



Control of room temperature fluctuations in the building by incorporating PCM in the roof

Nagappan Beemkumar¹ · Devarajan Yuvarajan² · Mahalingam Arulprakasajothi³ · Kariappan Elangovan⁴ · Thirugnanasambandam Arunkumar⁵

Received: 18 September 2018 / Accepted: 20 December 2019 / Published online: 3 January 2020
© Akadémiai Kiadó, Budapest, Hungary 2020

Abstract

The energy demand for maintaining the required thermal comfort in the building is always an increasing trend. The use of an air conditioner in the building for providing thermal comfort consumes more energy, and it leads to negative environmental impacts. Thermal energy storage (TES) systems are essential to reduce energy consumption in the building. The phase change material (PCM)-based TES in the building has attracted attention in the recent years. In the PCM-based TES system, the heat energy gained during daytime is absorbed by the PCM and the stored energy is released during the night time. The objective of the work is to control the room temperature fluctuations by incorporating PCM in the building roof. The experiments are conducted in two identical model buildings: one is constructed with the implementation of PCM, and another one is constructed without the implementation of PCM in the building roof. It has been observed that the temperature fluctuations in the building are reduced by the use of PCM in the roof. The average peak temperature rise is reduced about 1–2 °C in the building with PCM incorporation in the roof, and thus, the energy required for maintaining the thermal comfort of the room is greatly reduced.

Keywords Energy storage building · Thermal comfort in buildings · Room temperature fluctuation control · Phase change material · Green building

Introduction

The energy consumption to maintain the thermal comfort in the building is always increasing in trend. As per International Energy Agency (IEA) report, the energy consumption in the building sector is almost 40% of the total energy consumption rate. Particularly in India, the selling rate of

an air conditioner is an increasing trend of about 12% in every year for commercial applications. In order to reduce energy consumption in the buildings, several methods have tried and out of which the thermal energy storage (TES) in the building has proved the best ever practice. The thermal energy storage using phase change materials (PCMs) provides high heat storage capacity, i.e., high energy density

✉ Nagappan Beemkumar
beem4u@gmail.com

Devarajan Yuvarajan
dyuvarajan7@gmail.com

Mahalingam Arulprakasajothi
marulprakasajothi@gmail.com

Kariappan Elangovan
drelangovank@gmail.com

Thirugnanasambandam Arunkumar
arunkumar.t@cmrit.ac.in

² Department of Mechanical Engineering, Madanapalle Institute of Technology & Science, Madanapalle 517325, India

³ Department of Mechanical Engineering, Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, Chennai 600042, India

⁴ Department of Mechanical Engineering, Er. Perumal Manimekalai College of Engineering, Hosur 635117, India

⁵ Department of Mechanical Engineering, CMR Institute of Technology, Bengaluru 560037, India

¹ Department of Mechanical Engineering, Faculty of Engineering and Technology, Jain (Deemed-to-be University), Bengaluru 562112, India

almost at constant temperature [1–5]. The constant temperature in the room can be maintained by imposing PCM in the building roof or walls. The thermal comfort in the buildings with TES technology is achieved in two ways: one is with passive cooling, and another one is with active cooling. The passive cooling in the building with TES technologies is carried out by imposing PCM in the roof and in the walls without any external air circulation devices. The passive cooling technology may be preferred though it has a less cooling effect compared to the active cooling method since the energy consumption on external aid is neglected [6–8]. The thermal comfort of PCM-integrated building depends on the melting temperature of PCM, location of the building and physical properties of constructional materials.

Several studies are carried out in the buildings with the implementation of PCM both experimentally and numerically [9–13]. The experimental study conducted by Tyagi et al. [14] reported that the use of PCM-based technology in the building has a capacity to match the energy demand and supply. Yew et al. [15] calculated heat transfer through PCM-integrated building roof with the insulation coating and observed the reduction in the heat gain in the room. Zalba et al. [16] gave the consolidated report from those who have done theoretical and mathematical analyses; the author mentioned merits of using enthalpy method to calculate the energy stored and released during PCM melting and solidification process. Pasupathy et al. [17] investigated the effect of the thermal performance of the building by the incorporation of PCM in the roof. The results show that the performance of the system has been improved by increasing PCM layer thickness and also the room temperature fluctuations are greatly reduced. Gobinath et al. [18] reported that the use of PCM in the roof reduces the average peak temperature rise in the building. In India, most of the researches in the building have been carried out with paraffin wax as PCM, since it has high latent heat value and chemically stable [19, 20].

