Potential of PCM Materials in Building Walls in La Reunion Island: A Numerical Study

Dimitri Bigot, Bruno Malet-Damour, Lionel Trovalet, Lisa Liu, Nadia Hammami, Jean-pierre Habas

To cite this version:

Dimitri Bigot, Bruno Malet-Damour, Lionel Trovalet, Lisa Liu, Nadia Hammami, et al.. Potential of PCM Materials in Building Walls in La Reunion Island: A Numerical Study. 8th International Conference on Green Computing and Engineering Technologies, Sep 2022, Port Louis, Mauritius. hal-04317928

HAL Id: hal-04317928
https://hal.univ-reunion.fr/hal-04317928

Submitted on 1 Dec 2023

Potential of PCM Materials in Building Walls in La Reunion Island: A Numerical Study

Dimitri BIGOT[1], Bruno MALET-DAMOUR[1], Lionel Trovalet[1], Lisa Liu[1,2], Nadia Hammami[2] and Jean-Pierre HABAS[2]
1 : University of La Reunion Island, PIMENT Laboratory, La Reunion (France)
2 : Institut Charles Gerhardt, University of Montpellier, CNRS, ENSCM, Montpellier (France)
dimitri.bigot@univ-reunion.fr

Abstract

The French government has set up thermal regulation policy to minimize building energy consumption and ensure occupant's comfort in residential buildings, named RTAADOM in Reunion Island for "Acoustic, Aeraulic and Thermal Regulation applied to French overseas countries". It is used to design building walls, particularly the insulation materials they are made of, according to the building environment, which is described by four major climatic zones in the island. The present work highlights the potential of using phase change materials (PCM) as a candidate to improve insulation solutions traditionally used to comply with the regulation. The paper focuses on building's indoor temperatures to show that using a PCM can be an excellent solution to improve building thermal behavior in compliance with regulation needs. A reference building based on previous works on the development of a local insulating material is used to run a set of numerical thermal modeling in EnergyPlus. The results show differences between the thermal behavior of the reference building to ones with traditional regulation insulation and with three types of PCM material (a manufactured one and two imagined). Those two lasts were imagined from studies carried out within the framework of the MCP-iBAT FEDER project. The review shows that it is necessary to adapt the PCM properties (phase change temperature and range) to the building environment and uses. The present paper results show that the three PCMs can be used to partly or completely replace an insulation as recommended in the regulation. However, each environment needs a particular PCM configuration to optimize its impact on the building behavior. These results support the need to carry out additional studies to design the PCM material according to the building environment and its uses.

Keywords: *PCM, thermal modeling, thermal regulation, comfort.*

1. Introduction

The French government has set up a thermal regulation policy to minimize building energy consumption and ensure occupant's comfort in residential buildings. In French Overseas Countries, such as Reunion Island, this regulation is named RTAADOM for "Acoustic, Aeraulic and Thermal Regulation applied to French overseas country" [1]. The design offices of the building industry need to verify the compliance of the different building systems with this regulation to ensure the comfort of the building and minimize its energy consumption. For example, it is necessary to verify wall insulation according to the environment of the building. In that purpose, Reunion Island is divided into four climatic zones defined by the altitudes: 0-400 m, 400-600m, 400-600m, and more than 800m, as shown in Figure 1. For low altitudes, the regulation aims to minimize the absorption of solar radiation through walls or windows. In contrast, for high altitudes, heat transfer through the walls needs to be minimized due to outdoor cold air. To ensure low heat transfers through opaque walls, a standard solution is to set up an insulation material inside the wall system. To help the Reunion Island building industry, the Center of Innovation and Research on Tropical Building (CIRBAT) set up a tool for insulation design according to different wall systems commonly used on the island [2].

Traditional insulation materials included rock wool, glass wool, polystyrene, and polyurethane. All these materials need to be imported from the European or Asian continents. However, the recent geopolitical conditions of the island increased the cost of materials' importation. Local authorities, through the Reunion Region, have shown that it is very urgent to find solutions and to develop new building materials on the island [3].

In that respect, the University of Reunion Island has developed the European research project MCP-iBat, which aims at developing an innovative insulating material based on a phase change material from local biobased resources. In this paper, we propose to study the potential of using PCM materials as a candidate to improve insulation solutions traditionally used to comply with the regulation.

In the first part, a brief presentation of the regulation is proposed to identify the parameters that must be achieved in compliance with the regulations and those achievable in the case of a PCM wall. In a second step, we describe the building and its environment through the four climatic zones and their modeling. In a third step, we present the results of the simulation (or modeling) and conclude with the interest of the technology according to each climatic zone and regulation objectives.

