EFFECT OF PHASE CHANGE MATERIAL USING IN BUILDING THERMAL COMFORT APPLICATIONS THROUGH SEVERAL CLIMATE CONDITIONS.

Marwa El Yassi[1, 2*], *Ikram El Abbassi*[1, 2], *Alexandre Pierre*[2] *and Yannick Melinge*[2]
[1]Laboratoire de Recherche en Eco-innovation Industrielle et Energétique (LR2E), ECAM-EPMI, Cergy, France.
[2]Laboratoire de Mécanique et Matériaux du Génie Civil (L2MGC-EA 4114), Université de Cergy-Pontoise, France.

Abstract. Nowadays, buildings sector contributes to climate change by consuming a considerable amount of energy to afford thermal comfort for occupants. Passive cooling techniques are a promising solution to increase the thermal inertia of building envelopes, and reduce temperature fluctuations. The phase change materials, known as PCM, can be efficiently employed to this purpose, because of their high energy storage density. Among the various existing solutions, the present study is dedicated to solid-liquid phase change materials. Temperature evolution (according to their defined temperature range) induces the chemical change of the material and its state. For building applications, the chemical transition can be accomplished from liquid to solid (solidification) and from solid to liquid (melting). In fact, this paper presents a comparative thermal analysis of several test rooms with and without phase change materials embedded in a composite wallboard in different climates. The used PCM consist in a flexible sheet of 5 mm thickness (Energain, manufactured by the company DuPont de Nemours). The main properties of such a commercial solution have been delivered by the manufacturer and from analyses. The room model was validated using laboratory instrumentations and measurements of a test room in four cities: Lyon; Reading and Casablanca. Results indicate that this phase change material board can absorb heat gains and also reduce the indoor air temperature fluctuations during daytime. The aim of the study is to show the benefits of this layer with phase change material and compare it in different climatic zones.

1 Introduction

In recent years, interest in energy consumption is increasing steadily. The building sector is responsible for causing one part of global CO_2 emissions. That is why it's necessary to reduce this consumption and try to improve the energy efficiency.

Recently, many researchers focused their studies on thermal energy storage (TES) methods, which it can be classified as sensible, thermochemical and latent heat energy storage. These systems can provide better energy efficiency and low carbon footprint.

Phase change materials, known as PCM, represent one of these methods that use latent heat energy storage (LHTES). These materials can be directly integrated in the envelope of a building. And it is a way to improve thermal comfort and control temperatures within a specific range.
These materials can be immersed in the wall or in combination with a mixture of other wall panels, for example in concrete [1, 2, 3] or gypsum [4, 5, 6].

The main purpose of this article is to present a comparative analysis of one phase change material integrated into the wall of a building, by proposing three experimental studies in order to evaluate the energy performance and the influence of PCM boards on the temperature of the interior wall.

* Corresponding author: m.elyassi@ecam-epmi.com

2 Literature review

This section clearly describes the main evolution in the integration of PCMs into the building sector. **Fig. 1** shows the development of publications per year, characterized by an increasing number of scientific works from the beginning of the years 2005 until 2018.

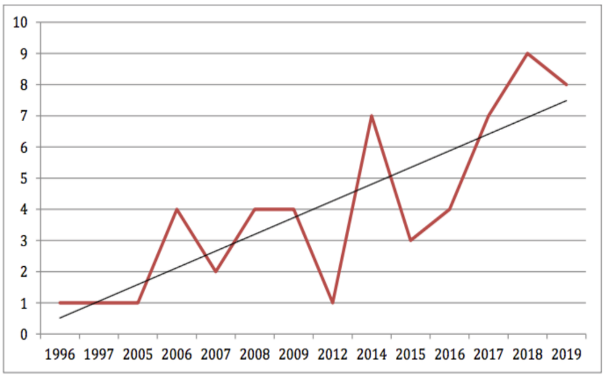


Fig. 1 Evolution of research in passive use of PCM.

Several researchers installed PCM in the wall and the ceiling of the building because of their various advantages. In fact, the impact of these materials is the enhancement of the thermal comfort inside buildings. In other words, they have the ability to absorb the energy coming from outside during the phase change (solid to liquid) and to release it in the cavity during the state change (liquid to solid).

