

# Thermal efficiency analysis of buildings with phase change materials

## Análisis de eficiencia térmica de edificios con materiales de cambio de fase

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### ABSTRACT

Increasing global temperature is alarming the need for construction industry to have thermally efficient building materials. Incorporating Phase Change Materials (PCM) in buildings is widely accepted method for reduction in temperature, thereby achieving better thermal efficiency. This paper focuses on the assessment of thermal performance of PCM-incorporated building under tropical climatic condition. The simulation process was carried out using Design Builder Software and the developed building model is validated with the results available in the literature. A parametric study is also performed in order to identify the effect of different parameters like building orientation, window to wall ratio, ceiling height and construction material on the indoor air temperature. The results showed that the maximum reduction was up to 2.76°C.

Keywords- Thermal Efficiency, Tropical climate, PCM

### RESUMEN

El aumento de la temperatura global está alarmando la necesidad de que la industria de la construcción cuente con materiales de construcción térmicamente eficientes. La incorporación de Materiales de Cambio de Fase (PCM) en edificios es un método ampliamente aceptado para reducir la temperatura, logrando así una mejor eficiencia térmica. Este documento se centra en la evaluación del rendimiento térmico de edificios incorporados en PCM en condiciones climáticas tropicales. El proceso de simulación se realizó utilizando el software Design Builder y el modelo de construcción desarrollado se valida con los resultados disponibles en la literatura. También se realiza

un estudio paramétrico para identificar el efecto de diferentes parámetros como la orientación del edificio, la relación ventana-pared, la altura del techo y el material de construcción sobre la temperatura del aire interior. Los resultados mostraron que la reducción máxima fue de hasta 2,76 ° C.

Palabras clave- Eficiencia térmica, clima tropical, PCM

## INTRODUCTION

Global rise in the atmospheric temperature is a major issue in the current scenario of the earth. Thermal efficiency has to be achieved inside the buildings for the comfort of inhabitants. But nowadays, most of the buildings are thermally discomfort due to the outdated building materials which are not thermally efficient. When used as construction material, phase variable thermal properties of the materials has crucial role, as the system efficiency depends on the thermal properties of the materials (A.Z. Rumina and K. Nowaka, 2015).

Air conditioners are usually used for achieving thermal comfort inside the buildings. But these air conditioners are causing severe harm to the environment. The refrigerant gas used in air conditioners are toxic. On other hand, air conditioner is an electronic device and it demands heavy energy consumption. This causes resource depletion and other environmental impacts. Building elements get deteriorated faster due to excessive heat absorption of building structure.

The effectiveness of PCM application is highly dependent on the climatic conditions, PCM melting temperature and on the occupants behavior (Saffari et. al., 2017). Study on the performance of PCMs in residential housing for different climates results on strong increase in the apparel thermal inertia of the room allowing a temperature reduction (Guarinova et. al., 2017). The buildings located in a hot summer and cold winter climate has the highest value of energy efficiency with PCM (X. Mi et. al., 2016). Encapsulated PCM based heat exchanger is able to reduce heat gain by approximately 50% as well as mean air temperature by 6°C. (Garg et al., 2018).

## METHODOLOGY

Using PCM to achieve thermal efficiency in buildings is comparatively a new research subject. But the need of the hour for this subject has made a vast collection of literatures on this topic. All the literatures gave an enormous data about the subject. Thus starting from literature review is very helpful in getting knowledge in the subject. Then the validation process makes good working knowledge about the simulation procedures. From the literature reviews, some of the factors which are identified to have major influence on

thermal efficiency of the building. Parametric study using those factors then makes a turning point in this project. And a detailed analysis on the peak temperature performance when PCM's applied finishes the project.

## RESULT AND DISCUSSION

Validation: The building used for thermal calculation was virtually made in the simulator (Bimaganbetova et al., 2020). The simulation software used is Design Builder. Phase change materials can be applied into building envelope to reduce the energy and fossil fuel consumption as well as to make the building more sustainable.