The detailed literature survey reveals that the use of PCM in the building roof can reduce the heat load and temperature fluctuations in the room. Moreover, no studies have been done with polyethylene glycol MW 600 as PCM in the building roof; this could be an alternative to paraffin wax PCM. The present work is intended to control the room temperature fluctuations by the implementation of new PCM polyethylene glycol MW 600 in the building roof, and also the comparison has been made between with and without the implementation of PCM in the building roof.

Experimental

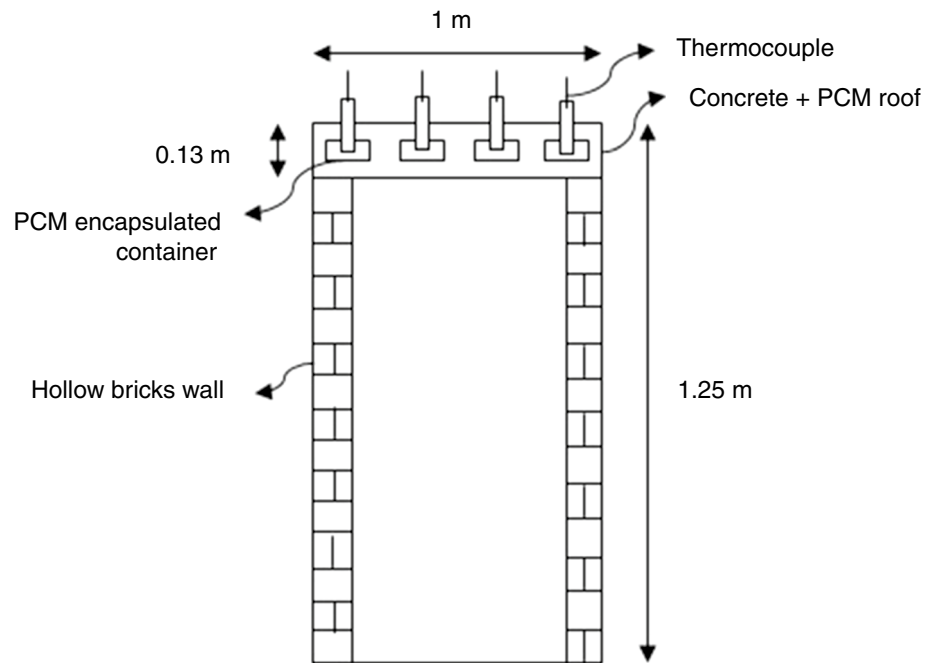
Two model building units are constructed with identical dimensions (1 m × 1 m × 1.25 m) and identical constructional features. One model unit is constructed with the

implementation of PCM in the roof, and another one is constructed without PCM in the roof; both units are made by concrete roofs, and the walls are made with hollow bricks. The selection of PCM depends on the temperature of the room to be maintained and also a high heat storage capacity. The polyethylene glycol MW 600 is chosen as PCM which is chemically stable and biologically safe. This PCM has a low melting temperature around 27–30 °C and has the high latent heat of fusion 148 kJ kg⁻¹. The PCM has high energy storage density and provides a high cooling energy to the building with less volume. The properties of polyethylene glycol MW 600 are shown in Table 1. The PCMs are encapsulated in the rectangular-shaped aluminium container of 15 numbers, and each has dimensions of 0.1 m × 0.1 m × 0.03 m. These encapsulated PCM containers are arranged in the middle of the concrete slab. The PCM-integrated building roof thickness has three layers; the top and bottom layers are concrete layers with the thickness of 5 cm each, and middle layer is a PCM layer with the thickness of 3 cm. The layout of the model building with the implementation of PCM in the roof is shown in Fig. 1. The grade I RTD thermocouple of 10 in numbers is used to measure the temperature fluctuations in the room. The selected thermocouple has a measuring range of 20 °C to 125 °C, and the permissible error is ± 0.5 °C. The temperatures from both model building units are recorded by data logger Agilent 32970A with specific software. The temperatures recorded for every 30 min are accounted to calculate temperature fluctuations and heat energy gained in the room. During the daytime, the PCMs present in the building roof absorb energy from surroundings and change its phase from solid to liquid, i.e., charging process of PCM. During night time, the surrounding temperature is lesser than the melting temperature of PCM and it is observed that the PCM releases heat to the surrounding and changes its phase from liquid to solid, i.e., discharging process of PCM. The readings are taken in the month of May, and both model buildings are located in Chennai, India. The average temperature variations are accounted