Recently, some manufacturers have started to commercialize different panels with phase change materials such as Rubitherm GmbH [7] and BASF [8] based in Germany, Phase change energy solutions [9] based in United States. Many researches integrated these products in different forms: For instance, new gypsum composite containing RT27 from Rubitherm GmbH [7] was studied [10], and shows a higher heat storage capacity by reducing the energy saving than ordinary gypsum. Or, microencapsulated paraffin manufactured from BASF [8] into a plaster mortar. This one is able to decrease the ambient temperature contrary to a classic mortar [11]

3 Methods and methodology

In this paper, the evaluation is focused on the analysis of the PCM applied in building in order to evaluate the total energy savings and temperature fluctuations in different climatic zones.

3.1. PCM characterization

The PCM analysed, ENERGAIN has been manufactured by the company DuPont de Nemours (Luxembourg) and is a mixture of paraffin wax (60%) and a mixture of ethylene based polymer (40%). The product is a rectangular panel of 5 mm thickness (see Fig. 2)

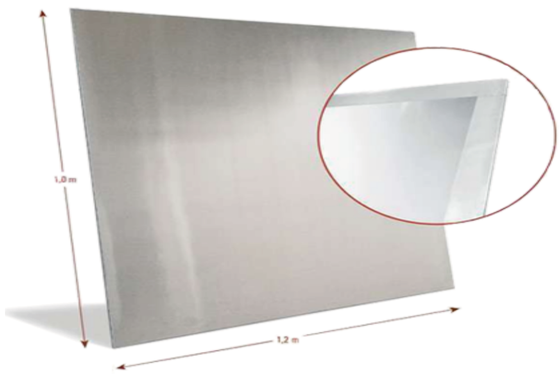


Fig. 2 Phase change material by DuPont de Nemours.

The PCM used has been measured [12]. The thermophysical properties of this product are listed in Table 1.

Table 1 Thermophysical properties of PCM [12].

Thermophysical property	Value
Thermal conductivity in solid phase (W/mK)	0,18
Thermal conductivity in liquid phase (W/mK)	0,22
Melting point (°C)	21
Freezing point (°C)	13,6
Latent heat (J/g)	106

This article presents the results of works done by [12, 13, 14] with the same PCM installed under several climatic conditions in three cities in order to compare a potential solution for cooling applications during heating season.

3.2. Experimental setup

This section describes the experimental set up of the different studies. The first one is located in the Department of Civil Engineering of Applied Sciences in Lyon. Fig. 3 represents the test room known as MINIBAT. The volume of the room is: 3.10×3.10×2.5 m^3. In this study, the PCM was integrated on the north, east and west walls with a night ventilation.

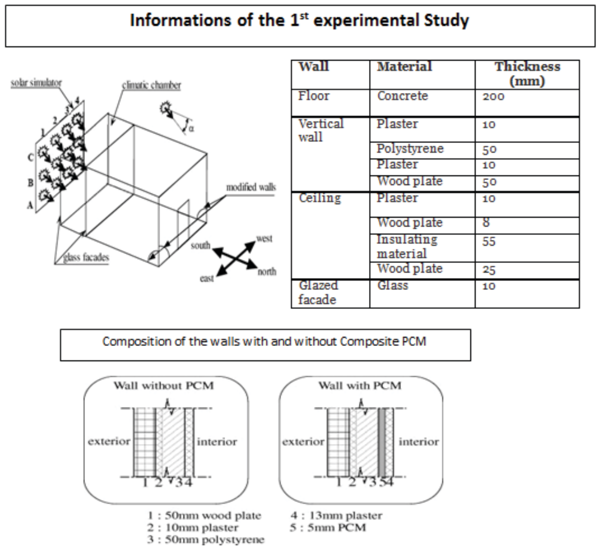


Fig. 3 Information of the first experimental study in Lyon [12]

The second study is located in Reading. Fig. 4 shows the experimental chamber with the following dimensions: 4×3×2.5 m^3. The PCM was installed on the Wall 5 (see Fig. 4).