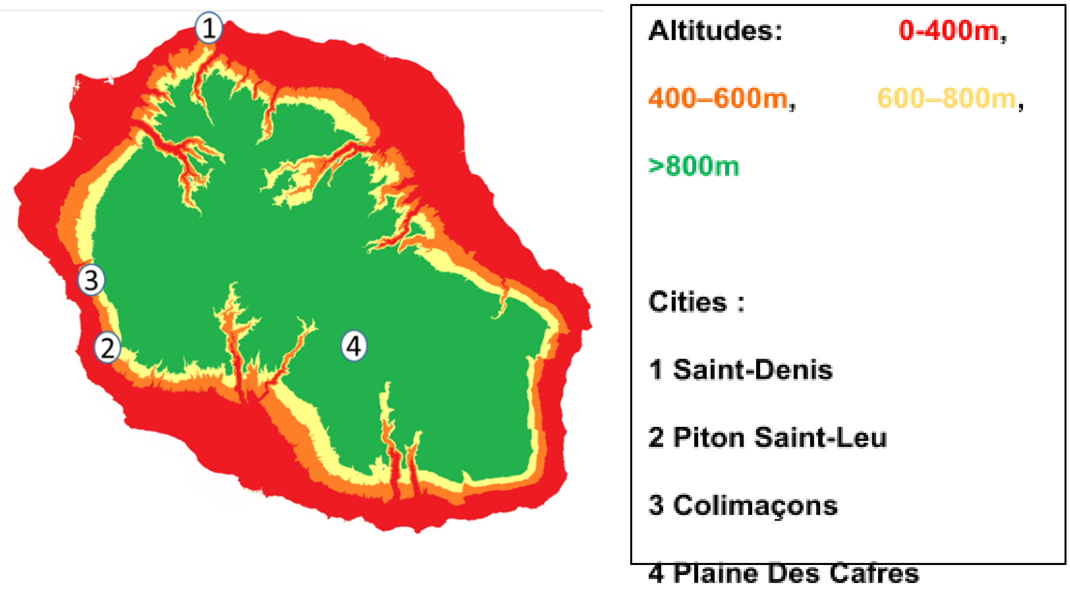


Figure 1: Climate zoning of the thermal regulation in La Réunion Island and location of the meteorological data [1].

2. Thermal regulation and its limitations

Compliance with RTAADOM regulations requires that the walls have solar transmittance factors S or thermal transmittances U below the regulatory thresholds depending on the type of wall and the climatic zone. Figure 1 shows the island's division into four climatic zones and the cities chosen for this work. These cities are representative of the climatic zones and meteorological data are available for the numerical study. To conform to the thermal regulation, two parameters must be checked: the global heat transfer coefficient through the wall and its solar factor, respectively U and S. The global heat transfer coefficient U corresponds to the amount of heat transferred through the wall from the outside to the inside of the building. The solar factor S corresponds to the proportion of solar radiation transferred through the wall to the indoor environment. Under 600m altitude, the walls have to comply with the global heat transfer coefficient of the regulation (see Table 1), whereas above the solar factors have to be matched (see Table 2).

Table 1. Maximum values of global heat transfer coefficient U [1]

Vertical walls	Roofs
$U \leq 2$ W.m^{-2}.K^{-1}	$U \leq 0.5$ W. m^{-2}.K^{-1}

According to the traditional method, the global heat transfer coefficient U of a wall is obtained with the reverse of the global thermal resistance. The global thermal resistance is simply the addition of the thermal resistance of each wall layer and thethermal surface resistances due to convective exchanges with air on both sides of the wall. In this paper, the global heat transfer coefficient U was obtained from the heat density transfer equation (1)

$$U = \frac{\varphi_{wall}}{\Delta T} \tag{1}$$

φ_{wall} being the heat density through the wall and ΔT the temperature difference between the two air points on either side of this wall.

The wall solar factor can be obtained by dividing the thermal heat that passes through it by its incident solar radiation (2).

$$S = \frac{\varphi_{wall}}{\varphi_{i,solar}} \tag{2}$$

$\varphi_{i,solar}$ being the incident solar radiation on the considered wall.

Table 2. Maximum values of solar factor S [1]

Vertical walls	Roofs
$S \leq 0.09$	$S \leq 0.03$

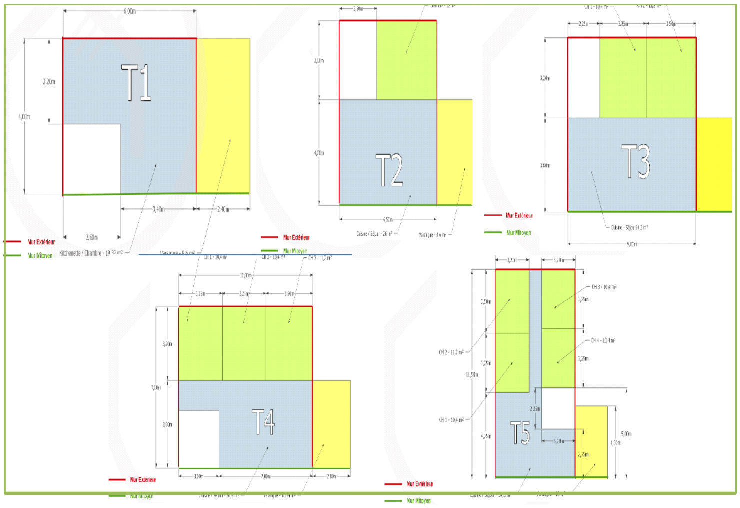
As the physical principle of the PCM is based on its phase change from solid to liquid, and inversely, , the two regulatory constraints U and S are impossible two comply with directly by calculation or estimation. So, it is necessary to compare the thermal behavior of the building with and without PCMon walls to evaluate its efficiency in comparison with traditional insulation materials.