A two-story residential building as shown in Figure 1 was used in this research for simulation purposes. The building has floor dimensions of 9.2 x 12.2 m and the height of each story is 2.6 m and located at Bangalore. It has one door which is facing southern side (1.2 m x 2.2 m) and several windows (1.2 m 2.0 m) that are placed at 1 m above the floor level. The building envelope and its thermo physical properties were adopted from (Bimaganbetova et al., 2020). For the analysis of thermal and energy performance, PCMs with a latent heat of 219 kJ/kg and a melting temperature range from 21°C to 31°C were considered. The results of the literature and present study were plotted as Figure 2.

Results of thermal performance during a summer day revealed that temperature fluctuations in PCM integrated building dropped by 2.76°C even when the Heating ventilation and air conditioning (HVAC) system was switched off. From energy analysis, this research confirmed that the narrow range of PCMs (PCM25-PCM29) were found to be optimum for this climate zone. Incorporation of PCM in buildings located in a tropical climate is feasible.

PCM having higher melting point demonstrate better results in the climate where cooling is dominant. During daytime, PCM layer absorbs the heat from outside when the outside temperature is higher than the melting point of PCM. Hence, the PCM integrated residential building shows lower indoor temperature during hot time and reduces the maximum indoor temperature. Also, when the outside temperature is minimum, then the indoor temperature increases due to the solidification process of PCM (Hasan et. Al., 2018).

