PERFORMANCE OF PASSIVE APPLICATION OF PCM IN SPAIN

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ABSTRACT

Contemporary construction systems tend to be thinner, lighter and better insulated than ever, but usually lack thermal mass. In order to improve the indoor temperature and reduce the energy consumption in the lightweight building it is necessary to add thermal energy storage capacity to the construction elements.

Phase change materials (PCM) have high a heat of fusion so they can absorb a lot of thermal energy before melting or solidifying without adding physical mass. The stored energy can be released later when it is necessary.

The main purpose of this study is to quantify the effectiveness of PCMs as interior temperature stabilizers in the Spanish construction. Another goal was to identify the influence of the windows sizes and their shading factor in a PCM´s passive application, and find out the most convenient combinations.

A comparative study has been made, simulating a Test Room, with and without PCM, to predict the annual interior temperature behavior in each case. The thermal performance of the test rooms was evaluated on an hour to hour basis, in several Spanish climate zones with diverse combinations of facade glazing ratio and window shadow factors (Fs).

The results indicate that the addition of PCM to building partitions help to maintain the interior thermal comfort, reducing the high and low temperature peaks in all Spanish climates studied. The PCM thermal stabilizing capacity is more noticeable in summer. However, the Test Room in the warmer climate falls behind in the overall results.

The PCM passive application has demonstrated to help to maintain a uniform interior temperature and to save energy, but its use is not a cost effective solution for all the cases in the study. This study helps to identify when, and where, the use of this PCM application should be more appropriate.

1. Introduction

Since the capacity of some materials to store thermal energy in a latent form was discovered, its application in buildings began to be investigated. M. Telkes had already begun his research in the 1930´s to store solar heat in PCM and use it to heat interior spaces [5]. Although since that date, at different points, some research on the incorporation of PCM in buildings were carried out, but technical limitations, failed attempts and cheap combustible fuel, held back its development.

Nowadays, people´s comfort standards have greatly increased, and have had to be satisfied, without stopping to think about the consequences. Our overuse of fossil fuels and degradation of the environment have reached unsustainable levels. It is necessary to find ways to cater to people´s thermal comfort and support the development of society, consuming minimum traditional energy and preserving the environment.

Renewable sources can satisfy the major part of a building´s needs, the problem is that they are not always available when we need them. Thermal Energy Storage (TES), offers us a solution to this reality and enables us to maximize the energy available.

Thermal Energy Storage is nothing new, vernacular architecture already used this strategy. Thick stone or brick walls in old buildings serve as a thermal battery that stores heat or cold. This type of accumulation is known as latent heat, as the material receives and store heat, its temperature rises. Building store capacity was related with its thermal mass.

However, we no longer build with such heavy elements. Materials tend to be increasingly thin and light. Construction systems are evolving towards lightweight constructions with an adequate level of insulation, but low thermal mass.

The problem is complex, on one hand, the availability of thermal energy doesn´t necessarily coincide with the moment when it´s needed, new construction systems lack thermal mass, the demands of thermal comfort are higher and we should reduce energy consumption caused by HVAC systems. To find a solution to this situation, “Phase Changing Materials” are being reconsidered. Recent research has given new ways to incorporate them in construction materials and innovative active and passive applications.

PCMs have a high capacity for thermal storage, and differing from traditional materials, they maintain their temperature at melting point, in other words, they accumulate and dissipate heat at a constant temperature. The wide availability of these materials, their light weight, and thermal storage potential makes them ideal for integration in new constructions, as well as rehabilitations.

This study brings up the need to construct buildings of higher quality in Spain, using innovative construction systems (lightweight, off-site construction, etc.), that maintain the interior temperature in the range of thermal comfort and that are highly energy efficient.

2. Description of the study

The study focused on testing the efficiency of the application of passive PCMs in different climatic zones in Spain, starting out with the premise that the high thermal storage capacity in gypsum board with PCM with microencapsulation would help to control the interior temperature of the study space and reduce temperature peaks, improving thermal balance.