3. Problem description

To be able to quantify the impact of the PCM on the thermal behavior of the building, we chose to model it with a building energy simulation code, validated by the scientific community and used by local design offices. A reference building has been chosen and several scenarios have been defined to highlight the use of PCM in buildings in compliance with the thermal regulation.

3.1. Building description

The chosen building is a residential one defined by previous local studies as in [2] and as shown in Figure 2. It can accommodate a family of four people (two parents and two children) with an inside volume of about 286 m^3 and a floor area of 80.5 m². An air renewing of one volume per hour (1 m^3/h ?) has been considered and internal loads due to standard equipment have been taken into account for sensible and latent heat [2]. For heat gains due to the occupants, a total power of 162 W has been considered, of which 70% for the latent part [2]. Furthermore, two types of heat gain due to electrical equipment have been defined. The first one is a base power of 250W for common electrical equipment throughout the day (television or computer for example). The second one consists of two power peaks at cooking times (12 am and 18 pm) of about 1000W for sensible heat and latent heat each. A door of 2 m² and two windows of 3 m² facing north and south respectively were also integrated in the model. The composition of the walls is given later in this paper in the description of the different studied scenarios. The heat transfer through the floor has been neglected by making it adiabatic. The roof of the building was made of two equal sides inclined at 21°, one facing north and the other south.



14
2
4

Figure 2: Plan view of the studied building [2].

3.2. Studied scenarios

Five building scenarios have been set up according to a type of wall to compare PCM material to traditional thermal insulation material. The first one is a reference building without thermal insulation in walls and obtained by the simplification of the second one. The second one is a traditional insulation type building based on previous local works [2]. The third one is the reference building where walls have been equipped with a commercial microencapsulatedPCM from Winco Technologies. The two last ones are imaginary PCMs that could be produced locally and based on the experimental observations of the MCP-iBAT project. These five scenarios are summed up in Table 3 with the abbreviations that are used to identify the results.

Table 3. List of the simulated scenarios and the corresponding abbreviations

Scenario number	Wall type	Insulation or PCM name	Abbreviation
1	Reference	-	ref
2	Insulated	Polystyrene	ins
3	Manufactured PCM	Paraffin PCM	com
4	Imagined PCM	PCM to design	PCM1
5	Imagined PCM	PCM to design	PCM2

The composition of each wall is given in Table 4 and Table 5 from the outer to the inner layer. The thermal properties of each material are presented in Table 6, and the particular properties of PCMsin Table 7 and Table 8.

Table 4. Composition of vertical walls from the outside layer to the internal one.

Scenario number	Composition from the outer to the inner layer			
1	Cinder block (200mm)	Air gap (20mm)	Plasterboard (13mm)	
2	Cinder block (200mm)	Polystyrene (20mm)	Plasterboard (13mm)	
3	Cinder block (200mm)	Air gap (20mm)	Plasterboard (13mm)	PCM Coated (4mm)
4	Cinder block (200mm)	Air gap (16mm)	PCM1 (4mm)	Plasterboard (13mm)
5	Cinder block (200mm)	Air gap (16mm)	PCM2 (4mm)	Plasterboard (13mm)

Table 5. Composition of roofs from the outer to the inner layer.

Scenario number	Composition from the outer to the inner layer			
1	Ribbed steel sheet (1mm)	Air gap (80mm)	Plasterboard (13mm)	
2	Ribbed steel sheet (1mm)	Polystyrene (80mm)	Plasterboard (13mm)	
3	Ribbed steel sheet (1mm)	Air gap (80mm)	Plasterboard (13mm)	PCM Coated (4mm)
4	Ribbed steel sheet (1mm)	Air gap (76mm)	PCM1 (4mm)	Plasterboard (13mm)
5	Ribbed steel sheet (1mm)	Air gap (76mm)	PCM2 (4mm)	Plasterboard (13mm)

Table 6. Thermal properties of wall materials.

Material	Conductivity ($W.m^{-1}.K^{-1}$)	Density ($kg.m^{-3}$)	Specific heat ($J.kg^{-1}.K^{-1}$)
Cinder Block	0,67	900	1250
Air gap	Calculation of thermal resistance based on air gap thickness		
Polystyrene	0,042	18	1450
Plasterboard	0,16	850	940
Ribbed steel sheet	16	8000	480

As can be seen in Table 8, the PCMs differ in their phase change properties. The properties of the two imagined PCMs were chosen to match the diversity of the climatic zones of the island. Indeed, several studies carried out in tropical climates showed that many different PCM types can be used to improve building thermal behavior according to their environment and the wall where it is installed [4-8]. The properties of the two fictitious PCMs were defined based on the experimental results of the MCP-iBAT project [9].