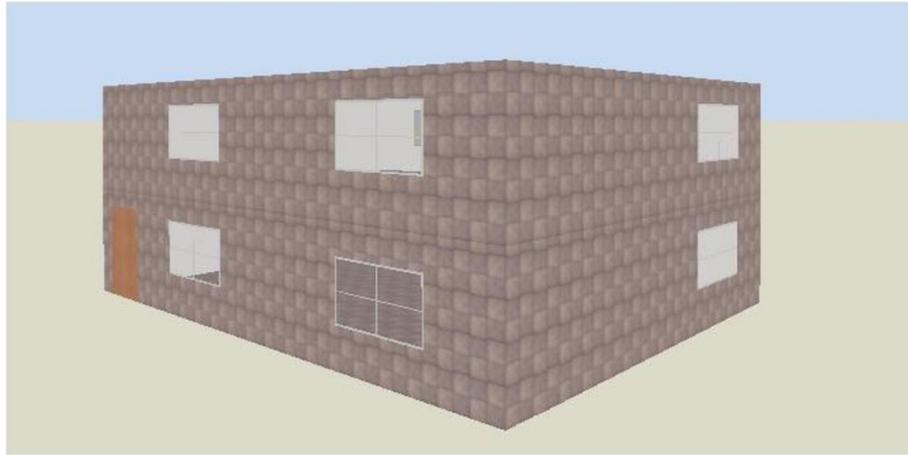


Fig 1: Two-story residential building model

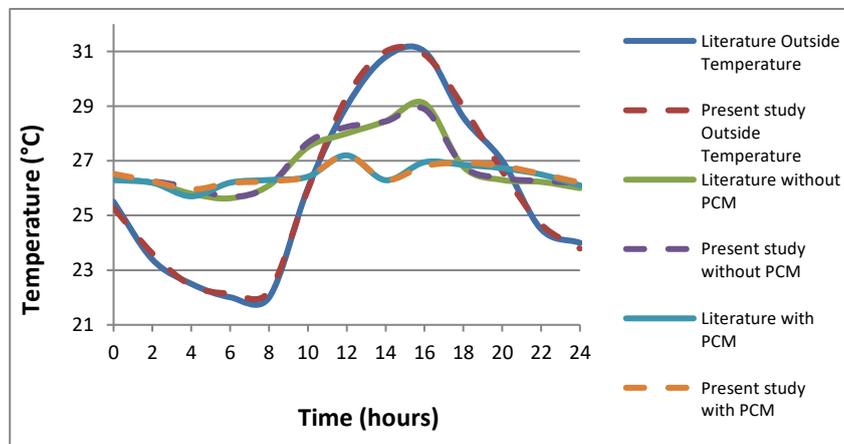


Fig 2: Validation Study Parametric Study

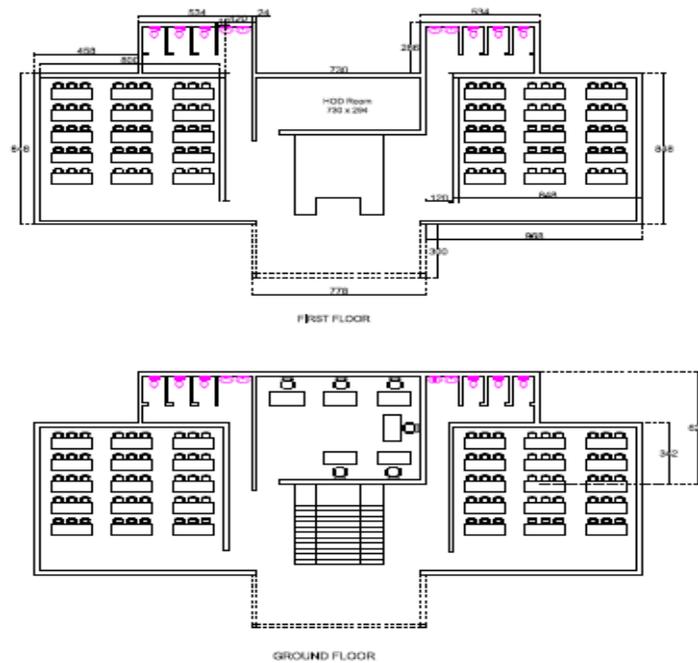


Fig 3: Plan view of simulated Building

From the literature reviews and present numerical study, some of the factors which are identified to have major influence on thermal efficiency of the building are orientation of the building, window to wall percentage, material used for wall construction and ceiling height.

The orientation of the building is a major factor determining the interior temperature of the buildings. When the sun moves from East to West, if the building openings face direct sunlight, it can lead to high temperature inside the buildings. Also, when the orientation is aligned as per the wind direction, natural airflow is sustained inside the building and thus the temperature is maintained comfortably. Optimum orientation can give natural lighting and natural ventilation for the building. Different orientations was given to a building and the following result is evolved.

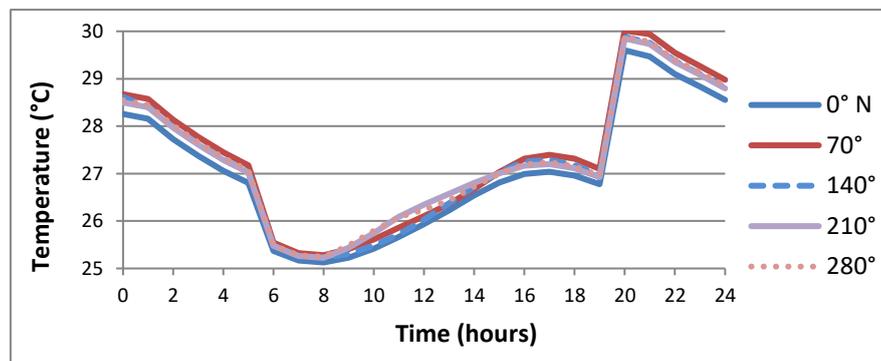


Fig 4: Thermal performance of building in different orientations without PCM

Windows maintain the exterior and interior temperature equilibrium of the buildings. But, it is seen that when the windows are increased, the heat outside the building is directly entered to the interior. This some times makes discomfort for inhabitants. Natural ventilation is necessary, but it should be only in optimum value. From the simulations ran with North facing (optimum orientation identified), it is found that optimum value for window to wall percentage is 20%.

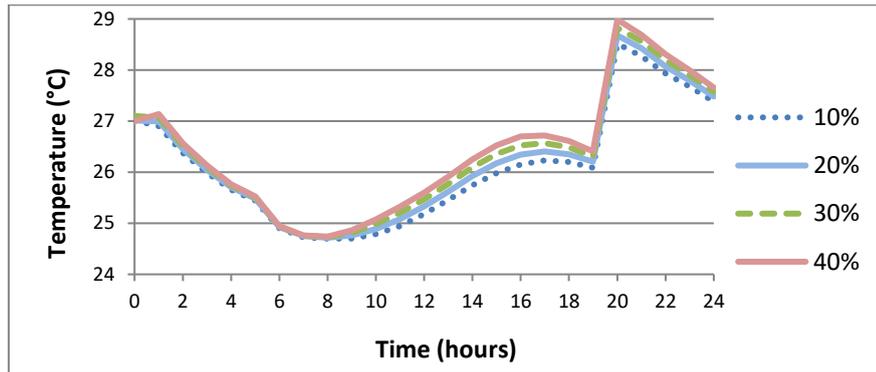


Fig 5: Thermal performance of building in different window to wall percentage and North orientation without PCM

