# Investigation of the appropriate phase change temperatures for an enhanced passive indoor thermal regulation in a semi-arid climate: Tunable PCM case.

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**Abstract.** Researchers in the building industry are becoming increasingly interested in phase change materials (PCM). As these PCMs might provide passive temperature adjustment, this will aid in lowering the energy consumption of Heating, Ventilation, and Air-Conditioning (HVAC) devices. To prevent leakage during phase change, an enclosure is needed when installing PCMs in buildings. The need to assess the passive thermal regulation of the PCMs at different melting temperature is necessary, so that we can get a sense of how much energy will be saved for this passive thermal regulation method. Hence, this paper will evaluate and identify the optimum phase change transition temperatures during the whole year for wall composition with tunable PCM in a semi-arid climate. Thus, the main objective of this study is to assess the indoor air temperature fluctuation reduction and the PCM activation while suggesting an appropriate phase change transition temperature that can be beneficial in the whole year and very practical. The results reveal a good passive temperature regulation during the summer period.

## 1 Introduction

Around half of all worldwide heat consumption across all industries is accounted for by heat consumption in buildings. Additionally, the need for cooling is far more prevalent in Morocco than the requirement for heating [1]. Moroccan energy consumption has grown by about 7% annually over the past decades [2]. Therefore, we must exercise caution or this will increase the risk of climate change, which can undoubtedly have devastating effects on the globe. It should be mentioned that the most popular energy source worldwide is heat, accounting for half of all energy use in 2018 [3]. The environmental impact of buildings can be lessened by creating high-performance structures with low energy and resource use. However, steps must be taken to reduce consumption and improve buildings' energy efficiency while maintaining comfort.

Furthermore, numerous research [4]–[7] have demonstrated that a comfortable range for indoor air temperature is 20 °C to 30 °C. Although somewhat the comfortability dependent greatly on high temperature transitions from very high to very low HVAC setpoints. Still, there is a need for lowering the energy to reach and stabilize the indoor air temperature at a particular setpoint. Consequently, a passive thermal regulation solution is required, which might significantly cut the energy used by the HVAC systems [8].

Researchers in the construction industry are interested in phase change materials (PCM) because they can passively regulate and stabilize indoor air temperature [9], which improves indoor air quality and lowers energy use for HVAC systems [10]. In addition, for the past ten years, researchers have been studying the use of PCMs in building envelopes. The issue with employing PCMs in building envelopes is that when a phase transition takes place, the PCM transforms from a solid to a liquid, requiring the prevention of leaks. Many PCM implementations, however, have been developed [11] including Shape-stabilized PCMs [12], Nano/Micro-encapsulated PCM [13] and Macro-encapsulated PCM [14], [15]. This made it easier to advance the use of PCM in all building envelope components, including windows, walls, floors and ceilings [16]–[19]. In order to reduce energy consumption through the ground and limit solar heat gain, it is strongly encouraged to use PCM on exterior walls, roofs, and floors [20]. The usage of PCMs on floors, external walls, and roofs has demonstrated significant indoor air temperature stabilization. Additionally, it has been demonstrated in the literature that improving a building's envelope through the incorporation of PCM can result in energy savings up to 90% [21]. Moreover, the placement of the PCM on walls and in the interior side of the external wall envelope has been widely recommended and shown great indoor temperature stabilization results [22]–[25].

The assessment of phase transition material potential in semi-arid climates is so lacking in the literature. Nevertheless, the external temperature affects the phase change materials' efficiency and utility. It normally enables the PCM with a phase change temperature close to that outdoor temperature to stabilize it; but, if the annual temperature variation is considerable, the PCM wouldn't be active throughout the year passively stabilizing the inside temperature. As a result, this study recommends evaluating a novel, as of yet undeveloped perspective on phase change materials [26], [27], which is tunable PCM. However, a numerical assessment of tunable

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PCM technology's potential is necessary. so that we can determine whether or not the PCM's tunability is indeed useful. In this work, we consider a tunable PCM that can be controlled to modify its temperature at least once per day. We will assess this in the summer for the Moroccan city of Ben Guerir, which serves as a representative city for a semi-arid climate.

