Thermal Storage Materials for Enhancing Indoor-Dwelling Temperature Conditions

Germán Ferreira, Ana M. López-Sabirón and Alfonso Aranda-Usón

Abstract The adequate impregnation of phase change materials (PCMs) into porous construction materials in a building can be significantly improved if technical and environmental aspects are evaluated. Sensible and latent heat storage using PCMs is well known technology governed by two principles Sensible Heat Storage (SHS) and Latent Heat Storage (LHS) but additional studies focused on the specific industrial applications considering its recent progress are required. One of the most recent progresses that have been achieved in this area is the large number of commercial PCMs available. This fact makes that the simple task of selecting the appropriate PCM considering technical and environmental aspects will not be evident. Large latent heat and high thermal conductivity, as well as, a melting temperature in the practical range of operation, low in cost, non-toxicant, non-corrosive and low environmental impacts are keys for choosing the suitable PCMs. In this chapter, an energy (ESP-r) and environmental (SIMAPRO) modelling study is carried out and presented for enhancing indoor-dwelling temperature conditions considering a real climate severity.

Keywords Phase change materials · Thermal storage · Energy modelling · ESP-r · Environmental modelling · Life cycle assessment

Nomenclature

CS	Climate severity
C_{ef}	Effective heat capacity
C_l	Liquid specific heat

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C_s	Solid specific heat
EM	Enthalpy method
EHCM	Effective Heat Capacity method
GHG	Greenhouse gas
HIM	Heat Integration method
HVAC	Heating, ventilating and air conditioning
L	Latent heat capacity
LCA	Life cycle assessment
LCI	Life cycle inventory
LHS	Latent heat storage
SHS	Sensible heat storage
PCM	Phase change material
$\vec{b}$	Volumetric forces
$\vec{n}$	Unitary vector perpendicular to the surface
$\vec{v}$	Velocity vector
$\vec{\sigma}$	External forces
$\dot{\vec{q}}$	Heat generation
S	Surface
t	Time
T_m	Melting Temperature
T_s	Solidification Temperature
V	Volume
ρ	Density

1 Introduction

Control of phase change heat transfer and temperature of natural and artificial porous media has received considerable attention in numerous technical processes due to its importance in latent heat energy storage and other applications. One of the most interesting promises is the impregnation of phase change materials (PCMs) into porous construction materials with the objective of increasing thermal mass and optimising the control of the indoor temperature to reduce energy consumption. This promise is particularly significant since the residential and tertiary building sector demands about 40 % of worldwide energy consumption [1, 2]. Therefore, this technology represents one of the existing routes for reducing the energy consumption during the use stage of a building, and consequently, its environmental impacts [3]. However, the performance of PCMs depends not only on the heating, ventilating and air conditioning (HVAC) system properties such as the efficiency [4] but also on the climate, building design, materials and envelope characteristics [5, 6, 7, 8] which have a strong influence on the electricity consumption to maintain the indoor temperature condition.

In this sense, the thermal storage approach can manage the energy exchanged with the surrounding contributing to downsize the HVAC equipment, reduce the energy demand and increase the indoor thermal comfort. Also, energy storage components improve the energy efficiency of the systems by reducing the mismatch between supply and demand [9]. As mentioned above, this approach can be achieved by using two principles: sensible heat storage (SHS) or latent heat storage (LHS). This later is based on the heat capacity content and a variation in the temperature of the material, and therefore, thermal energy is stored by raising the temperature of a solid or liquid. In contrast, in LHS systems, such as PCMs, the heat absorption or release is generated by a phase change process [10].

Some previous studies [10, 11] have demonstrated a better performance of the LHS compared to SHS since they can passively cool and heat a living area without including heavy mass or high extra space typically required by SHS systems. The main reason is found when the latent heat and the sensible heat exchanged are compared. Consequently, the integration of PCMs in building walls, ceiling or floor is a good method to enhance the storage capacity of building envelope considering the advantages of high-energy storage density and the isothermal nature of these LHS systems [12, 13]. These materials foster the thermal inertia of the construction elements leading to lower temperature peaks.

Nevertheless, selecting the appropriate PCM for the climate condition is essential to improve the heat transfer mechanism in the building since PCM performance is strongly influenced by the climate conditions as was reported by Aranda et al. [7]. It becomes even more complicated when the environmental impacts generated, due to the inclusion of PCMs in a building, must be considered for balancing them with those that can be obtained from the reduction of energy consumption and other benefits. To this end, the energy and environmental performance of these materials need to be evaluated following a whole methodology that allows obtaining results from both points of view as can be seen graphically in Fig. 1 and widely described in Sect. 2.