Table 1 Properties of polyethylene glycol MW 600 PCM

Property	Value	References
Melting/freezing Temperature/°C	25–28	Gopinath et al. [18]
Specific heat/kJ kg ⁻¹ °C ⁻¹	2.135	Gopinath et al. [18]
Thermal conductivity/W m ⁻¹ K ⁻¹	0.53 (liquid) 0.85 (solid)	Zalba et al. [16]
Density/kg m ⁻³	1126 (liquid) 1232 (solid)	Zalba et al. [16]
Heat of fusion/kJ kg ⁻¹	148	Zalba et al. [16]

Fig. 1 PCM-integrated building roof



for to calculate room temperature fluctuations and heat gain in the room.

Results and discussion

The model buildings are situated in Chennai, India, and the readings are taken in the month of May. The average temperature variations for 24 h are considered to compare the temperature fluctuations and heat gain in the model buildings. Also, the average ambient conditions are considered for the comparison between the two buildings. The average ambient conditions are shown in Table 2.

The factors that influence the heat gain in the building are depended on the climate zone, the size of the building, the orientation, the age of the building, the number of occupants, the activities of occupants, the wind speed, and most importantly solar intensity value at that particular location. The model buildings are built according to the guidelines of the Bureau of Energy Efficiency (BEE), Government of India, using the prescribed materials. Chennai City is located in the hot and humid climate zone with 13.0827° N and 80.2707° E, respectively, latitude and longitude. The ambient temperature is mostly influenced by the solar intensity values.

Figure 2 shows the variation of ambient air temperature with respect to the solar intensity values and the time. It is

seen that the variation in the ambient temperature is about 4.5°C with an increase in solar intensity value from 600 to 920 W m^{-2} during the interval 9.30 h to 13.00 h. According to BEE's guidelines, to provide thermal comfort in the room, the 1°C increase in ambient temperature requires 6% of electricity. It is obvious that the constant room temperature would minimize the need for energy and therefore the implementation of PCM in the buildings could provide the solution to the above-mentioned problem.

The room temperature variations in the building without the implementation of PCM in the roof are shown in Fig. 3. It is seen that the room temperature varies with respect to ambient conditions, and the temperature of room decreases from 0 h to 8 h due to lesser ambient temperature and then increases due to an increase in solar intensity. The average peak temperature rise in the room has been noticed in the time 16 h to 18 h due to the accumulation of heat in the room from the surroundings.

It is noticed from Fig. 4 that the fluctuations in the room temperature are very small and it is about $1\text{--}2^{\circ}\text{C}$ when the PCM is implemented in the building roof. It reveals that the PCM in the roof absorbs heat energy from the surroundings and undergoes a phase transformation from solid to liquid state during the daytime. This absorbed energy is released during night time due to low ambient temperature than the melting temperature of PCM which is about 29°C . Thus,

Table 2 Climatic data of Chennai, India

Month	January	February	March	April	May	June	July	August	September	October	November	December
Maximum mean temperature/°C	28	30	34	38	39	36	34	34	33	31	28	27
Minimum mean temperature/°C	21	22	21	26	28	26	25	25	24	23	22	21
Maximum mean wind speed/m s ⁻¹	5.42	5.32	5.60	6.52	7.2	7.1	6.52	6.37	5.21	5	5.98	6.3
Minimum mean wind speed/m s ⁻¹	2.02	1.53	2.3	3.02	2.2	3	2.12	2.01	1.84	1.53	2.53	3

the constant room temperature is maintained due to the incorporation of PCM in the building roof and the energy demand for maintaining the thermal comfort in the room is also reduced.