## 2 Methodology

The tunable PCM chosen for this study, was a fictional PCM that can shift its phase change temperature at least once a day, which mean that it can have two different phase change temperature in one day. We have also supposed that this phase change temperature shift happens at a certain time on the day.

$$c_{p,PCM}(T) = c_{p,solid}.(1 - f(T)) + c_{p,liquid}.f(T) + L_m \frac{df(T)}{dT} \quad (1)$$

$$f(T) = \begin{cases} 0, & T < T_{solid} \\ ]0,1[, & T_{solid} \le T \le T_{liquid} \\ 1, & T > T_{liquid} \end{cases} \quad (2)$$

This can be modelled using the apparent heat capacity method shown in equation ***(1)***, which consists of three terms, two are sensible heat terms for solid and liquid state and the last term is for the latent heat distribution in the phase change temperature. Generally, the phase change temperature is described by a range from $T_{solid}$ to $T_{liquid}$, still, the peak is modelled in the middle of the range, which has a constant value. We can change the phase change temperature peak, from a constant value to a variable one, this is shown in Fig. 1. Moreover, we can evaluate the PCM activation by assessing the term shown in equation ***(2)***. This term is the melt fraction which is between 1 and 0, if its equal to 0 its mean that the PCM is solidified and when its equal to 1, it means that the PCM is in liquid state. Thus, we can count the time, the PCM melt fraction is not equal to 0 or 1, in order to assess the percentage of the PCM activated during that day.

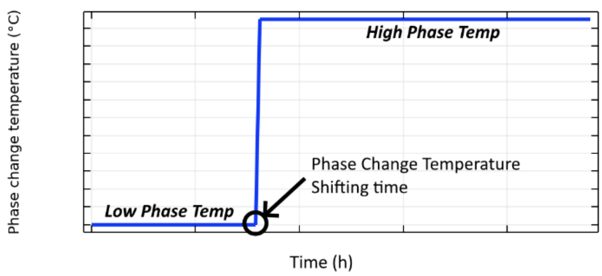


**Fig. 1.** Tunable PCM at least once a day (2 temperature transitions)

COMSOL Multiphysics is used to model the apparent heat capacity method. The numerical model is verified against the experimental results of Kuznik et al [28], the validated model is shown in the numerical validation section. The geometrical and PCM thermophysical properties are configurated according to the experimental setup of Kuznik et al [28]. The numerical model consists of three layers, which is shown in Fig. 2.

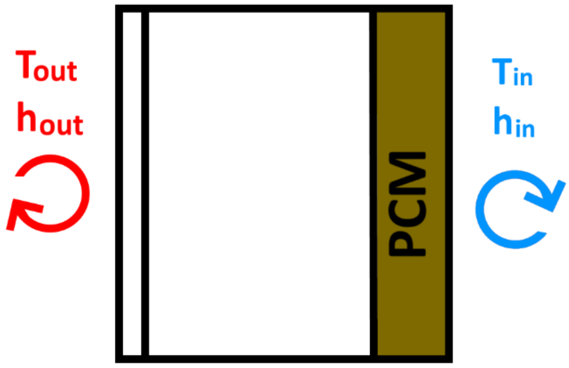


**Fig. 2.** Numerical model

The first layer consists of 2 mm aluminium plate, the middle layer is filled with 60 mm polyurethane foam (insulation) and finally the last layer is a 5 mm PCM layer for the case with PCM and for the case without PCM, this last layer consists of a 5mm cardboard. The assumptions that were considered in the numerical model are the following:

- No natural convection is considered inside the PCM.
- The external ($h_o$) and internal ($h_i$) heat transfer coefficients are equal to 5 W/m$^2$.K and 20 W/m$^2$.K.
- The radiation heat transfer was neglected.
- The wall envelope upper and lower boundaries are considered symmetrical.