Therefore, this chapter is focused on modelling them using ESP-r to study the transport phenomena and SIMAPRO to evaluate midpoint environmental impact categories. This novel methodology shows how they can be integrated to improve industrial and technological applications of PCMs.

2 Methodology

2.1 PCMs Energy Modelling

The physical processes along a wall or in a room can be described from the governing equations of the fundamental principles of mass conservation, momentum and energy. Considering an arbitrary volume (V) in a region of space, bounded by a closed surface (S), the fundamental principles can be described by Eqs. (1), (2) and (3).

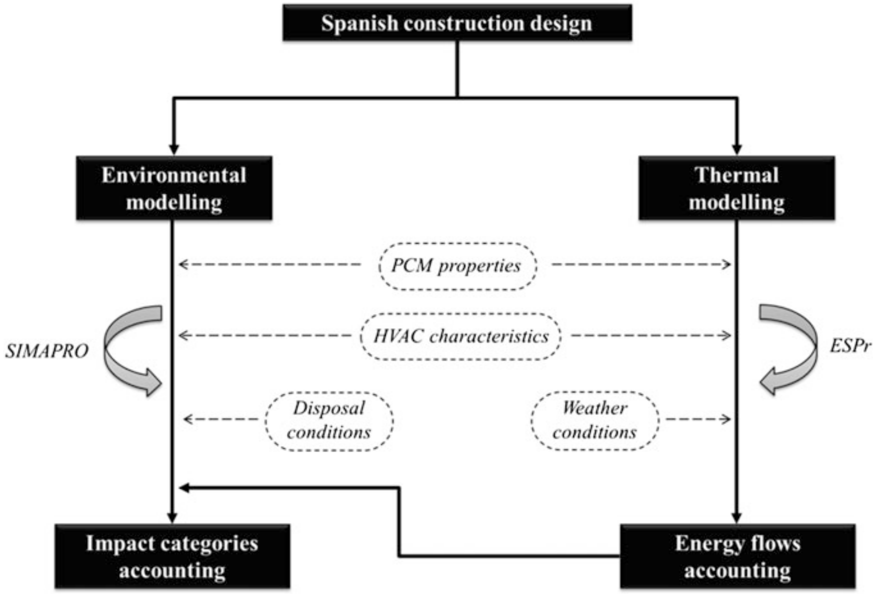

Fig. 1 Schematic description of the methodology used in this study

$$\frac{\partial}{\partial t}\int_{V}\rho dV+\int_{S}\rho\vec{v}\cdot\vec{n}dS=0 \tag{1}$$

$$\frac{\partial}{\partial \mathrm{t}}\int_{\mathrm{V}}\vec{v}\rho \mathrm{dV}+\int_{\mathrm{S}}\vec{v}\rho\vec{v}\cdot\vec{n}dS=\int_{\mathrm{S}}\vec{n}\cdot\vec{\sigma}dS+\int_{\mathrm{V}}\vec{b}\rho dV \tag{2}$$

$$\begin{aligned}\frac{\partial}{\partial t}\int_{\mathrm{V}}(\mathrm{u}+\mathrm{e_c})\rho \mathrm{dV}+\int_{\mathrm{S}}(\mathrm{u}+\mathrm{e_c})\rho\vec{v}\cdot\vec{n}\mathrm{dS}=-\int_{\mathrm{S}}\vec{q}\cdot\vec{n}\mathrm{dS}\\+\int_{\mathrm{S}}\vec{v}\cdot(\vec{n}\cdot\vec{\sigma})\mathrm{dS}+\int_{\mathrm{V}}\vec{v}\cdot\vec{b}\rho \mathrm{dV}+\int_{\mathrm{V}}\emptyset\rho \mathrm{dV}\end{aligned} \tag{3}$$

where ρ is the density, $\vec{v}$ the velocity vector, $\vec{n}$ the unitary vector perpendicular to the surface, $\vec{\sigma}$ the external forces which includes pressure forces and viscous stress, $\vec{b}$ the volumetric forces, $\vec{q}$ the heat generation and ϕ represents to an intensive property.

However, the heat transfer modelling in two-phase media or phase change process is much more complex than a single phase model.

According to several authors such as Regin [14] and Dutil [15], the main challenging tasks which hinder the thermal modelling of the phase change process can be described as,

- The moving boundary in the two phase interface
- The strongly non-linearity of the problem

- The buoyancy driven natural convection in the fluid interface
- The volume varies with the phase change in case of non-capsulated materials and the uncertainty of the interface thermal resistance between the container and the PCM when they are encapsulated
- The non-physical discontinuities between the two phases

In this regard, and especially due to the non-linear nature of the problem at moving interfaces where the displacement rate is dominated by the latent heat exchanged at the boundary, numerical analysis is generally required to obtain appropriate solutions for the thermal behaviour of two phase systems.