A passive system was chosen as it doesn´t require any additional energy, it´s the simplest method of application, and according to research carried out up to now, the most cost-effective and environmentally sound means of using PCM [3].

A comparative study was carried out using dynamic energy simulations of all the possible combinations of study variables. For each simulation two cell studies were always used, the “Reference Cell” without PCM and the “Cell Test” with PCM incorporated, in order to verify the benefits, if any, of the incorporation of phase change materials.

The key issues for improving the interior thermal conditions by means of PCM that were analyzed are:

- Reduction of peak temperature
- Reduction of temperature swing
- Reduction of hours with temperature out of the comfort zone (21º a 26º C)

2.1. Selected PCM

The study was carried out using gypsum board with PCM with micro encapsulation, see fig. 1. It was the first construction material with PCM introduced in the Spanish market although its use is not very wide spread. The ease of installation, the same as traditional panels, and the possibility of passive use were also key in its selection.

The gypsum board microencapsulation use paraffin as phase changing material. When the temperature rises, the paraffin inside the microscopically small plastic spheres begins to melt, and as it changes phase it absorbs and accumulates a great amount of heat. When the temperature drops, the paraffin begins to solidify and emit heat as it changes phase. During the change from solid to liquid or vice versa, the temperature remains constant. Their physical and thermal properties are reflected at the end of Table 1.

Figure 1. Micronal PCM microencapsulate system and PCM SmartBoard panels (Source: BASF)

2.2. Object of experimentation

As object of study, spaces corresponding to the living-dining room or the master bedroom of a house in a multifamily building were chosen (see fig. 2). The study cells correspond to spaces with one side in contact with the outside environment facing south and the other five are related in adiabatic form to the interior of the building. The study cells were placed with their long axis east-west. See detailed study cells information at Table 1.

The Reference Cell and the Cell Test are identical, differentiated only as the Experimentation one has plasterboard with PCM in the ceiling and on the inside of the partitions to the east, north and west, see fig. 2. It was decided not to place PCM on the inside of the southern wall, because this wall surface varies since the size of the window is one of the study variables, and this variation impedes making an effective correlation of the results.

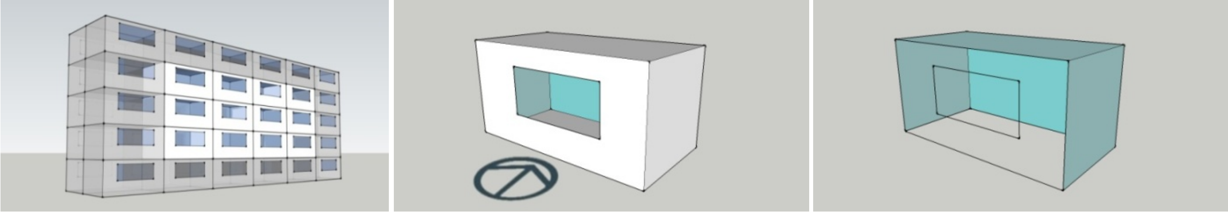


Figure 2. Multiple Dwelling Unit. Reference and Cell Test proportions and orientation. PCM location

The study constants are related to the study cells, their dimensions (3mx5mx3m), use (housing), orientation (east-west with glazing to the south) and the area of gypsum panels with PCM (51 m^2).