Table 7. Thermal properties of PCM materials.

Material	*State*	Conductivity ($W.m^{-1}.K^{-1}$)	Density ($kg.m^{-3}$)	Specific heat ($J.kg^{-1}.K^{-1}$)
PCM coating	Liquid	0.053	640	1100
	Solid	0.037	940	1100
PCM1	Liquid	0.13	640	1100
	Solid	0.2	940	1100
PCM2	Liquid	0.13	640	1100
	Solid	0.2	940	1100

3.3. Numerical modeling

This work has been achieved using a standard building energy simulation code EnergyPlus [10]. The PCM model is the one developed by NREL Laboratory and implemented in EnergyPlus [11] and named "EnergyPlus Hysteresis PCM Model".

The previous building and scenarios have been implemented in EnergyPlus and simulated in each of the four climatic zones. This has been achieved by setting up a building description file for each scenario and simulating it with meteorological data corresponding to each reference city. These simulations led to five simulation result files for each climatic zone presented below.

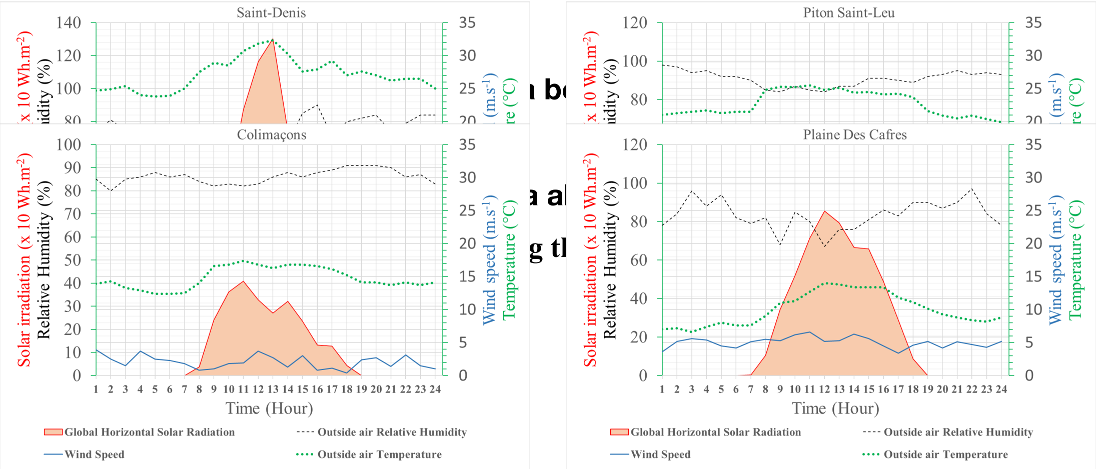
Table 8. Phase change properties of PCM materials.

Material	Latent heat of phase change (J.kg^{-1})	Phase change type	PCR[1] (°C)	PCT[2] (°C)
PCM coating	138000	Melting	26.9-29.9	29
		Freezing	26.4-22.8	24.4
PCM1	195000	Melting	19.5-22	21
		Freezing	19.5-18.5	19
PCM2	145000	Melting	17.5-28.5	24.5
		Freezing	21.5-14.5	20.5

4. Results and discussion

The simulation results have been analyzed and separated into three parts to show both the impact of the different materials on the building temperatures.The interest was to study the PCM solutions from the thermal comfort point of view and for their ability to comply or not with the thermal regulations in use in Reunion Island. The first part focuses on the behavior of the building's indoor air temperatures. The second part focuses on solar factors of walls for a building located in a climatic zone below an altitude of 600m. The last part shows the compliance of the results with the other requirements of the thermal regulation for a building located above an altitude of 600m.

For the three following parts, we analyzed two representative days of the year: a hot day in the summer (March 22nd) and a cold day in the winter (August 7th). As the compliance of solar factors is needed for an altitude below an altitude of 600m, we chose to present the meteorological data of Saint-Denis and Piton Saint-Leu on March 22, in Figure 3. Similarly, we decided to show the meteorological data of Colimaçons and Plaine Des Cafres on August 7th to study global heat transfer coefficients (Figure 4).