Finite difference methods (FDM) and finite element methods (FEM) are two popular techniques for numerical analysis. Nevertheless, several discretisation methodologies have been developed to characterised the heat transfer problem such as the variable grid method [16], the front fixing method [17] or adaptive grid generation method [18], being the fixed grid method the most extended [19].

Specifically, in case of the phase change phenomenon, the heat transfer process should be modelled independently and there is a wide spectrum of additional numerical methods such a the Enthalpy Method (EM), the Effective Heat Capacity Method (EHCM) or the Heat Integration Method (HIM), where the interface position is neglected initially and the Stefan condition is assumed. The Stefan condition [20, 21] establishes the relationship between the latent heat fluxes in both sides of the phase change interface and provides the movement of the interface. This means that the amount of released latent heat due to the interface displacement and the net heat flow on the surface are equal. These methodologies are able to obtain a solution considering one or two phases.

The preferred two methods of phase change problem resolution are the EHCM and the EM. First of them is characterised by highly non-linear temperature and enthalpy dependence where the effective heat capacity is directly proportional to the stored and released energy during the phase change. The second method uses an enthalpy function as a dependent variable with the temperature. It can be graphically described as a small and width peak of capacity [22, 23].

ESP-r is an integrated energy modelling tool for the simulation of the thermal, visual and acoustic performance of buildings. This software is based on a finite volume conservation approach in which a problem (specified in terms of geometry, construction, operation, leakage distribution, etc.) is transformed into a set of conservation equations (for energy, mass, momentum, etc.) which are then integrated at successive time-steps in response to climate, occupant and control system influences [24]. The ESP-r control volume approach was adapted to describe the physical elements of the PCM model using ESP-r's zones and networks elements. Kelly [25] developed a module for ESP-r to analyse materials which are able to change their thermo-physical properties in response to some external excitation such as PCMs. In this sense, this module may be applied to a particular node within a multi-layer construction, and subsequently, to establish a time variation in the node basic thermo-physical properties [12].

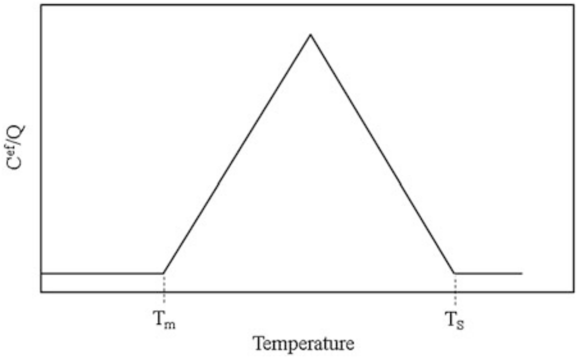

Fig. 2 Schematic representation of the effective heat capacity method

EHCM is the method applied by ESP-r to solve the phase transition in the PCM material. The method is based on a function of the latent heat of fusion and the temperature, which is defined by Eqs. 4, 5 and 6.

$$C_{ef} = \rho \cdot C_s \quad T < T_s \tag{4}$$

$$C_{ef} = \rho \cdot C_l + \frac{L}{T_m - T_s} T_s < T < T_m \tag{5}$$

$$C_{ef} = \rho \cdot C_l \quad T > T_l \tag{6}$$

Where L is the latent heat of fusion, T_m is the melting temperature, and T_s is the solidification temperature, C_s and C_l the specific heat capacity of the material in solid and liquid state respectively and ρ is the density.

As is described graphically in Fig. 2, considering a liquid–solid phase change material, this function has a narrow and finite width peak between melting and solidification temperatures where temperature fluctuations of the material are limited due to the phase change process.

However, when the temperature is lower than the melting point, the material is solid and thus, it is fully discharged. On the other hand, if the temperature is higher of the solidification temperature, the material is completely liquid and, therefore this means that it is storing energy [22].

Figure 3 shows the analysed building configuration considered for both case studies, one office including a PCM layer in the construction and another office without PCM. The buildings have the same dimensions, a plant of 16 m^2 and a height of 2.7 m. As can be seen in Fig. 3, there is a window in the south face which uses 35 % of the wall surface and a simple door in the north face of the office.