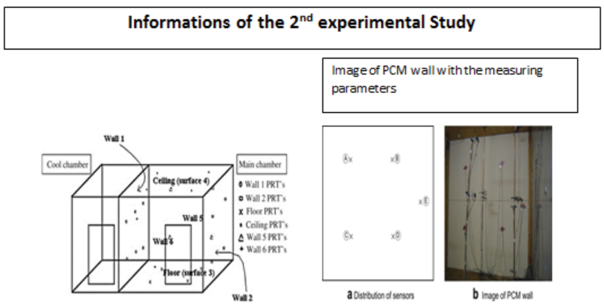
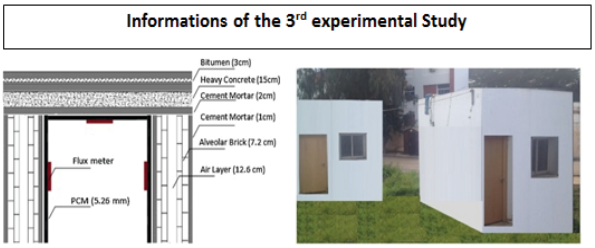


Fig. 4 Information of the second experimental study in Reading [13]

The last study is located in the Faculty of Sciences Aîn Chock, Casablanca. The experience was conducted in two same full-scale cubicles (see Fig. 5). The PCM was integrated on the ceiling and vertical walls in one of the cubicles. The volume of the PCM-Cavity is: 3×3×3 m^3.



Wall	Composition	Thickness (cm)	Thermal conductivity (W/m.K)	Density (kg/m3)	Heat capacity (kJ/kg.K)	U-Heat transfer coefficient (W/m2.K)
Vertical walls	Cement mortar	1	1.15	1700	1	0.531
	Alveolar brick	7.2	1.15	1700	0.794	
	Air layer	12.6	0 0.08	1	1.227	
	Alveolar brick	7.2	1.15	1700	0.794	
	Cement mortar	1	1.15	1700	1	
Ceiling	Cement mortar	2	1.15	1700	1	2.722
	Bitumen	3	0.5	1700	1	
	Cement mortar	2	1.15	1700	1	
	heavy concrete	15	1.75	2300	0.92	
	Cement mortar	2	1.15	1700	1	
Floor	Cement mortar	5	1.15	1700	1	0.694
	Clay	3	0.6	2000	1.5	
	Polystyrene	2	0.039	25	1.38	
	Heavy Concrete	4	1.75	2300	0.92	
	Limestone	10	2.25	2400	0.8	

Fig. 5 Information of the third experimental study in Casablanca [14]

3.2 Instrumentation and measurements

For each study, different instrumentations are used to measure ambient temperatures of the test rooms, such as resistance thermometers (PRT) sensors and thermocouples (See Fig. 4, Fig. 5). These one are placed on the wall of the test room exposed to the local weather or a climatic chamber where the temperature can be controlled (See Fig. 3, Fig. 4). In this case, there are three weathers: Lyon, Reading and Casablanca.

4 Cooling energy performance

This part describes the different experimental results in order to compare the cooling energy performance of this PCM.

Fig. 6 shows the room air temperatures of different walls (North, East and West) of the test room located in Lyon. It's interesting to see the difference between the temperature with and without PCM. The wall with PCM presents a temperature fluctuation lower than the wall without. For the west and east walls, the PCM have the same effect on the temperature evolution and can reduce it of 3.5°C.

Fig. 7 shows the ambient temperature with two probes at heights 0.85 m and 1.70 m in order to evaluate the thermal stratification of the ambient air. With this material, the temperature variation can be decreased of about 3.9 °C. It can be noticed an interesting observation: a difference of about 1.3 °C between the two probes.