The variations in the room temperature between the model buildings of PCM-integrated concrete roof and the plain concrete roof are shown in Fig. 5. It is seen that the temperature fluctuations in the PCM-integrated building are lesser than the building without PCM. Whereas the PCM in the concrete is almost at a constant temperature, it undergoes a phase transformation from solid to liquid in daytime and liquid to solid in the night time. The rise in solar intensity value increases the atmospheric temperature which increases the heat load in the room. The implementation of PCM in the building roof results in a reduction in the heat load and thus reduces the energy consumption for maintaining the indoor thermal condition.

The heat transfer Q between the surroundings and the inner room air temperatures through the composite ceilings is calculated based on the Fourier equation [21] as follows:

$$Q = \frac{(T_o - T_i)}{\frac{1}{A} \left(\frac{1}{h_o} + \frac{L_1}{K_1} + \frac{L_2}{K_2} + \frac{L_3}{K_3} + \frac{1}{h_i} \right)} \quad (1)$$

where T_o and T_i are the outer room temperature and the inner room temperature, respectively, L refers the thickness of the individual layer of the composite concrete ceiling. Based on the literature [22–25], the outer surface convective coefficient h_o and the inner surface convective coefficient h_i are considered as $5 \text{ W m}^{-2} \text{ K}^{-1}$ and $1 \text{ W m}^{-2} \text{ K}^{-1}$, respectively. Figure 6 illustrates the heat flow of the rooms due to the temperature difference between outer and inner surfaces. It is noted that the average heat transfer rate from the room with PCM and without PCM is 0.55 W and 0.09 W , respectively. This is because the PCM maintains lower indoor temperature in the room compared to room without PCM. It is also noted that the heat flow of the room without PCM was negative during the session 0–6 h and 21–24 h; this is due to lower ambient temperature than room temperature. The heat flow of the room without PCM increases with an increase in solar irradiation values. The results obtained from the experiments are in good agreement with the studies reported by Pasupathy et al. [17], Reddy et al. [20] and Beemkumar et al. [22].