The construction of the offices used in the case studies was based on a typical Spanish residential structure according to the Spanish Technical Building Code [26]. Figure 4 describes graphically the layers and Table 1 shows the main physical and thermal properties of the different layers. The roof and ground are common in both buildings. The floor is made up of 5 layers consisting of earth (f),

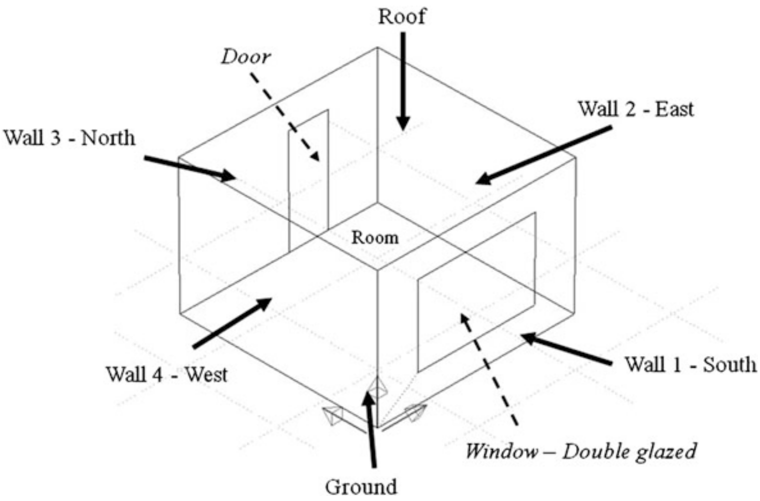

Fig. 3 Model description and orientation of the walls

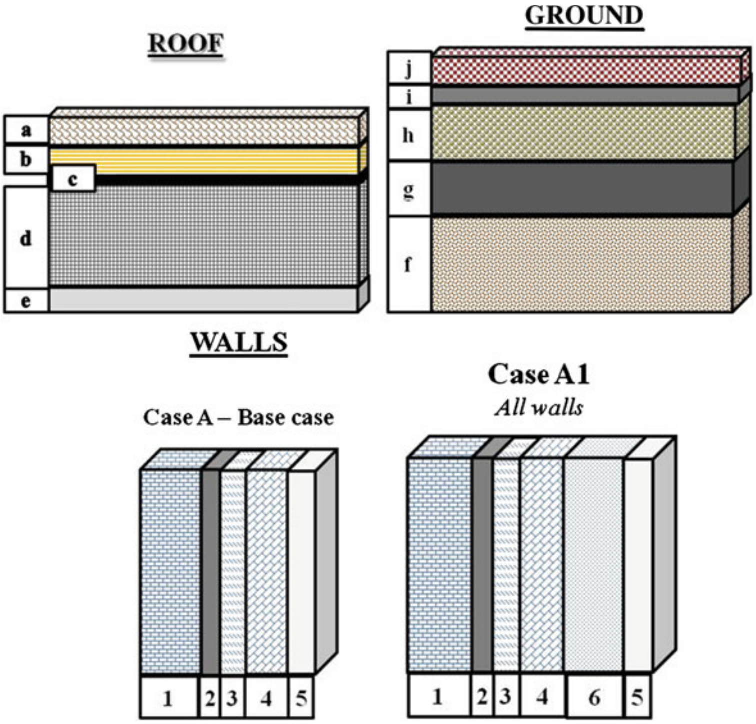

Fig. 4 Description of the main layers in roof, ground and walls of the building

Table 1 Properties of the construction layers

		Thickness mm	Density kg/m^3	Conductivity W/(m·K)	Specific heat capacity J/(kg·K)
	ROOF				
a	Ceramic outside tile	20	2,000	1	800
b	EPS	20	30	0.029	1,000
c	Bitumen	1	1,050	0.17	1,000
d	Forged one-way concrete infilling	250	1,330	1.323	1,000
e	Plasterboard (1,000 < d<1,300)	15	1,150	0.57	1,000
	GROUND				
f	Earth	350	2,000	0.52	1,840
g	Mass concrete	150	2,150	1.65	1,000
h	Sand and gravel	150	1,450	2,0	1,050
i	Plastering mortar	15	1,900	1.3	1,000
j	Inside tile	30	2,300	1.3	840
	WALL				
1	Perforated ceramic brick	115	1,020	0.567	1,000
2	Plastering mortar	15	1,900	1.3	1,000
3	Insulation: mineral wool	20	40	0.04	1,000
4	Hollow brick (60 < E<90 mm)	70	930	0.432	1,000
5	Wall tile	20	2,300	1.3	1,000
6	PCM	3.5	300	0.25	2,000

mass concrete (g), sand and gravel (h), plastering mortar (i) and inside tile (j). The roof is structured also in five layers, a ceramic outside tile (a), an isolation material (b), bitumen (c), forged one-way concrete infilling (d) and plasterboard (e). The ground and roof description is common in both models.