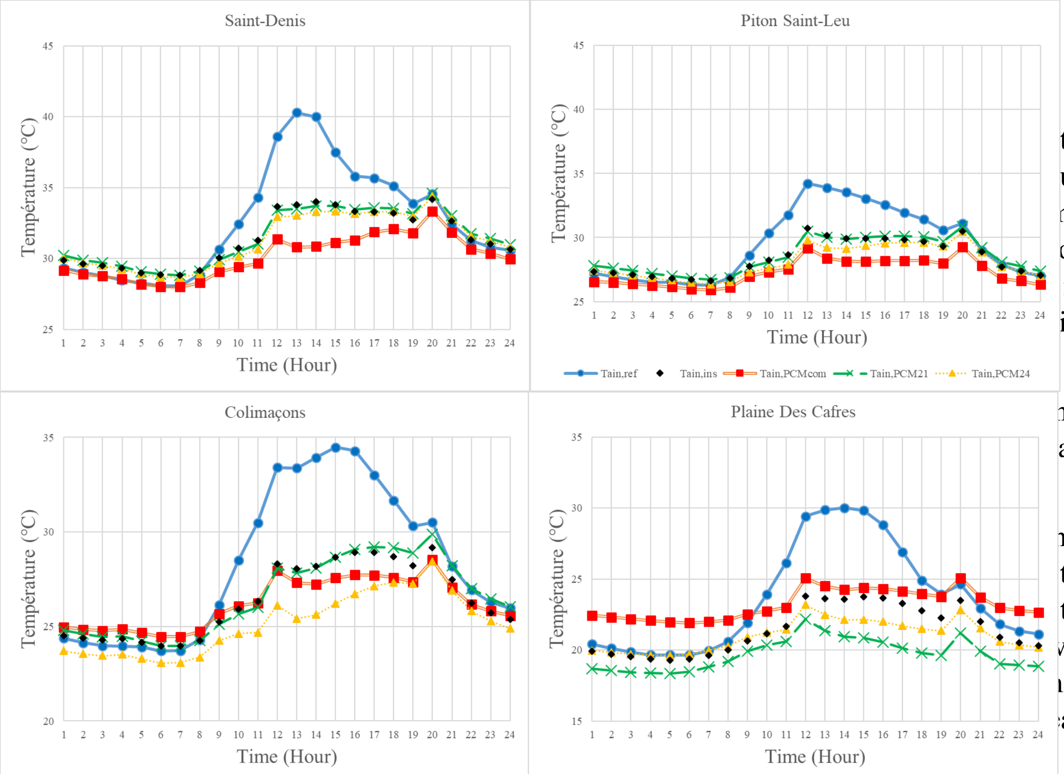
4.