Fig. 2 Solar intensity versus ambient temperature

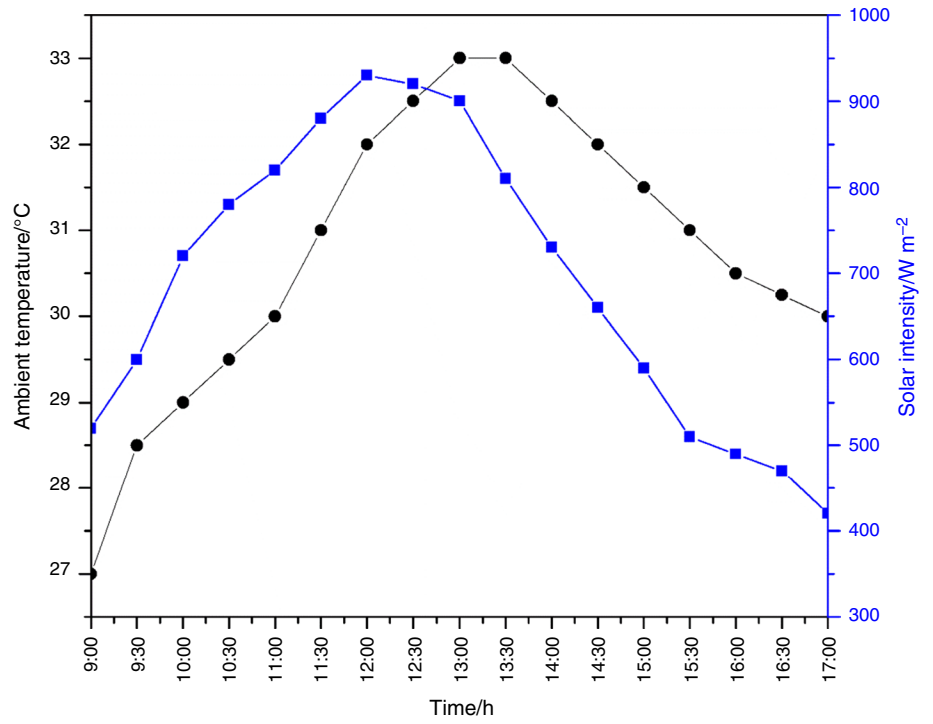


Fig. 3 Room temperature variations without using PCM in the roof

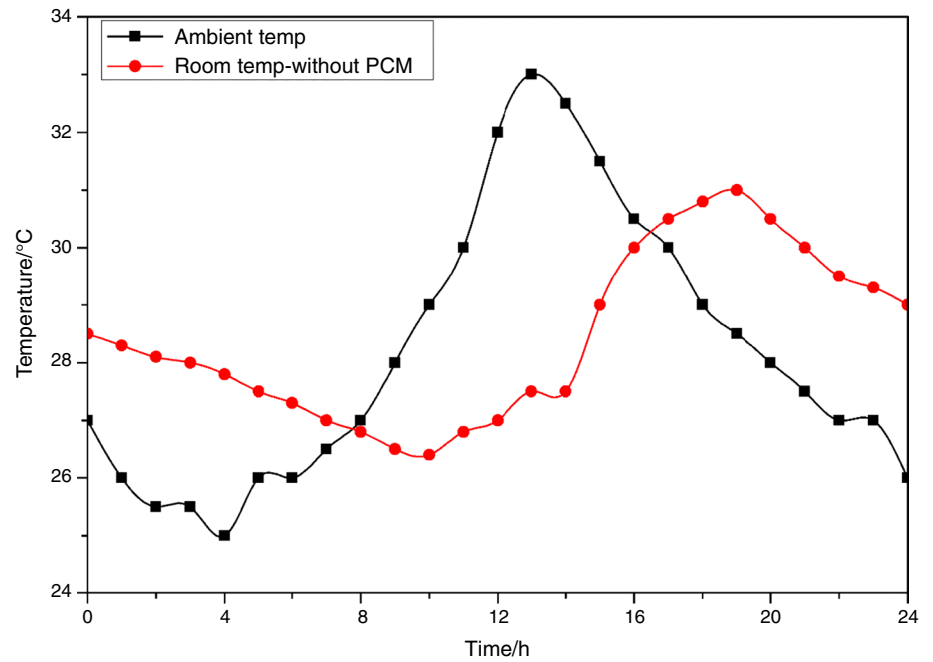