On the other hand, the walls are made up of perforated ceramic brick (1), plastering mortar (2), isolation material (3), hollow brick (4) and tile (5). PCM model places the special material (6) between the hollow brick and the tile layers in the case study where PCM influence is analysed. In addition, a constant PCM load of 2.5 kg PCM/m^2 of the plant was distributed in the walls.

The operational details of the office have been implemented in ESP-r and they are based on a simple control loop with a constant set point within the comfort range temperature. The HVAC control set point is set in the established comfort range of temperature (21–24 °C), around 23 °C. When the room air temperature differs from this temperature, the HVAC equipment is activated being the maximum heating and cooling capacities 2,500 W. Internal gains as the gains from occupants, lighting or other electric appliances have not been applied to the model.

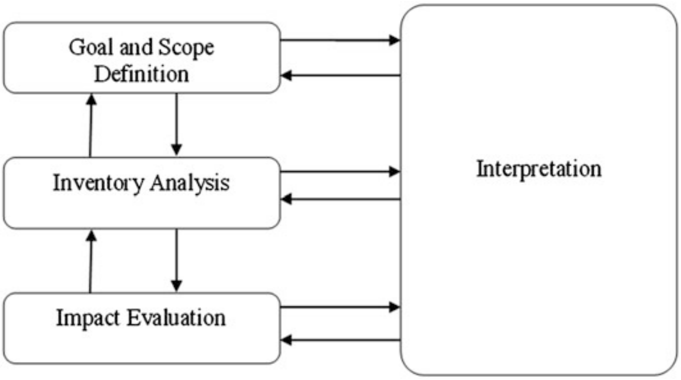

Fig. 5 Phases of an LCA

2.2 PCMs Environmental Modelling

The environmental analysis is based on the life cycle assessment (LCA) methodology to determine if environmental impacts and energy saving are large enough to balance those caused and consumed, respectively, during PCM manufacture and installation. LCA is a well-known methodology which has fully technically and scientifically proven for analysing the environmental impact of products and processes [27,28].

The structure of the LCA is proposed by the standard ISO 14040 [29,30]. Figure 5 shows that this methodology can be synthesised in four main phases. The first of them is focused on goal definition and scoping which defines the objective of the study, the functional unit and the limits of the system studied.

Since the studied system must be modelled as a complex sequence of unitary operations that communicate among themselves and with the environment through inputs and outputs from a life cycle perspective, clear boundaries of the system should be defined.

The second phase is the life cycle inventory (LCI) which represents the data gathering and the quantitative assessment procedures aimed at calculating the relevant inputs and outputs of a production system. This is an iterative process, which may be repeated if a need for further information emerges during its implementation.

The following phase is focused on the evaluation of the significance of the potential environmental impacts associated with data derived from the inventory phase. In this phase, the level of detail, the choice of the impacts to evaluate and the methods of evaluation depend on the objectives and scope of the study. The last phase covers the life cycle interpretation. In this phase, the interpretation of the results of the inventory phase and of the evaluation of impacts takes place, as well as obtaining all conclusions and recommendations for the improvement of the environmental performance.

Environmental impacts can be modelled from midpoint and endpoint approaches. The former are considered to be points in the cause-effect chain (environmental mechanism) of a particular impact category somewhere between stressor and endpoints [29]. This approach defines the environmental mechanism throughout the quantification of the impacts.

SIMAPRO v7.3.2 allows calculating midpoint indicators using different methods. One of the most recent and harmonised method available in this version is RECIPE. This method permits to calculate eighteen midpoint categories (e.g. ozone depletion, climate change, human toxicity, etc.).

2.2.1 Functional Unit and System Description

As commented above, materials and dimensions of the building envelope and PCM materials are modelled in ESP-r software to obtain the thermal behaviour through the walls and identify the benefits of integrating phase change materials in constructions elements. In this sense, two single zoned houses were developed on the building energy simulation package ESP-r. One of them incorporates the phase change material into the walls, whilst the other serves as a reference zone in order to gauge the effect of the PCM on heating and cooling loads.

For environmental analysis, the stages considered for analysing are: PCM and tile manufacturing, tile installation, use phase and PCM disposal and recycling. A non-common element between the environmental and energy analysis is the exclusion of conventional building construction materials in the former of them. Since the modification in the construction of the building with PCM is only due to inclusion of tiles doped with PCM, the environmental impact of these conventional materials is the same when comparing the case of a building without tiles. Consequently, the environmental analysis is deepened in all the stages that are necessary for manufacture, installation, removal and disposal of those tiles doped with PCM to balance them with the energy benefits obtained from the environmental analysis. Additionally, in this study, all transport stages, such as the transport of the PCM materials to the tile plant, are not included in the assessment due to the fact that the specific locations of the PCM seller, the tile plant, the building and the disposal sites are not known.