The period of study is only in summer as shown in Fig. 3, because for semi-arid climates, the demand for cooling during summer is much higher than heating or cooling during other seasons. So, the outdoor temperature during summer is usually between 14°C to 46°C. So, we will model a sinusoidal outdoor temperature that varies between this range. For the tunable PCM, in the initial state it will have 2 phase change temperature, that can be shifted after 10 hours (because at 10 am, the temperature during a summer day is already high and above 32 °C), meaning that the day will be divided in to two halves with different phase change temperature. We will start by evaluating the low phase temperature before shifting, then the high phase temperature after shifting and finally we will assess the phase change temperature shifting time.

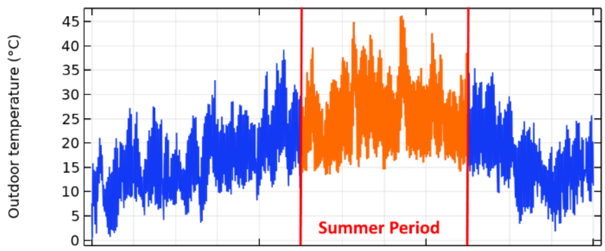


**Fig. 3.** Outdoor temperature of Benguerir city (semi-arid climate case)

## 3 Numerical Validation

We can see the numerical results for both cases, without and with PCM in the Fig. 4 and Fig. 5. The results show a good agreement between experimental and numerical results with a maximum deviation of 11% and 4% for the case with and without PCM, respectively.

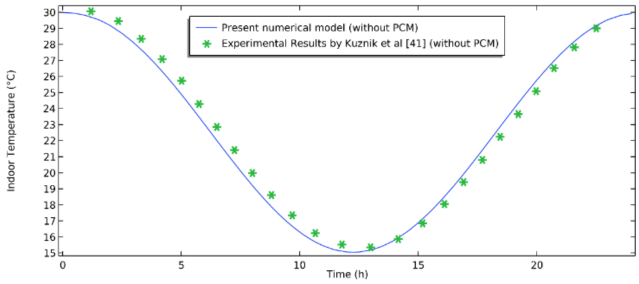


**Fig. 4.** Validation of the numerical model for the case without PCM compared to the experimental results of Kuznik et al [28].

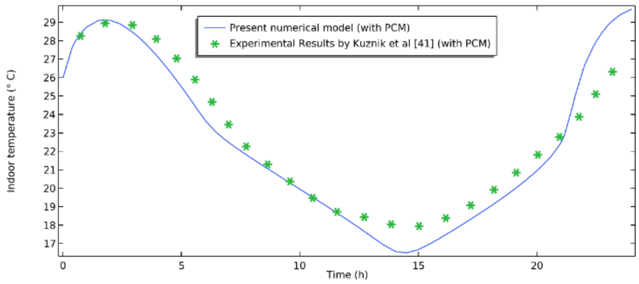


**Fig. 5.** Validation of the numerical model for the case with PCM compared to the experimental results of Kuznik et al [28].

# 4 Results & Discussions

## 4.1 Low phase temperature assessment

**Fig. 6** shows the PCM activation for the different low phase change temperatures during a typical hot day in a semi-arid climate, it can be observed that the low phase change temperature that has the highest PCM activation is 18 °C. The PCM activation exceeds a difference of 80% and when compared with a low phase temperature of 24 °C, which is typically a good phase change temperature for buildings thermal comfort applications.

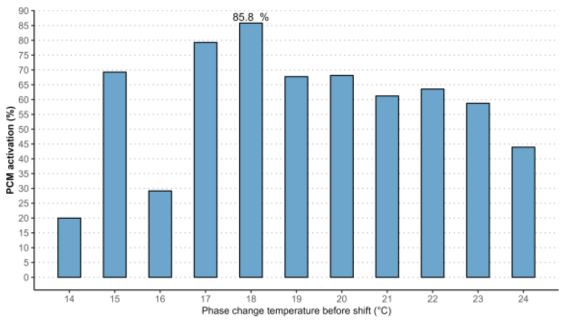


**Fig. 6.** Low phase temperature impact assessment on PCM activation during a typical hot day in summer for semi-arid climate.