Fig. 4 Room temperature variations with the implementation of PCM in the roof

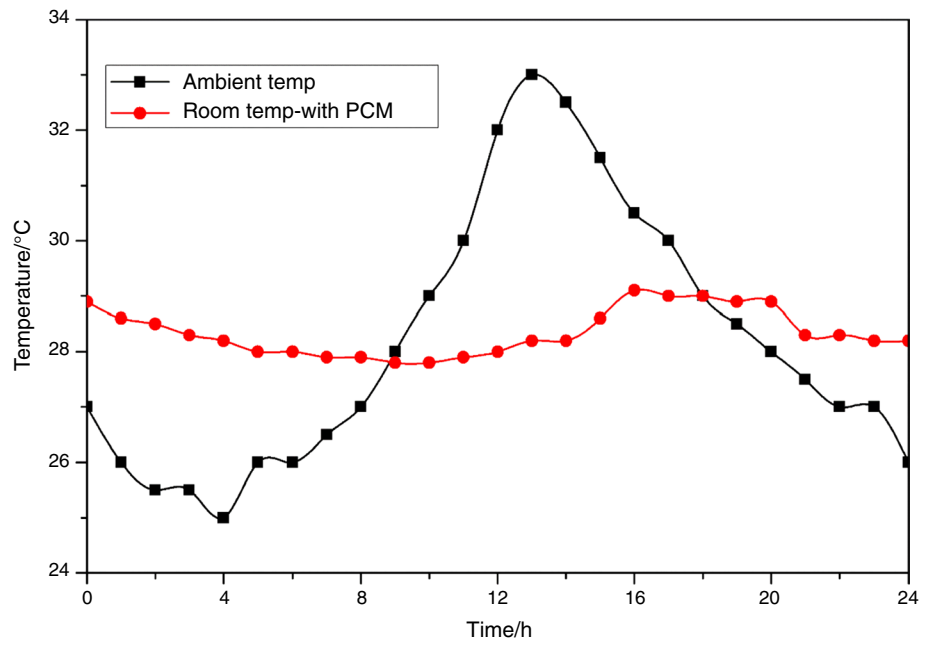


Fig. 5 Room temperature variations with and without PCM

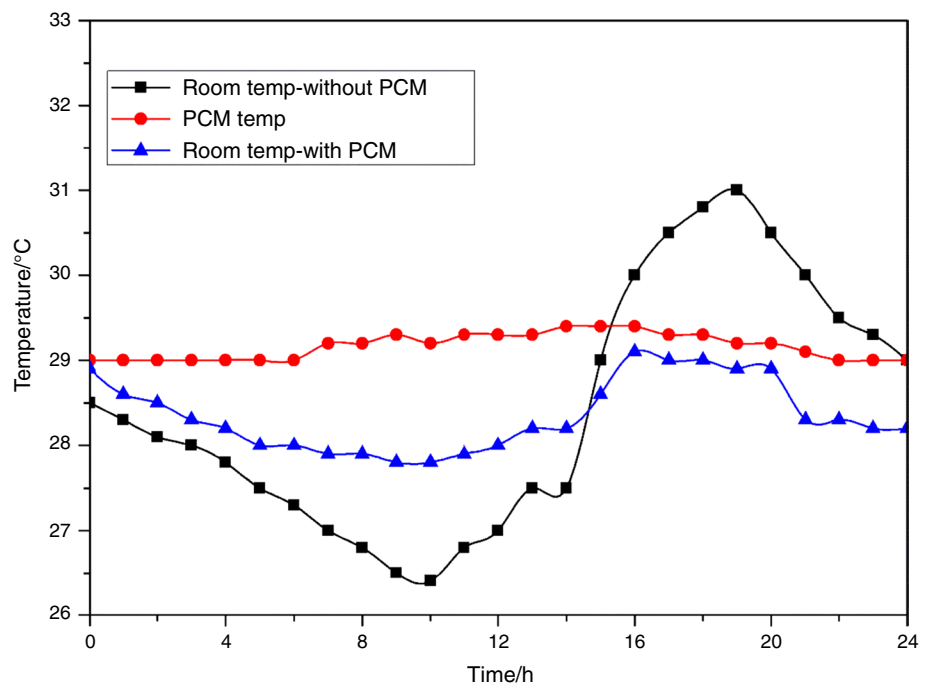
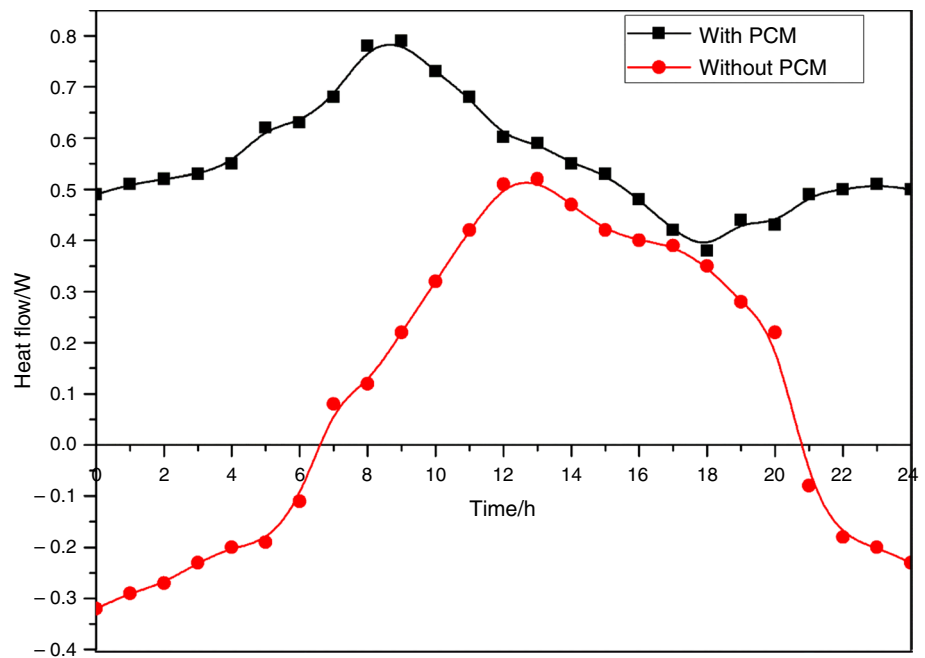