---

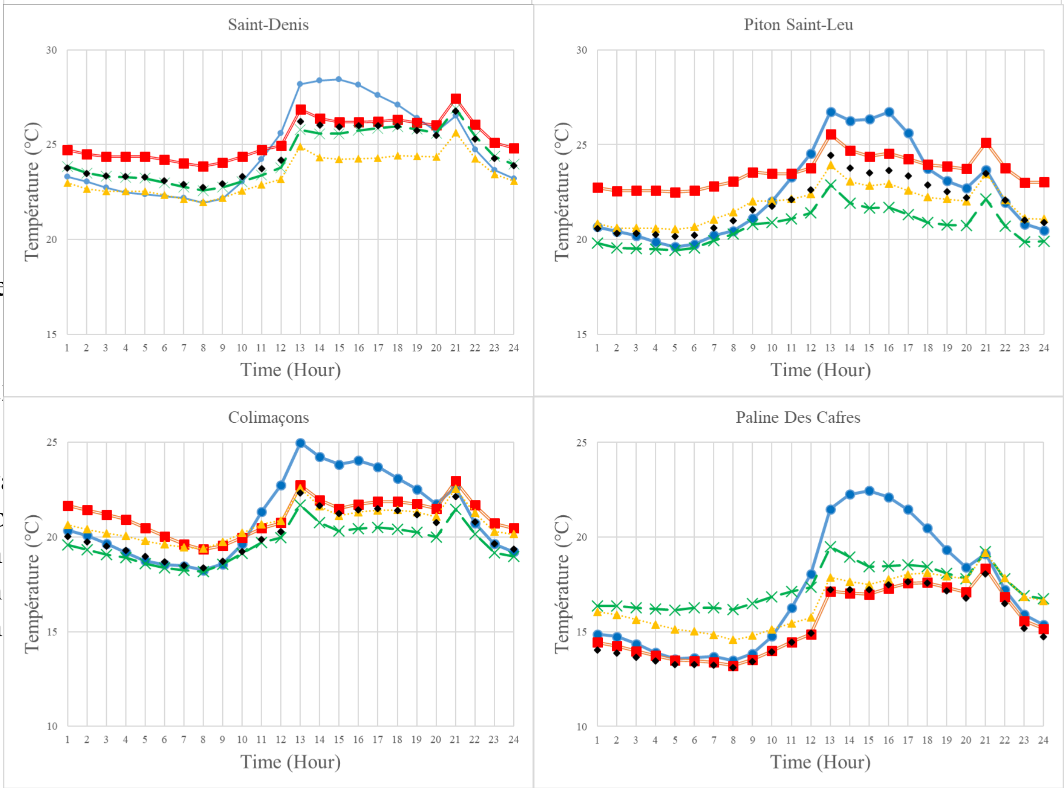
[1] P

[2] P

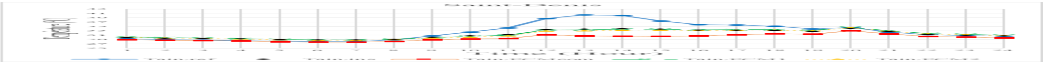
The aim of studying the thermal behavior of the building's indoor air temperature in such work is to verify the impact of the insulation and of the PCM. Figure 5 compares the reference building (without insulation or PCM) with regulation-complying insulation and the three studied PCM materials for a hot day. As it can be observed, insulation and PCM materials all allow the decrease of the building's indoor air temperature. In all cases, PCMs are at least as effective as thermal insulation.



to
be ut
10 ns
m of
8. is
PC in
ag
ne
bu as
tra
ng
th to
be to
be vn
th nis
wa eat
lo



al
he
4.
ed
wa ic
zo as
m in
th ne
in



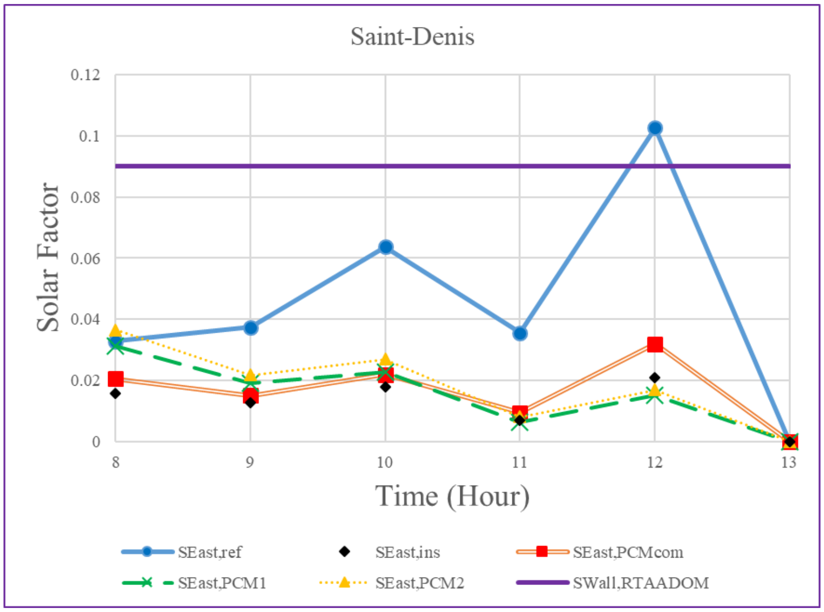


Figure 7: Solar factor of east vertical walls on March 22nd.

Figure 7 presents the solar factors of east vertical walls at Saint-Denis on March 22nd. The RTAADOM threshold is also represented on Figure 8. As it can be seen, every studied PCM solutions enabled to reach the RTAADOM requirements.

Figure 8 presents the solar factors of north roofs at Saint-Denis on March 22nd. Except for the 8 a.m. slot, where the incident radiation is too weak compared to the convective exchanges to correctly evaluate the solar factor, it can be seen that every studied PCM solutions also allow reaching the RTAADOM thresholds for roofs.

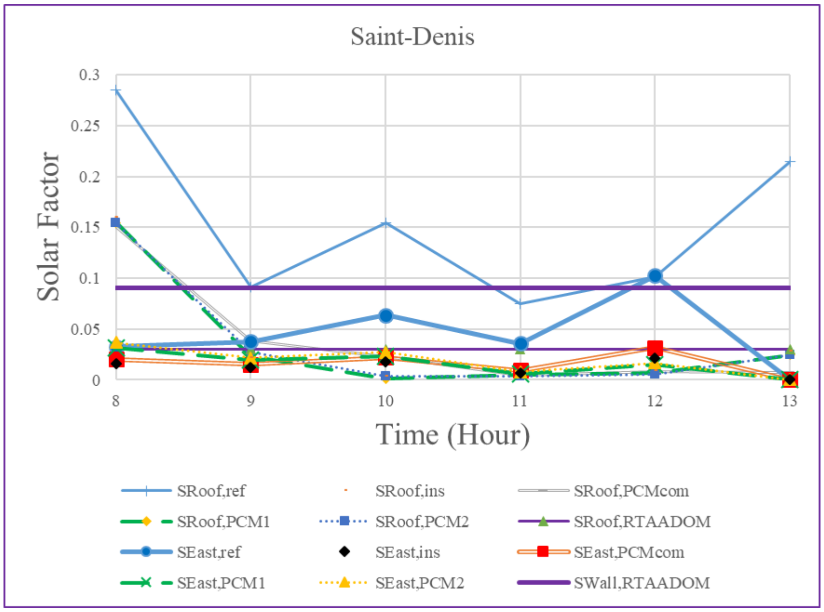


Figure 8: Solar factor of North roofs on March 22.