Table 1. Cell Details

GENERAL DATA			Use	Living
	Length	6 m	Furniture	Normal
	Width	3 m	Orientation	Exterior wall south facing
	Height	3 m	Internal load	20 w/m^2
	Floor Area	18 m^2	Free ventilation	0,8 l/h
	Volume	54 m^3	Natural ventilation with windows possible	
CEILING (18 m^2)	Construction	Material	Thickness (mm)	Thermal Conductivity (W/mK)
		Plasterboard Panel*	12.5	0,25
		Air Layer	150	0.28
		Concrete Slab	250	1.6
		Insulation PU	20	0.025
		Cement floating screed	30	1.6
	Situation	Interior (Adiabatic)		
SOUTH WALL (18 m^2)	Construction	Material	Thickness (mm)	Thermal Conductivity (W/mK)
		Pressed Chipboard Panel	16	0.11
		Glass Wool	160	0.038
		OSB	15	0.13
		Mineral Fiber	50	0.04
		External Finish	10	0.8
	Window	Thermal Insulated Double Glass G-value = 62 Glass/Frame Ratio = 70		1.2
	Situation	External Wall (to outside air)		
WEST, NORTH and EAST PARTITIONS (9m^2, 18 m^2, 9 m^2)	Construction	Material	Thickness (mm)	Thermal Conductivity (W/mK)
		Plasterboard Panel	12.5	0.25
		Mineral Fiber	75	0.04
		Plasterboard Panel	12.5	0.25
	Situation	Interior (Adiabatic)		
FLOOR (18 m^2)	Construction	Material	Thickness (mm)	Thermal Conductivity (W/mK)
		Cement floating screed	30	1.6
		Insulation PU	20	0.025
		Concrete Slab	250	1.6
		Air Layer	150	0.28
		Plasterboard Panel	12.5	0,25
	Situation	Interior (Adiabatic)		
PCM	Construction	Material	Thickness (mm)	Thermal Conductivity (W/mK)
		PCM SmartBoard 26 Panel	15	0.196
		Operating temperature 26°C		
		Latent heat capacity ΔH: ca.330 kJ/m²		
		Spez. heat capacity: ca.1.20 kJ/kgK		
		Heat conductivity: ca. 0.134 W/mK		

* Substituted by Micronal PCM SmartBoard Panel in the PCM Cell Test.

Another factor chosen as a constant is the possibility of ventilation via the windows. In passive systems with PCM, the ventilation is very important for the optimal working of the system. In summer it´s essential to have night ventilation so that the system can let out the heat accumulated during the day.

2.3. Study variables

Taking the study of the influence of PCMs in housing in Spanish climates as a study objective, the first study variable is the different climatic zones found in Spain. The process to determine this variable is explained in the following section, in this the variables related to the study cells was explained.

In passive systems, such as the one evaluated in this study, the main source of heat is the direct radiation that comes in through the windows, for this, two additional variables were identified: the glazing percentage of the façade and the shadow factor (Fs) of the windows. This helped to identify the influence of these variables on the thermal performance of the study cells.

Glazing percentage: each of the combinations were analyzed taking into account three different glazing percentages, 20%, 40%, 60%. The maximum glazing percentage for houses found in the “Spanish Building Code” CTE is 60%.

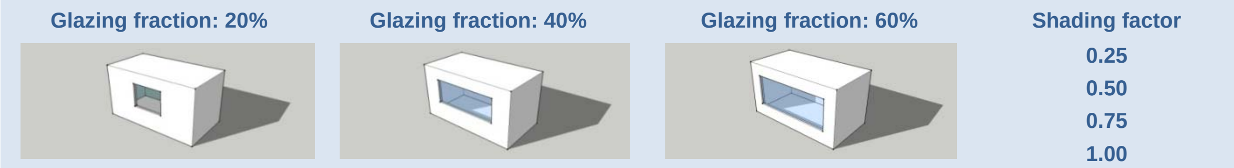


Figure 3. Variables: Window area and Shadow Factor

Shadow factor (Fs): quantifies the fraction of radiation incident in **a** window that´s not shading. Each combination was analyzed using four different shadow factors: Fs=0.25, Fs=0.50, Fs=0.75, Fs=1.00. Shadow factor 1.0, is equivalent to a window with no shading, on the other hand, a window is complete shading when its shadow factor is 0.