Construction material market has wide varieties of materials. Concrete which is commonly used in wall construction is a thermally inefficient material. Simulation was ran among AAC blocks, Solid concrete blocks, aerated concrete bricks and burned bricks by fixing orientation towards North and 20% window to wall ratio.

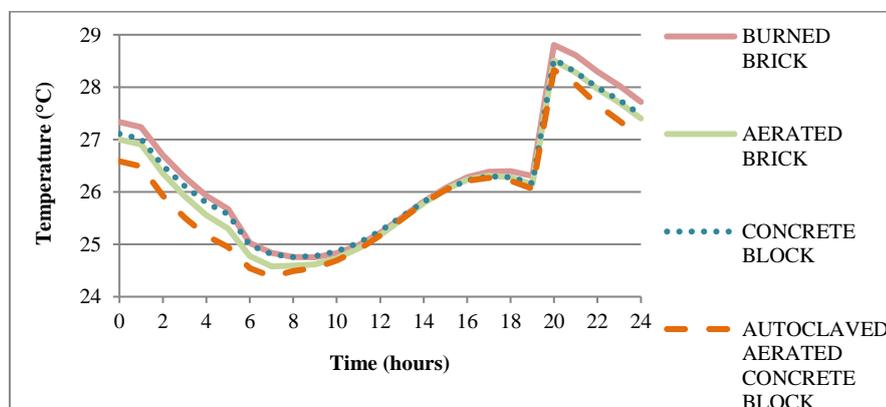


Fig 6: Thermal performance of building in different building blocks, 20% window to wall percentage and North orientation without PCM

Warm air always moves upwards. So providing enough space to accommodate hot air in the top of room can decrease the temperature discomfort for the habitants who are at bottom. A simulation was ran to find the optimum value of ceiling height by fixing north orientation, 20% window to wall ratio an AAC building blocks.

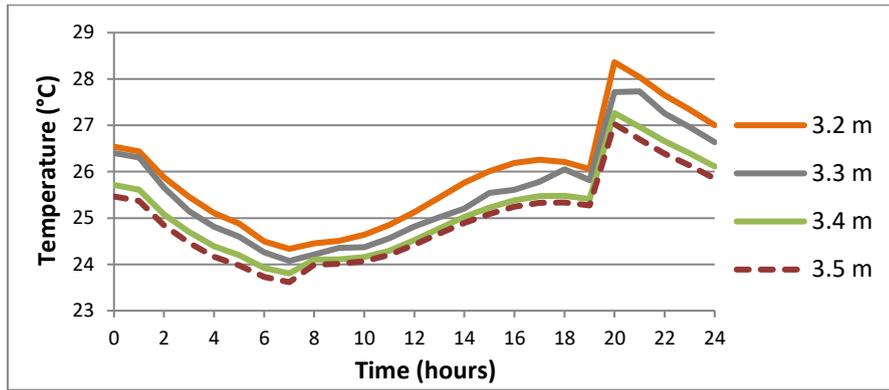


Fig 7: Thermal performance of building in different building heights, AAC building blocks, 20% window to wall percentage and North orientation without PCM

The optimum orientation of the building to obtain minimum indoor temperature is towards North, the optimum window to wall percentage is 20%, The optimum material used for wall construction to is AAC blocks and the optimum ceiling height of the building is 3.5 m.

From the literatures, it is found that PCM 29 is the best suited PCM for tropical climate. Thus PCM 29 is applied on a building with all optimum parameters identified.