## 4.2 High phase temperature assessment

**Fig. 7** shows the PCM activation for the high phase temperature cases, as we increase the high phase temperature after the shift, the activation increases, we can observe 3 different peaks at 30°C, 39°C and 41 °C, the high phase temperature with the highest peak is shown to be at 41 °C. This high phase temperature was able to reach a PCM activation of 85.8% during a typical hot day in semi-arid climate.

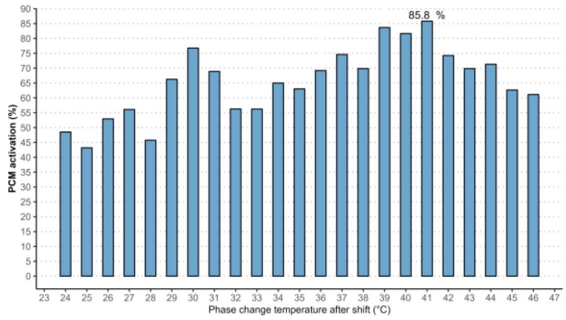


**Fig. 7.** High phase temperature impact assessment on PCM activation during a typical hot day in summer for semi-arid climate.

## 4.3 Phase change temperature shifting time assessment

**Fig. 8** shows the PCM activation for the different phase change temperature shifting time, we can observe that the highest PCM activation is still at 85.8%, still, this can be achieved if we shift from a low phase temperature to high phase temperature after 8 hours to 11 hours. However, if we shift earlier or later than this, the PCM activation suffers a lot.

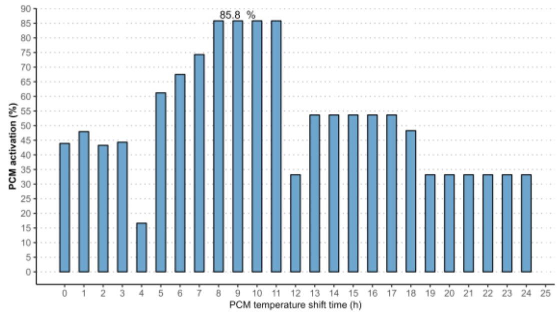


**Fig. 8.** Phase change temperature shifting time impact assessment on PCM activation during a typical hot day in summer for semi-arid climate.

## 4.4 Tunable PCM performance evaluation

We can now evaluate and compare the indoor temperature fluctuation reduction of regular PCMs that melts at 18°C and 41°C with a tunable PCM that has a low phase temperature of 18°C, high phase temperature of 41°C and a phase temperature shift time of 8 hours. This is shown in **Fig. 9**, we can observe that the PCM case which melt at 18°C has stabilized the temperature between 0 to 5 AM, however, it didn't have any effect during the rest of the day. The same can be inversely said for the case of PCM that melts at 41°C. However, the tunable PCM was able to take the good characteristics of both cases and even enhance it and offer a larger stabilized temperature at 41 °C.

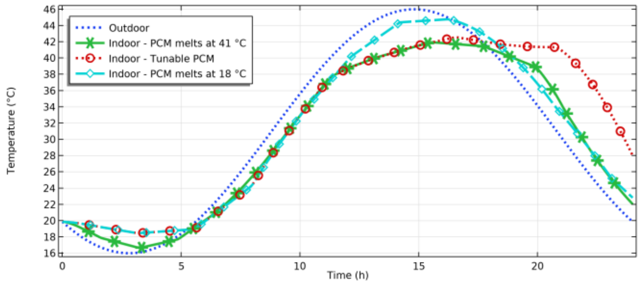


**Fig. 9.** Indoor temperature fluctuation comparison during a typical hot day in summer for tunable PCM and regular PCMs (semi-arid case).

## 5 Conclusion

In this study we have evaluated a high technology tunable PCM, which can shift its phase temperature at least once a day with ordinary PCM cases, the numerical model was setup by using the apparent heat capacity method and validated with experimental data from the literature. The tunable PCM was able to achieve an 85.8% PCM activation for the case with a low phase temperature of 18 °C, high phase temperature of 41 °C and a phase change temperature shift time of 8 hours to 11 hours. The tunable PCM has shown a great indoor temperature passive regulation during a typical hot day in a semi-arid climate.

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