2.4. Variable: Climatic Zones

To choose this variable, different climate classifications in Spain and the division of territory by climates found in the “Spanish Building Code” CTE were studied.

The climate in peninsular Spain is predominantly Mediterranean, its location latitudes North 36º and 46º, occupying the western part of continental Europe, contribute to the definition of its climate. Northerly winds opening onto the Atlantic Ocean give the northwest zone a differential maritime climate. Relief and altitude make some zones enjoy a cold mountain climate. In some peninsular zones, such as areas of Murcia and Almeria, dry subtropical zones can be found. Outside of the peninsular, in the Canary Islands the climate is subtropical with dry humid areas.

In the Spanish Building Code CTE, 12 climatic zones are defined according to winter climate severity, identified with a letter, and summer climate severity represented by numbers (see fig. 4).

Climate severity is defined by degree day and solar radiation, the idea is that when two locations have the same winter climate severity (WCS) the energy heating demand in two identical buildings is approximately the same. The same concept also applies to summer climate severity (SCS).

Winter Climate severity		Summer Climatic Severity	
A	WCS ≤0,3	1	SCS ≤0,6
B	0,3 <WCS≤0,6	2	0,6 <SCS ≤0,9
C	0,6 <WCS≤0,95	3	0,9 <SCS ≤1,25
D	0,95 <WCS ≤1,3	4	SCS>1,25
E	WCS>1,3		

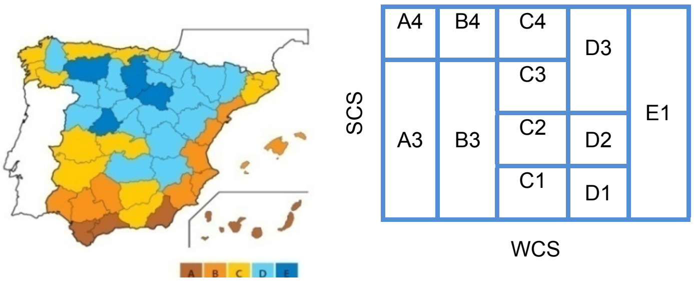


Figure 4. Spanish Building Code Climatic Classification

Taking the study of climatic conditions predominately in peninsular Spain into account, and according to the Spanish Building Code CTE climatic classification, four climatic zones were chosen, represented by the following study cities: Bilbao, Madrid, Seville and Soria.

Table 2. Selected cities of study

ID Code	City	Climatic Zone	Spain Building Code (CTE)	Altitude
BI	Bilbao	Humid Marine Climate (Atlantic)	C1	214
MA	Madrid	Continental Climate	D3	589
SE	Seville	Mediterranean Warm Climate	B4	9
SO	Soria	Mountain Climate (Cold)	E1	984

2.5. Simulation program

The simulations were carried out using PCM-AKTIV (PCMexpress). This is a simulation program was developed in the “Development of a user-friendly planning and simulation program” within the project framework “PCM Thermal Storage Active Systems in Buildings”.

The mathematical models and algorithms of the Project were developed by the Fraunhofer Institute of Solar Energy Systems (ISE) in Freiburg, Germany, with the support of the industrial sector and the Federal Ministry of Economy and Technology (BMWi) and its interface was designed by Valentin Energiesoftware.

2.6. Simulations

The thermal performance of the reference cells was simulated and those of experimentation in dynamic regime hour by hour. This process was repeated with each of the possible combinations of variables established in the study. From the results, daily and annual charts were generated with the evolution of the interior temperature of the reference cells and cell test (see fig. 5).