4.3. Global heat transfer coefficients

Like solar factors, the global heat transfer coefficient study can be limited to the cities above 600m altitude. We chose to show the results obtained at Plaine Des Cafres in Figures 9 and 10.

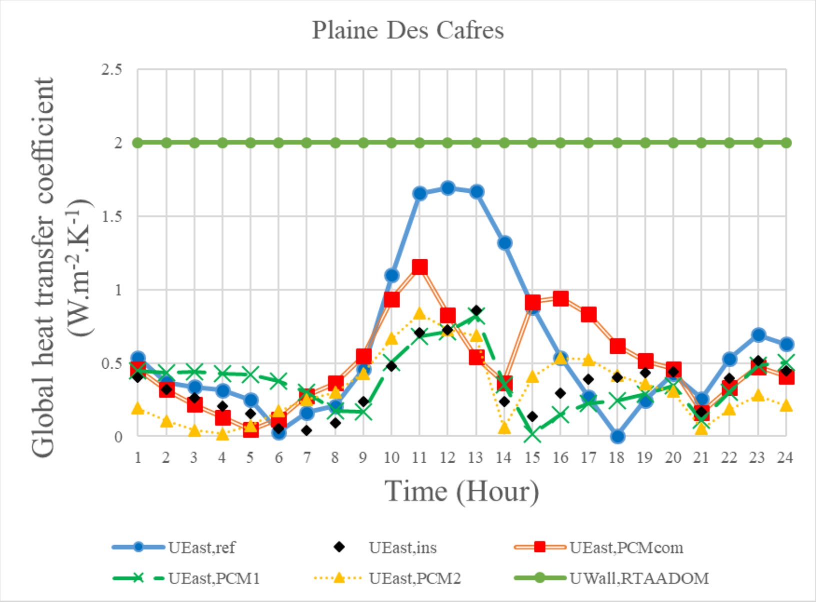


Figure 9: Global heat transfer coefficient of east vertical walls on March 22nd.

Figure 9 shows the results for vertical walls and the compliancy of PCM solutions with RTAA DOM regulation.

Figure 10 shows only the manufactured PCM and PCM1 comply with RTAADOM thresholds. During the day, when solar radiation increases, the global heat transfer coefficient threshold is not respected. Indeed, this method of evaluation of the global heat transfer coefficient is only valid when the solar radiation is low or close to zero, i.e. before 7 a.m. and after 7 p.m. according to meteorological data presented in Figure 4.

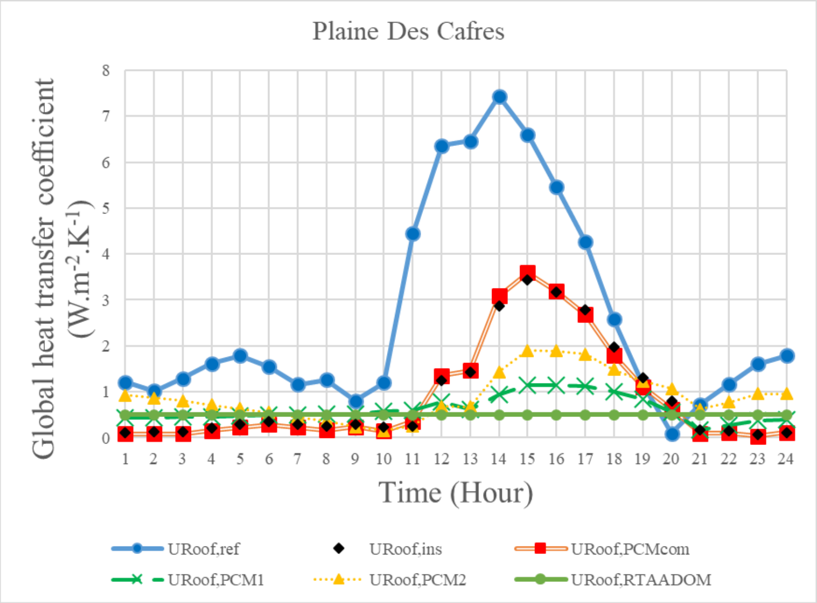


Figure 10: Global heat transfer coefficient of North roofs on March 22.

5. Conclusion and perspectives

A numerical study of 3 PCMs has been presented in comparison with a reference building and an insulation material complying with the thermal regulation in use at Reunion Island. The regulations thresholds and the island's climatic context have been explained. After describing the studied building and the modeling methodology, the simulation results have been discussed.

These results have shown that they can help improve indoor comfort conditions by positively influencing the building's indoor air temperature. On hot days, the use of PCMs can lead to a reduction up to 10°C, similarly to traditional insulation. On cold days, the same benefits have been observed to keep the heat in the building.