Fig. 6 Heat flow of the rooms with and without PCM



Conclusions

There are several studies in the building with a PCM-based TES system, and all reveal that the fluctuations in the room temperature are reduced with the implementation of PCM in the building roof. In addition, the present work is aimed to study the impact of room temperature fluctuations with the implementation of new PCM polyethylene glycol 600 in the building roof. The experiments are conducted in the two identical model buildings: one is with PCM implemented in the building roof, and another one is without using PCM in the building roof. The results are shown that the implementation of PCM in the building roof reduces the average peak temperature rise in the room and also reduces the fluctuations of temperature in the room which is about 1–2 °C. Based on the results, it is concluded that the reduction in the temperature rise leads to a reduction in the heat load in the room and provides more energy-saving opportunities in order to maintain the required thermal comfort.

References

1. Jeon Jisoo, Lee Jung-Hun, Seo Jungki, Jeong Su-Gwang, Kim Sumin. Application of PCM thermal energy storage system to reduce building energy consumption. *J Therm Anal Calorim.* 2013;111:279–88.
2. Beemkumar N, Karthikeyan A, Yuvarajan D, Lakshmi Sankar S. Experimental investigation on improving the heat transfer of cascaded thermal storage system using different fins. *Arab J Sci Eng.* 2017;42:2055–65.
3. Nagappan Beemkumar, Alagu Karthikeyan, Devarajan Yuvarajan. Heat transfer enhancement of a cascaded thermal energy storage system with various encapsulation arrangements. *Therm Sci.* 2017. <https://doi.org/10.2298/TSCI160926227N>.
4. Nagappan B, Alagu K, Devarajan Y, Munuswamy DB. Energy and exergy analysis of multi-temperature PCMs employed in a latent heat storage system and parabolic trough collector. *J Non Equilib Thermodyn.* 2018;43(3):211–20. <https://doi.org/10.1515/jnet-2017-0066>.
5. Beemkumar N, Karthikeyan A, Saravanakumar B, Jayaprabakar J. Performance improvement of D-sorbitol PCM-based energy storage system with different fins. *Int J Ambient Energy.* 2018;39(4):372–6.
6. Tyagi VV, Pandey AK, Kothari R, Tyagi SK. Thermodynamics and performance evaluation of encapsulated PCM-based energy storage systems for heating application in building. *J Therm Anal Calorim.* 2014;115:915–24.
7. Lorwanishpaisarn Narubeth, Kasemsiri Pornnapa, Posi Patcharapol, Chindaprasirt Prinya. Characterization of paraffin/ultrasonic-treated diatomite for use as phase change material in thermal energy storage of buildings. *J Therm Anal Calorim.* 2017;128(3):1293–303.
8. Ramakrishnan Sayanthan, Wangb Xiaoming, Sanjay Jay, Wilson John. Thermal performance assessment of phase change material integrated cementitious composites in buildings: experimental and numerical approach. *Appl Energy.* 2017;207:654–64.
9. Paris Jean, Falardeau Michel, Villeneuve Cécile. Thermal storage by latent heat: a viable option for energy conservation in buildings. *Energy Sources.* 1993;15(1):85–93.
10. Cabeza LF, Mehling H, Hiebler S, Ziegler F. Heat transfer enhancement in water when used as PCM in thermal energy storage. *Appl Therm Eng.* 2002;22:1141–51.
11. Kuznik F, Virgone J, Noel J. Optimization of a phase change material wallboard for building use. *Appl Therm Eng.* 2007;28:1291–8.
12. Lee T, Hawes DW, Banu D, Feldman D. Control aspects of latent heat storage and recovery in concrete. *Sol Energy Mater Sol Cells.* 1999;62:217–37.

