for the occupants.

The inclusion of PCM in buildings with very low thermal mass through plasterboard can improve their energy efficiency, in terms of heating energy. However in order to downsize the cooling system the use of PCM elements (plaster/wallboards) must be coupled with a low energy mechanical night ventilation system.

Regarding modern building constructions thermal improvement approaches 62%, of the initially required heating energy while a 32% decrease in the heating system sizing, can be achieved.

However, the required cooling energy appears negligible improvement with the integration of PCMs. The use of night ventilation can reduce, by almost 16% the energy cooling load and at the same time downsize the cooling system about 3%.

Aknowledgements

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