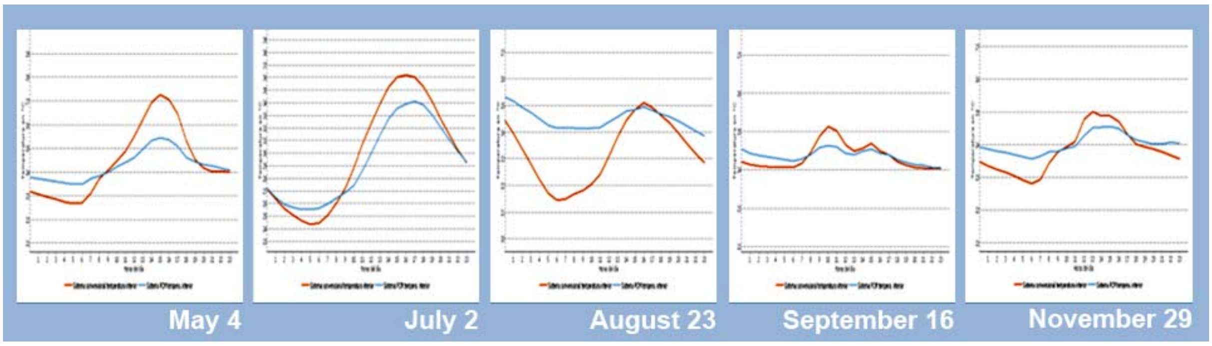


Figure 5. Example of Daily Charts. MA2025 (Madrid, 20% glazing, Fs= 0.25)

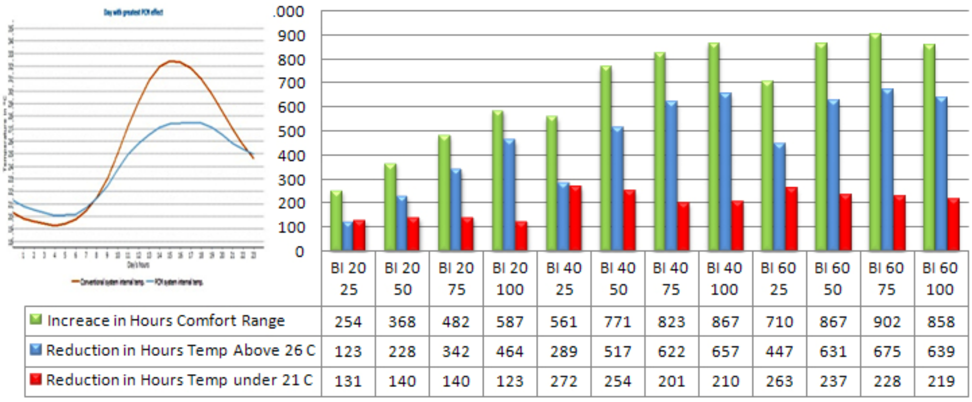
3. Results and Discussion

All the information generated by the simulations (data, results and charts) were organized in charts in order to make the data analysis easier and more effective. In addition, the following code system was used: two letters (cities), two numbers (glazing percentage) and two or three numbers (shadow factor), e.g. “MA 20 25”, refers to a cell study located in Madrid, with 20% glazing and a shadow factor of 0.25. See cities codes in Table 2.

Treating this as a study of multiple variables, the results were analyzed from very different angles. Each of the variables was studied as isolated elements and as a combination with others, which has produced a large amount of elements of analysis. The results obtained show a lot of information referring to the influence of window size and shadow factors as passive elements to achieve interior comfort, however, this report focus on the key issues related to the improvement of interior thermal conditions as a result of the incorporation of PCM in the study cells.

Bilbao (Humid Marine Climate): In the BI6025 cell with PCM the highest percentage of hours in the range of thermal comfort was achieved, 93.4%. However, the BI6075 cell with PCM is where the highest increase in comfort hours is achieved with 902 hours, reducing the hours above 26ºC by 41% and the hours under 21ºC by 51%. On analyzing all the possible combinations, we found the average annual decline in comfort hours over 26ºC due to the use of PCM is 499 hours, 675 hours being the largest reduction. In the cells with PCM reductions in temperature peaks were achieved up to 5ºC and on some days in July, the temperature swing was reduced from 13º to 7ºC (see fig. 6).