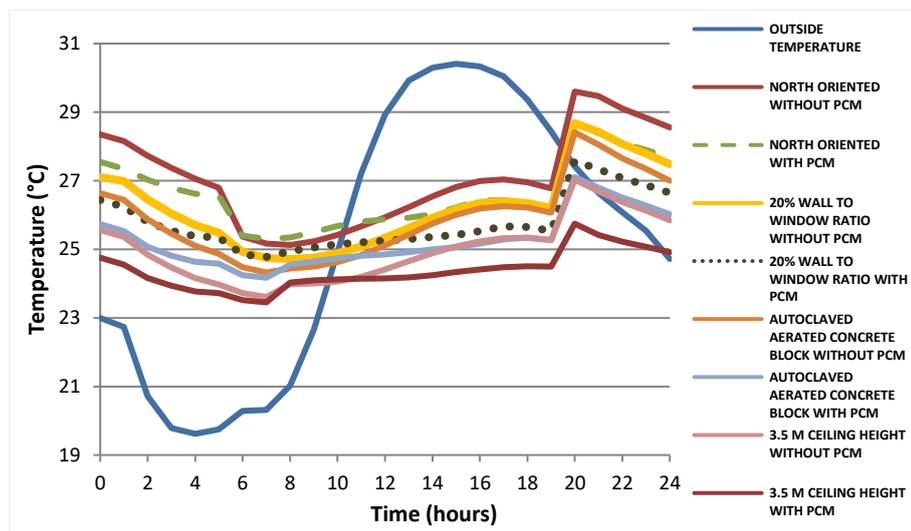


Fig 8: Comparison graph when PCM 29 is applied

A histogram is built to analyze the temperature drops when the parameters are changed and PCM is applied. The histogram is shown in Figure 9.

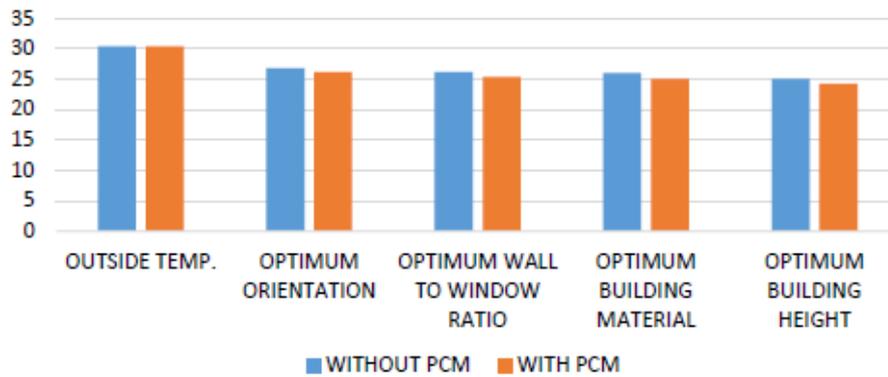


Fig 9: Maximum Temperature Performance

From the histogram, it is understood that a temperature drop of 5.3°C from outside temperature to inside temperature is achieved when all optimum parameters are applied, A temperature drop of 6.1°C from outside temperature to inside temperature is achieved when all optimum parameters and PCM 29 are together applied. An average temperature drop of 1.8°C is achieved from normal interior temperature, alone with optimum parameters without PCM. An average temperature drop of 2.5°C is achieved from normal interior temperature, using PCM 29.

#### CONCLUSION

Applying PCM over finished wall surfaces is an excellent way to reduce the internal temperature inside the buildings. Also, Provide optimum values for parameters like building orientation, ceiling height, window to wall percentage and building materials. Temperature drop of 2.5°C is achieved from normal interior temperature of the building, when PCM and optimum parameters are used. A temperature drop of 6.1°C from outside temperature to inside temperature is achieved when all optimum parameters and PCM 29 are together applied. The major disadvantage in using PCM for achieving thermal comfort inside buildings is the cost of PCM application. Further studies have to be done to reduce the cost of PCM. If so, it will be a great initiative for reducing pollution, increasing energy efficiency and increasing thermal comfort inside the buildings.

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Received: 15<sup>th</sup> February 2021; Accepted: 20<sup>th</sup> March 2021; First distributed: 29<sup>th</sup> March 2021