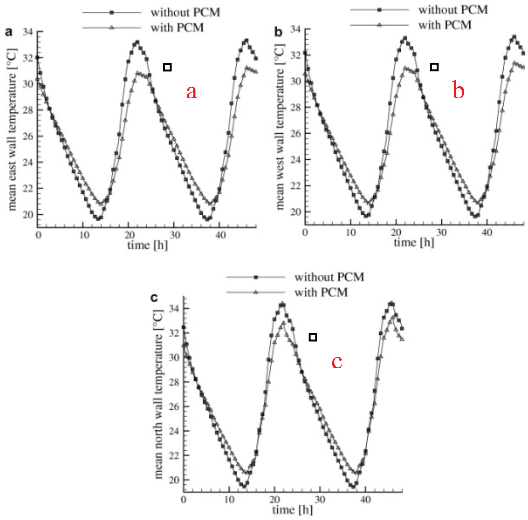


Fig. 6 Temperatures of the east wall (a), the west wall (b) and the north wall (c) for the sunny season [12]

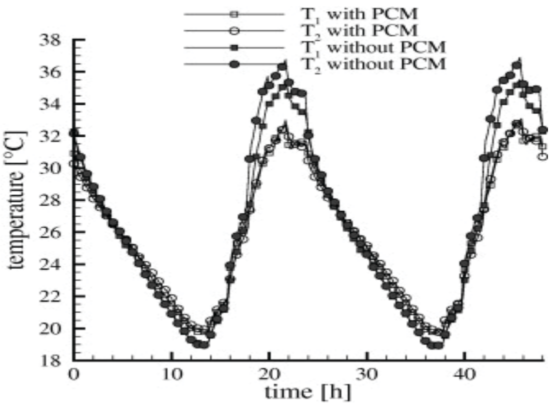


Fig. 7 Test room temperatures – T1 and T2 at height 0.85m and 1.70m. [12]

Concerning the second study located in Reading, the efficiency of the phase change material wall can be shown in Fig. 8, which represents a comparison between the wall with and without PCM. This one illustrates that the wall with PCM can cause a decrease of about 1.3 °C.

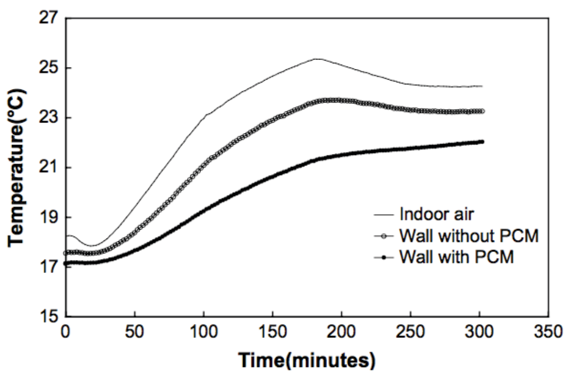


Fig. 8 Evolution of indoor temperature with phase change material in a complete-cycle [13]

Conversely, it was found that during spring season in Casablanca, the application of this PCM board have the ability to increase the ambient temperature inside the cavities of about 2.2 °C as shown in Fig. 9.

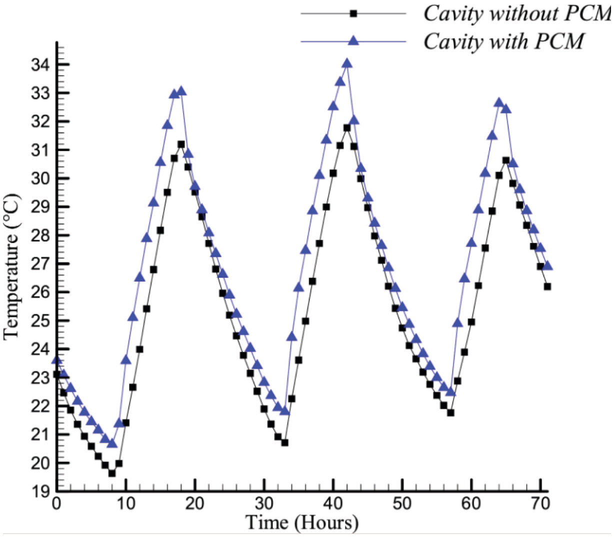


Fig. 9 Evolution of the temperature of the wall with and without PCM [14]

5 Analysis and discussion

This paper discusses three experimental studies in order to analyse the impacts of a PCM integrated in a building. These experiments can show that the cooling energy and peak temperature are reduced during the hottest periods with different climate conditions and experimental techniques. Their results are local and can be compared with each other. The experiments have shown that the phase change materials tested have the ability effectively maintain the temperature variation in the test room within the comfort zone by reducing the air temperature. However, these materials can reduce the maximum air temperature depending on several conditions such as the climate, the building envelops and the ventilation. Taking into consideration all of these conditions of the experiments, the results were different of each other. Contrary to Lyon and Reading, in Casablanca, the PCM wallboard was able to keep the temperature of the cavity higher than the reference-cell and destroy the thermal stratification. In Lyon, a night ventilation was switched on to help the PCM to complete the fully cycle (melting/solidification), to improve the thermal inertia of the building envelop and contribute to air renewal. Moreover, thermal stratification doesn't exist for the PCM's case with a temperature reduction. In Reading, the results were lower than Lyon.