To allow the comparison of the different data, the functional unit used in this study was the standard building described before.

2.2.2 Climate Severities

The winter and summer climate severities (CS) quantify the climate conditions of every climatic area in the winter and summer, respectively. These variables are the result of the combination of the degree days and the solar radiation for the location studied. Their calculation comes from the Basic Document on Energy Saving (HE); section HE-1 included in the Spanish Building Technical Code [26].

Table 2 Description of the main climate characteristic of the selected location [31]

	C1
Location	43°27′N 3°48′W
Climate	North Atlantic
Annual sunshine hours	1,638
Temperature range	4–25
Annual precipitation days	128

The winter climate severity is divided into five ranges of severity coded from A to E, where A is the lowest and E the highest severity. The summer climate severity is divided into four ranges, 1–4, from lowest to highest severity. In this regard, it is assumed that when the winter climate severity increases more energy heating is demanded. In case of summer climate severity, number 4 represents the highest energy cooling demand. Finally, if two locations have the same climate severity the energy demand associated is also the same.

There are 12 climate zones in Spain. In this study, one Spanish target area has been analysed following this criterion. C1 (Santander) has a high density of population [32] and medium winters and mild summers. Table 2 shows a more detailed description regarding the climate conditions of this location. The annual weather data associated and used in the simulation were acquired from the U.S. Department of Energy [33].

2.2.3 PCM Description

The PCM impregnated into porous construction materials can be based on organic (e.g. paraffin, fatty acids or polyethylene glycol) or inorganic (e.g. salt hydrates) compounds. In comparison to inorganic PCMs, the organic compounds show congruent phase changes, they are not dangerous because of their chemical stability, they can be recyclable and they have a good nucleation rate [13].

In this research, a commercial organic PCM based on paraffin and waxes is analysed. Table 3 presents the main thermal properties of this PCM where T_s is the fusion temperature, T_m is the melting temperature and L is the latent heat of fusion.

Different considerations have been followed to select this PCM: (1) the temperature of fusion of the material which should be in the range of comfort (21–24 °C) and the latent heat value which should also be high; (2) a commercial status; and (3) their usability by some industries in order to research new

Table 3 Main properties of the PCMs considered in the research study

T_m °C	T_s °C	L kJ/kg
22	24	100

Table 4 Life cycle inventory

Component/process	
Paraffin (kg)	40.00
Resin (kg)	93.8
$E_{\text{manufacturing-installation}}$ (kW h)	20

constructive elements. This is an important factor to obtain some data to be included in the environmental assessment.

2.2.4 Life Cycle Inventory

To develop the LCI, a constant PCM load of 2.5 kg PCM/m^2 has been taken into account as well as a specific quantity of resin to support the PCM layer in the tile structure. Table 4 shows the most relevant data included in the LCI for the commercial PCM selected in this research and considering the system boundaries defined.

3 Results and Discussion

3.1 Effect of the PCM Addition on the HVAC Performance

In order to evaluate the effect of the introduction of the PCM material on the thermal modelling of the building and, thus, on the indoor dwelling conditions, predictions of the temperature gradient in the walls and the energy consumption in the HVAC systems for the base case study (without PCM) and case A (with PCM) were analysed under the climate severity C1.

To start with the results obtained, Fig. 6 shows the evolution of the PCM node temperature during a random day for the climate severity considered. As can be seen in Fig. 6, during the night the temperature in the phase change range is approximately stable. The main reason for this situation can be found in the fact that the PCM is discharging energy by means of the latent heat use in the phase change. However, when the PCM is completely solid, that means, it is out of the phase change temperature range, the temperature behaviour of the PCM is dominated by the sensible heat of the material and, therefore, a conventional variation of the temperature with the time is observed. In this case, a steeper slope dominates the PCM behaviour.

Additionally, Fig. 7 and Table 5 illustrate the annual energy consumption associated with the case studies involved in this research and the rate of energy saving achieved as a function of the HVAC mode in terms or heating and cooling demand in climate severity C1. In this case, the simulation demonstrates that a global reduction in energy demand is obtained by the use of PCM in the building construction.