CODE	% Hours Comfort
BI 20 25	90.1
BI 20 50	91.3
BI 20 75	91.8
BI 20 100	91.6
BI 40 25	92.4
BI 40 50	92.5
BI 40 75	90.6
BI 40 100	87.8
BI 60 25	93.4
BI 60 50	91.2
BI 60 75	86.5
BI 60 100	82.2

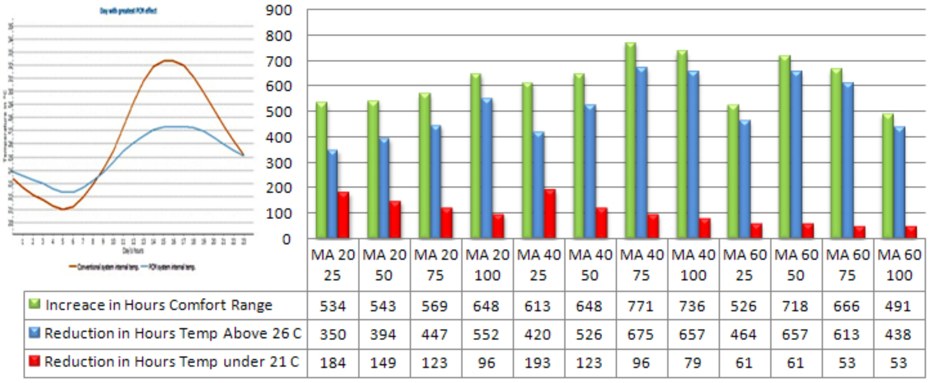


	BI 20 25	BI 20 50	BI 20 75	BI 20 100	BI 40 25	BI 40 50	BI 40 75	BI 40 100	BI 60 25	BI 60 50	BI 60 75	BI 60 100
🟩 Increace in Hours Comfort Range	254	368	482	587	561	771	823	867	710	867	902	858
🟦 Reduction in Hours Temp Above 26 C	123	228	342	464	289	517	622	657	447	631	675	639
🟥 Reduction in Hours Temp under 21 C	131	140	140	123	272	254	201	210	263	237	228	219

Figure 6. Bilbao with PCM Annual Results and BI40100 chart of interior temperatures on July 12.

Madrid (Continental Climate): In the MA2025 cell with PCM, the highest percentage of hours in the thermal comfort range was achieved, 92%. However, the MA4075 cell with PCM is where the highest increase in comfort hours is achieved with 771 hours, reducing the hours above 26º by 32% and hours below 21º by 44%. On analyzing all the possible combinations, we found the average annual decline in comfort hours over 26ºC due to the use of PCM is 516 hours, 675 hours being the largest reduction. In the cells with PCM, reductions in temperature peaks were achieved up to 4.5ºC and on some days in July, the temperature swing was reduced from 11.5º to 6ºC (see fig. 7).

CODE	% Hours Comfort
MA 20 25	**92.0**
MA 20 50	91.0
MA 20 75	89.4
MA20100	87.4
MA 40 25	89.9
MA 40 50	86.6
MA 40 75	82.4
MA40100	76.9
MA 60 25	88.6
MA 60 50	82.7
MA 60 75	74.3
MA60100	67.0