13. Demirbas MF. Thermal energy storage and phase change materials: an overview. *Energy Sources Part B Econ Plan Policy*. 2006;1(1):85–95.
14. Tyagi VV, Buddhi D, Kothari R, Tyagi SK. Phase change material (PCM) based thermal management system for cool energy storage application in building: an experimental study. *Energy Build*. 2012;51:248–54.
15. Yew MC, Sulong NHR, Chong WT, Poh SC, Ang BC, Tan KH. Integration of thermal insulation coating and moving-air-cavity in a cool roof system for attic temperature reduction. *Energy Convers Manag*. 2013;75:241–8.
16. Zalba B, Marin JM, Cabeza LF, Mehling H. Review on thermal energy storage with phase change: materials, heat transfer analysis and applications. *Appl Therm Eng*. 2003;23:251–83.
17. Pasupathy A, Athanasius L, Velraj R, Seeniraj RV. Experimental investigation and numerical simulation analysis on the thermal performance of a building roof incorporating phase change material (PCM) for thermal management. *Appl Therm Eng*. 2008;28:556–65.
18. Gobinath S, Senthilkumar G, Beemkumar N. Comparative study of room temperature control in buildings with and without the use of PCM in walls. *Energy Sources Part A Recovery Util Environ Effects*. 2018. <https://doi.org/10.1080/15567036.2018.1486910>.
19. Shanmuga SA, Seeniraj RV, Velraj R. An experimental investigation on passive cooling system comprising phase change material and two-phase closed thermosyphon for telecom shelters in tropical and desert regions. *Energy Build*. 2010;42(10):1726–35.
20. Reddy KS, Vijay M, Tapas KM. Thermal performance analysis of multi-phase change material layer-integrated building roofs for energy efficiency in built-environment. *Energies*. 2017;10:1367. <https://doi.org/10.3390/en10091367>.
21. Li ZX, Al-Rashed Abdullah AAA, Rostamzadeh Mahfouz, Kalbasi Rasool, Shahsavar Amin, Afrand Masoud. Heat transfer reduction in buildings by embedding phase change material in multi-layer walls: effects of repositioning, thermophysical properties and thickness of PCM. *Energy Convers Manag*. 2019;195:43–56.
22. Beemkumar N, Yuvarajan D, Arulprakasajothi M, Ganesan S, Elangovan K, Senthilkumar G. Experimental investigation and numerical modeling of room temperature control in buildings by the implementation of phase change material in the roof. *ASME J Sol Energy Eng*. 2019;142(1):011011. <https://doi.org/10.1115/1.4044564>.
23. Siva K, Lawrence MX, Kumaresh GR, Rajagopalan P, Santhanam H. Experimental and numerical investigation of phase change materials with finned encapsulation for energy-efficient buildings. *J Build Perform Simul*. 2010;3(4):245–54. <https://doi.org/10.1080/19401491003624224>.
24. Beemkumar N, Karthikeyan A. Experimental analysis of heat transfer characteristics of solar energy based latent heat storage system. *Mater Today Proc*. 2016;3(6):2475–82. <https://doi.org/10.1016/j.matpr.2016.04.165>.
25. Alam M, Sanjayan J, Zou PXW, Ramakrishnan S, Wilson J. Evaluating the passive and free cooling application methods of phase change materials in residential buildings: a comparative study. *Energy Build*. 2017;148(1):238–56. <https://doi.org/10.1016/j.enbuid.2017.05.018>.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.