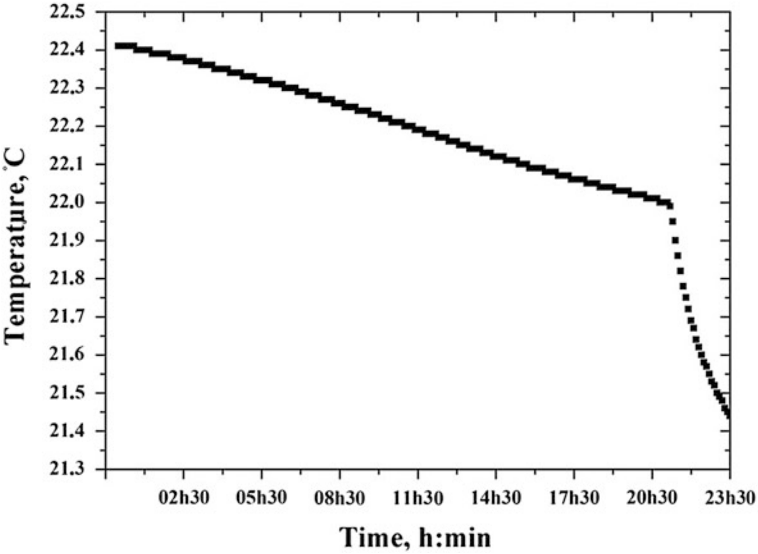

Fig. 6 Evolution of the PCM temperature during a random day

From the point of view of the annual energy savings, the results obtained in the simulations show that the 6.60 % of the total energy involved during the year can be avoided when the PCM are impregnated into porous construction materials.

On the other hand, focusing on the HVAC system mode, data depicted in Table 5 conclude that the highest values in energy savings are obtained in the cooling mode considering that the evaluation has been performed under climate severity C1. Specifically, energy savings about 9.07 % can be achieved under this case study. However, the reductions obtained in the heating mode are quite low, since only 5.54 % of the energy involved in heating process is save by the introduction of PCM to the system.

Additionally, Table 6 shows the main energy savings obtained by annual season. In this case, higher savings are achieved in spring and autumn, 15.51 and 11.23 % respectively. The main reason for these results can be found when climate severity C1 is analysed. As was described in Table 2, this climate is characterised by medium winters and mild summers. Therefore, in winter, the outdoor temperature is lower than the phase change temperature, and rarely achieves the transition values. Similarly, in summer, temperatures are higher than the phase change temperature during all day. Therefore, in both cases the performance of the PCM by changing and discharging energy to the media is limited and higher consumptions in HVAC are found. In this cases energy savings are limited up to 2.78 % in winter and 2.12 % in summer seasons.

Nevertheless, in medium seasons as spring and autumn is possible to attain temperatures above the phase change material during the day, which decrease during the night under the phase change temperature transition. Next day, the

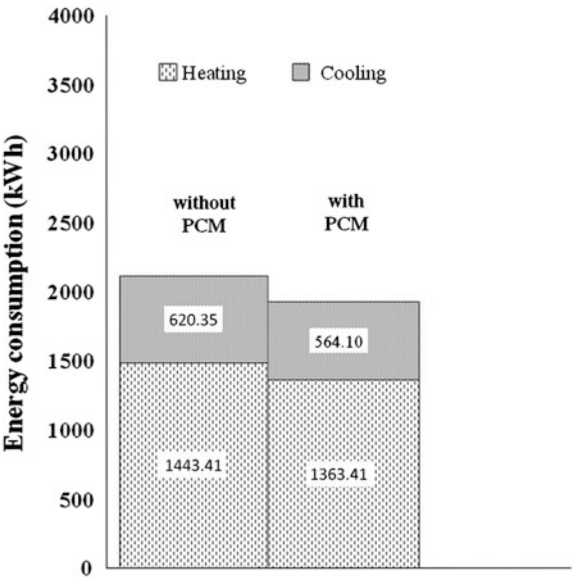

Fig. 7 Annual energy consumptions by climate severity and the HVAC mode

Table 5 Annual energy savings by PCM introduction considering HVAC mode

	Heating saving (%)	Cooling saving (%)	Total Saving (%)
C1	5.54	9.07	6.60

temperature rises again to complete other PCM transition cycle. In these cases, the PCM performance is enhancing and a higher number of charges and discharges are achieved by the PCM and thus, a relative descent in the HVAC equipment are observed.

Finally, focusing on the consumption by HVAC mode and annual season, a very low performance of the heating mode is observed in summer, as is depicted in Table 7. Nevertheless, summer season entails the highest values of cooling energy during the year. On the other hand, the highest performance on HVAC in heating mode is risen in winter.

Seasons as spring and autumn show middle energy values, although the difference between the energy consumption with PCM and without PCM is maximized, as mentioned before and observed in Table 6.