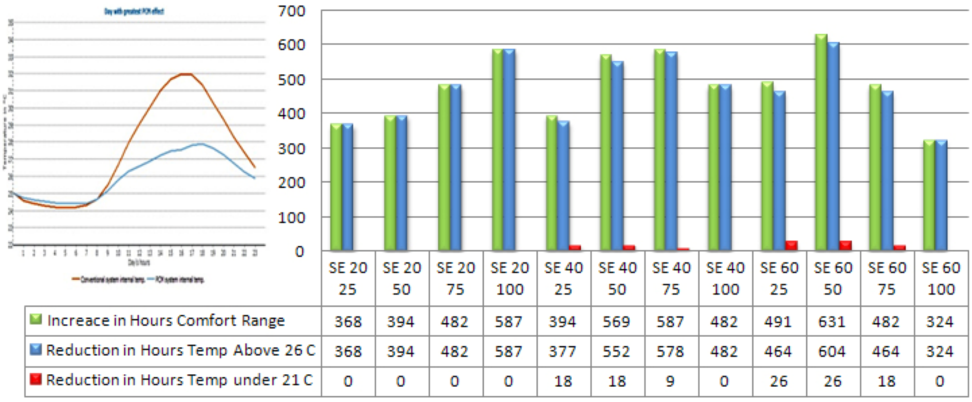


	MA 20 25	MA 20 50	MA 20 75	MA 20 100	MA 40 25	MA 40 50	MA 40 75	MA 40 100	MA 60 25	MA 60 50	MA 60 75	MA 60 100
🟩 Increace in Hours Comfort Range	534	543	569	648	613	648	771	736	526	718	666	491
🟦 Reduction in Hours Temp Above 26 C	350	394	447	552	420	526	675	657	464	657	613	438
🟥 Reduction in Hours Temp under 21 C	184	149	123	96	193	123	96	79	61	61	53	53

Figure 7. Madrid with PCM Annual Results and MA4075 chart of interior temperatures on June 14.

Seville (Mediterranean Climate): In the SE2025 cell with PCM, the highest percentage of hours in the thermal comfort range was achieved, 76.5%. However, the SE6050 cell with PCM is where the highest increase in comfort hours is achieved with 631 hours, reducing the hours above 26º by 16º and without any hours below 21º. On analyzing all the possible combinations, we found the average annual decline in comfort hours over 26ºC due to the use of PCM is 473 hours, 604 hours being the largest reduction. In the cells with PCM, reductions in temperature peaks were achieved up to 4.5ºC and on some days in July, the temperature swing was reduced from 7.75º to 3.25ºC (see fig. 8).

CODE	% Hours Comfort
SE 20 25	**76.5**
SE 20 50	73.7
SE 20 75	71.2
SE 20 100	68.8
SE 40 25	72.6
SE 40 50	68.1
SE 40 75	62.9
SE 40 100	57.5
SE 60 25	69.7
SE 60 50	62.7
SE 60 75	55.0
SE 60 100	49.1

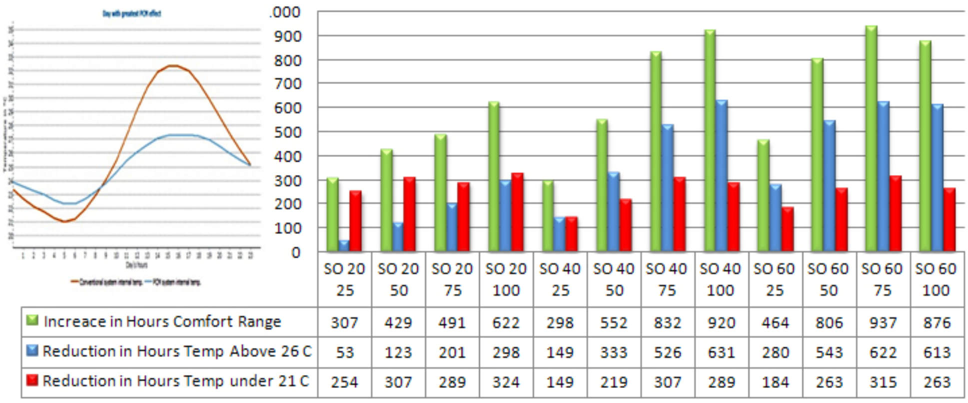


	SE 20 25	SE 20 50	SE 20 75	SE 20 100	SE 40 25	SE 40 50	SE 40 75	SE 40 100	SE 60 25	SE 60 50	SE 60 75	SE 60 100
🟩 Increace in Hours Comfort Range	368	394	482	587	394	569	587	482	491	631	482	324
🟦 Reduction in Hours Temp Above 26 C	368	394	482	587	377	552	578	482	464	604	464	324
🟥 Reduction in Hours Temp under 21 C	0	0	0	0	18	18	9	0	26	26	18	0

Figure 8. Seville with PCM Annual Results and SE20100 chart of interior temperatures on May 31.