To conclude, it can be noted that the results of these experiences were different mainly because of the local climate: In the Oceanic climate, the more the outdoor temperature is higher, the more the PCM wallboard is effective: In comparison to Lyon, Reading has the coolest climate with the lower results in terms of temperature variation (Table 2). For the Mediterranean climate, the impact of the PCM wallboard was different: The inverse effect on the ambient variation has been noted.

Thus, according to these studies, the geographical location is significantly important for better results. Despite the noted difference, there is an interesting impact of a PCM on the variation of air temperature in the Oceanic climate even if in the caseof Reading. For Casablanca, it can be a great solution for a passive heating application during cold season. In fact, all of the results of this product can represent a potential solution to improve the thermal comfort of building.

City	Köppen-Geiger Climate classification	Average temperature in the year
Lyon (France)	Oceanic climate (Cfb)	11.6 °C
Reading (United Kingdom)	Oceanic climate (Cfb)	9.9 °C
Casablanca (Morocco)	Mediterranean climate (Csa)	17.7 °C

Table 2 Climate characteristics according to Köppen-Geiger classification of selected cities. [15]

6 Conclusions

In this article, a comparative study was made for the same PCM installed under several climates. The use of this phase change material wallboard can decrease the fluctuation ambient temperature in the test cavity, enhance the thermal inertia and try to minimize the thermal stratification. This paper has analysed results of the three experiments and has confirmed that this solution is particularly interesting to reduce energy consumption of buildings.

In perspectives, supplementary investigations are needed in order to validate the application of this phase change material wallboard for architecture envelope. Other numerical simulations must be realized too: It will be interesting to evaluate this PCM under Parisian climate.

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References

1. Cabeza, Luisa F., C. Castellón, M. Nogués, M. Medrano, R. Leppers, O. Zubillaga. *Ene and Buil* 39, n° 2 (2007): 113-19.
2. Memon, Shazim Ali, H. Z. Cui, Hang Zhang, et Feng Xing. *App Ene* 139 (2015): 43-55.
3. Stritih, U., V. V. Tyagi, R. Stropnik, H. Paksoy, F. Haghighat, et M. Mastani Joybari. *Sus Cit and Soc* 41 (2018): 286-95.
4. Athienitis, A. K., C. Liu, D. Hawes, D. Banu, et D. Feldman. *Buil and Env* 32, n° 5 (1997): 405-10.
5. Borreguero, Ana M., A. Serrano, I. Garrido, Juan F. Rodríguez, Manuel Carmona. *Ene Conv and Man* 87 (2014): 138-44.
6. Voelker, Conrad, O. Kornadt, Milan Ostry. *Ene and Buil* 40, n° 5 (2008): 937-44.
7. « Rubitherm GmbH »
8. « BASF – France »
9. Phase Change. « Phase Change Energy Solutions: Leader in Efficient Building Materials ».
10. Sá, Ana Vaz, M. Azenha, H. de Sousa, et A. Samagaio. *Ene and Buil* 49 (2012): 16-27.
11. Borreguero, Ana M., A. Serrano, I. Garrido, Juan F. Rodríguez, M. Carmona. *Ene Con and Mant* 87 (2014): 138-44.
12. Kuznik, Frédéric, J. Virgone. *App Ene* 86, n° 10 (2009): 2038-46.
13. Liu, Hongim, Hazim B. Awbi. *Buil and Env* 44, n° 9 (2009): 1788-93.
14. A. Mourid, M. El Alami, F. Kuznik. *Sus City and Soc* 41 (2018): 35-43.
15. Climate-Data.org ». 2019.