Table 6 Energy saving by annual seasons (%)

	Winter	Spring	Summer	Autumn
C1	2.78	15.51	2.12	11.23

Table 7 Energy loads by HVAC mode and annual season

	Heating (kWh)		Cooling (kWh)		Total (kWh)	
	with PCM	w/o PCM	with PCM	w/o PCM	with PCM	w/o PCM
Winter	765.97	784.19	6.50	10.39	772.47	794.58
Spring	223.75	251.45	48.27	70.50	272.02	321.95
Summer	0.14	0.92	453.18	462.23	453.32	463.15
Autumn	373.55	406.85	56.15	77.23	429.70	484.08

3.2 Effect of the PCM Addition on the Environmental Impact Assessment

The impact assessment was carried out with the purpose of evaluating the midpoint approach. To this end, the Recipe method with a time frame of 50 years was applied to evaluate it. This time value corresponds to the design working life in housing or office buildings, according to the Code of Structural Concrete EHE-08 approved by the Spanish Royal Decree 1247/2008 [26]. It is also assumed as a typical use stage time for a building in LCA research studies [34–36].

This study has demonstrated that the results obtained are strongly influenced by the energy involved during the use stage of the building, observing similar trends to those obtained in the analysis of the energy calculations. This means that during the useful life of the building the impacts associated with the manufacture of the

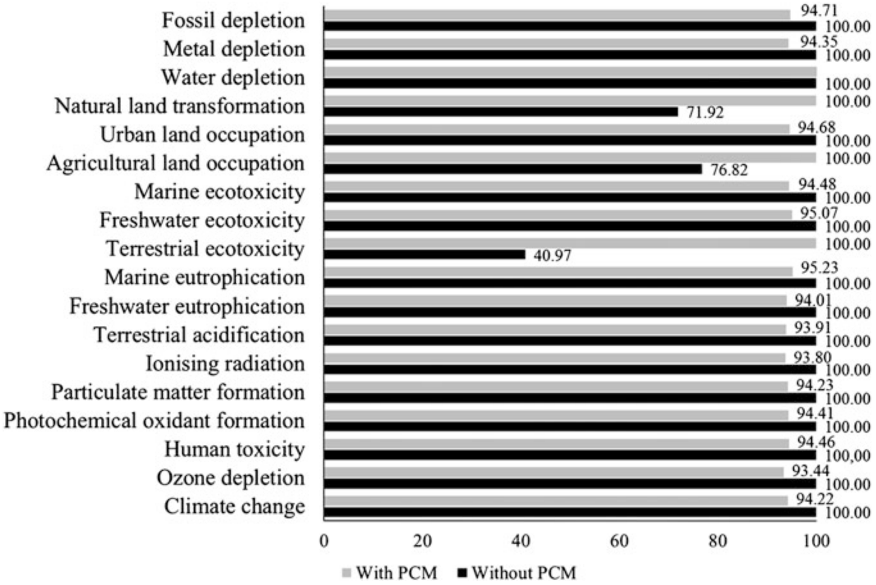

Fig. 8 Environmental impacts of (%) the PCM analysed for the most relevant impact categories in climate severity C1

PCMs, their installation in the construction materials and their disposal stage are fully recouped through the benefits obtained by the decrease of the electrical consumption during the use stage.

As is depicted in Fig. 8, only three impact categories (agriculture land occupation, terrestrial toxicity and agriculture land transformation) show higher environmental impacts when the PCM is introduced. In this case, the PCM addition, represented by the material, process manufacturing and disposal stage, has a strong influence and the stage of use in the building lifetime is not able to compensate the environmental impacts.

However, analysing globally all the impact categories higher environmental benefices are observed by the impregnation of phase change materials (PCMs) into porous construction materials to enhance indoor-dwelling temperature conditions.

4 Conclusions

Results have demonstrated that tiles doped with PCM materials can be used to reduce the energy consumption needs keeping constant the occupant level comfort. It is shown that energy saving is not only dependent on the physical and thermal characteristics of the PCM, such as the fusion temperature, latent heat, etc., but also is affected by the climate severity. The environmental analysis has demonstrated that it is highly influenced by energy savings obtained by the use of PCM in a lifetime of 50 years of a building following a midpoint approach and using RECIPE method. In this sense, environmental impacts in dwellings where PCMs are involved in the construction are lower in most of the environmental categories than those where only conventional materials are used.

In addition, results reveal the importance of the PCM selection considering thermal and environmental conditions as one significant path to achieve a sustainable industrial and technological application of these materials. It establishes an innovative guideline to apply PCMs taking into account both energy and environmental modelling considering building locations.

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