Soria (Mountain Climate): In the SO6050 cell with PCM, the highest percentage of hours in the thermal comfort range was achieved, 92.4%. However, the SO6075 cell with PCM is where the highest increase in comfort hours is achieved with 937 hours, reducing the hours above 26º by 50% and the hours below 21º by 54%. On analyzing all the possible combinations, we found the average annual decline in comfort hours over 26ºC due to the use of PCM is 473 hours, 631 hours being the largest reduction. In the cells with PCM, reductions in high temperature peaks were achieved up to 4ºC and up to 2% in low peaks. On some days in July, the temperature swing was reduced from 12º to 6ºC (see fig. 9).

CODE	% Hours Comfort
SO 20 25	83.1
SO 20 50	86.3
SO 20 75	88.1
SO 20 100	89.4
SO 40 25	88.8
SO 40 50	91.1
SO 40 75	91.5
SO 40 100	90.0
SO 60 25	92.0
SO 60 50	**92.4**
SO 60 75	89.7
SO 60 100	85.2



	SO 20 25	SO 20 50	SO 20 75	SO 20 100	SO 40 25	SO 40 50	SO 40 75	SO 40 100	SO 60 25	SO 60 50	SO 60 75	SO 60 100
🟩 Increace in Hours Comfort Range	307	429	491	622	298	552	832	920	464	806	937	876
🟦 Reduction in Hours Temp Above 26 C	53	123	201	298	149	333	526	631	280	543	622	613
🟥 Reduction in Hours Temp under 21 C	254	307	289	324	149	219	307	289	184	263	315	263

Figure 9. Soria with PCM Annual Results and SO6075 chart of interior temperatures on July 9.

Although the maximum reduction in low temperature peaks in cells with PCM was generally lower than the reduction in high temperature peaks, in Soria, the average annual reduction in hours below 21° was 263, reaching 324 in SO20100. Similarly, a reduction of up to 272 hours was observed, and in Madrid a maximum of 192. In Seville, with a predominantly warm climate, the improvement is negligible.

4. Conclusions

The energy simulations corroborate that, in the studied conditions, the incorporation of PCM reduction of interior temperature fluctuations are achieved, increasing the thermal comfort and reducing the necessity for active systems, this is a reality found in all the cities studied.

The results reflect that PCMs increase the capacity for thermal storage in lightweight construction building in Spain. The cell tests in Bilbao obtained the highest average increase in annual comfort hours, followed by those in Soria and Madrid with similar results. The Madrid cells achieved the highest annual average in reduction of hours above 26ºC. Although the results show a PCM lower capacity for reduce the hours under 21°C, the important increase in annual comfort hours in Soria is partly due to the reduction of more than 260 hours per year below 21ºC. Although Seville showed a high average annual reduction in overheating, fall behind in the overall results.

The thermal comfort increased with the incorporation of plasterboard panels with PCM in the cell tests. The interior thermal conditions improved by means of the reduction in thermal peaks of up to 6ºC, the reduction in temperature swing of up to 60% and the increase of up to 1000 hours with temperatures within the comfort range in the period of a year.

The energy efficiency of passive systems with PCM has been tested in different climate zones in Spain by means of simulations. The results demonstrate the capacity of the system to reduce design loads and the daily consumption of active HVAC systems. The reduction in energy consumption related to interior HVAC translates into an economic saving for users and into fewer greenhouse gases emissions that have such an impact on the environment.

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