The three types of PCM, with different temperature ranges of melting (or freezing) and different latent heats, from 19 to 29°C and 138 to 195 kJ.kg-1 respectively have shown various advantages and disadvantages. According to these parameters and climatic zone, each type of PCM can be helpful. It also seems that the building thermal loads can impact the choice of the best PCM.

Future studies should highlight the impact of building thermal loads on PCM design, particularly from a comfort point of view. It will also be interesting to study the combination of several different layers of PCM to achieve better building energy consumption, thermal regulation thresholds and user's comfort.

6. ACKNOWLEDGEMENTS

This work was carried out within the framework of the FEDER MCP-iBAT project funded by Region Réunion and Europe. The authors would also like to thank them warmly for their trust.

7. References

[1] Code de la construction et de l'habitation, Article R162-1, modifié par Décret n°2013-1296 du 27 décembre 2013 - art. 2 et Arrêté du 11 janvier 2016 **(2016)**

[2] J. Castelnau and D. Bigot, Guide de pose des Isolants à La Réunion, CIRBAT and University of La Réunion, France **(2017)** URL :https://www.isolation.re

[3] CESER, Diagnostic et vision pour un usage raisonné et concerté des matériaux de construction nécessaires à un aménagement durable de La Réunion, France **(2021)**

[4] P. Boobalakrishnan, P. M. Kumar, G. Balaji, D. S. Jenaris, S. Kaarthik, M. J. P. Babu, K. Karthhik, Thermal management of metal roof building using phase change material (PCM), Materials Today: Proceedings 47 **(2021)**

[5] M. Song, F. Niu, N. Mao, Y. Hu, S. Deng, Review on building energy performance improvement using phase change materials, Energy and Buildings 158 **(2018)**

[6] M. Bimaganbetova, S. A. Memon, A. Sheriyev, Performance evaluation of phase change materials suitable for cities representing the whole tropical savanna climate region, Renewable Energy 148 **(2020)** 402–416.

[7] J. Lei, J. Yang, E.-H. Yang, Energy performance of building envelopes integrated with phase change materials for cooling load reduction in tropical Singapore, Applied Energy 162 **(2016)**

[8] A. Sheriyev, S. A. Memon, I. Adilkhanova, J. Kim, Effect of phase change materials on the thermal performance of residential building located in different cities of a tropical rainforest climate zone, Energies 14 **(2021)**

[9] B. Malet-Damour, D. Bigot, J.P. Habas, L. Trovalet, L. Liu and N. Hammami, MCP-iBAT project reports, European FEDER, Reunion Island Region, France **(2018-2022)**

[10] Crawley, Drury B, Linda K. Lawrie, Curtis O. Pedersen, and Frederick C. Winkelmann. EnergyPlus: Energy simulation program. ASHRAE Journal 42 **(2000)**

[11] Lee, Edwin S. EnergyPlus Hysteresis PCM Model: Cooperative Research and Development Final Report, CRADA Number CRD-16-639. United States **(2018)**

[12] K. Faraj, M. Khaled, J. Faraj, F. Hachem, C. Castelain, A review on phase change materials for thermal energy storage in buildings: Heating and hybrid applications, Journal of Energy Storage 33 **(2021)**

[13] L. Yang, X. Jin, Y. Zhang, K. Du, Recent development on heattransfer and various applications of phase-change materials, Journalof Cleaner Production 287 **(2021)**

[14] L. F. Cabeza, A. Castell, C. Barreneche, A. D. Gracia, A. I. Fernández, A. de Gracia, A. I. Fernández, Materials used as pcm in thermal energy storage in buildings: A review, Renewable and Sustainable Energy Reviews 15 **(2011)**.

[15] C. Barrenechea, H. Navarro, S. Serrano, L. F. Cabeza, A. I. Fernández, New database on phase change materials for thermal energy storage in buildings to help pcm selection, Energy Procedia 57 **(2014)**

[16] B. Lamrani, K. Johannes, F. Kuznik, Phase change materials integrated into building walls: An updated review, Renewable and Sustainable Energy Reviews 140 **(2021)**

Authors

Dr. Dimitri BIGOT*, Associate professor at University of Reunion Island, PIMENT Laboratory, Researcher in Building Physics

Dr. Bruno MALET-DAMOUR, Associate professor at University of Reunion Island, PIMENT Laboratory, Researcher in Building Physics (Multimodal Comfort and Efficiency of Built Spaces)

Dr. Lionel TROVALET, Ph.D. in Energy and research engineer of the MCP-iBAT project, PIMENT laboratory

Ms. Lisa LIU, Engineer in Physics and Energy and design engineer of the MCP-iBAT project, PIMENT laboratory

Dr. Nadia HAMAMMI, Ph.D. in Chemistry and research engineer of the MCP-iBAT project, University of Montpellier, ICGM

Pr Jean-Pierre HABAS, Full professor, University of Montpellier, ICGM, Researcher in physical chemistry of polymers

*Corresponding author: dimitri.bigot@univ-reunion.fr