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THE EFFECT OF PHASE CHANGE MATERIALS ON ROOM TEMPERATURE FOR WINTER AND SUMMER

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Abstract: The efficient use of our existing energy resources is as important as finding new energy sources, since the demand for energy is increasing day by day. Heating and cooling loads in buildings constitute a large part of energy consumption. Therefore, it is very important to improve the energy performance of buildings. The utilization of phase change materials to increase the energy efficiency of buildings is one of the recent research topics. In this study, the effect of phase change materials on room temperature for winter and summer months was investigated numerically by defining real environmental conditions in the virtual environment. Phase change material with thermophysical properties suitable for Mediterranean climate conditions was selected for summer and winter. It can keep the room temperature at a slightly lower level during the daytime in summer and the room temperature higher in winter than in the insulated state case. As a result, phase change materials can be used as a natural air conditioner in the summer, as well as a natural heater at night in the winter. On the other hand, smart bricks can be produced that can absorb the heat transmitted from the inside to the outside by using different phase-change materials.

Keywords: Heating and cooling loads, Insulation, Phase change materials

Faz Değiştirici Malzemelerinin Kış Ve Yaz İçin Oda Sıcaklığına Etkisi

Öz: Enerjiye olan talep her geçen gün arttığından, mevcut enerji kaynaklarımızın verimli kullanılması yeni enerji kaynakları bulmak kadar önemlidir. Binalardaki ısıtma ve soğutma yükleri, enerji tüketiminin büyük bir kısmını oluşturmaktadır. Bu nedenle, binaların enerji performansının iyileştirilmesi çok önemlidir. Binaların enerji verimliliğini artırmak için faz değiştirici malzemelerin kullanımı son zamanlardaki araştırma konularından biridir. Bu çalışmada, sanal ortamda gerçek çevre koşulları tanımlanarak, faz değiştirici malzemelerin kış ve yaz aylarında oda sıcaklığına etkisi sayısal olarak incelenmiştir. Akdeniz iklim koşullarına uygun termofiziksel özelliklere sahip faz değiştirici malzemeler yaz ve kış için seçilmiştir. Yazın gündüzleri oda sıcaklığını biraz daha düşük, kışın ise oda sıcaklığını yalıtımlı durumda olduğundan biraz daha yüksek tutabilir. Sonuç olarak, faz değiştirici malzemeler yazın doğal klima, kışın geceleri doğal ısıtıcı olarak kullanılabilir. Öte yandan farklı faz değiştirici malzemeler kullanılarak içeriden dışarıya iletilen ısıyı soğuran akıllı tuğlalar üretilebilir.

Anahtar Kelimeler: Isıtma ve soğutma yükleri, Yalıtım, Faz değiştirici malzemeler

1. INTRODUCTION

The efficient use of energy becomes more important with the rapid increase in energy consumption. The energy can be used more effectively by minimizing energy losses. Especially in buildings, heating and cooling losses are at very high levels. In order to reduce these losses, the

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use of new technologies as well as insulation becomes important. For this reason, studies on the utilization of phase change materials (PCM) in buildings along with insulation are increasing day by day. Due to the heat holding capacity and thermophysical properties of PCMs, it is predicted that the utilization of appropriate PCM will contribute to the insulation. Alqallaf and Alawadhi (2013) studied heat transfer by creating cylindrical cavities inside a building roof and filling it with PCM to minimize heat transfer from outside to inside. It has been shown that working time and melting temperatures should be considered in the selection of PCMs. Ascione et al. (2014) studied the utilization of PCM to reduce the building cooling load in Mediterranean climate conditions for an office building. The system was simulated, the cooling load was determined for over a renovated building with adding PCM to the interior of the building's outer shell and compared to insulated one. Castell and Farid et al. (2014) validated experimentally a previously proposed methodology for the brick, concrete and wood structures incorporating PCM. The methodology was found to be successful for buildings with low thermal insulation, but failed to determine the potential benefit of PCM for highly insulated one with low heat gains. Jayalath et al. (2016) studied the use of PCMs in building envelope to reduce heating and cooling loads. It has been observed that PCMs placed on the roofs of buildings can reduce fluctuations in indoor temperatures. Panayiotou et al. (2016) studied in the case of applying capsulated PCM to a house by using two types of simulations as temperature and energy ratio. The energy savings reached by adding PCM sheet on the envelope of the cabinet compared to the non-insulated condition have been calculated to be between 21.7% and 28.6%. Jamil et al. (2016) studied the feasibility of PCM to decrease room temperature and augment thermal comfort in a house. Phase change material was applied to the rooms with and without PCM and modeled using Energy Plus simulation software. Pirasaci (2020) investigated the heat performance during the heating season by integrating the PCM sheet into the outer wall of a building. Building features and environmental factors were modeled and verified with literature, and winter energy saving potential was determined. Al-Yasiri and Szabo (2021) investigated the effects of improvements to the building envelope with new techniques and methods on energy efficiency. Different types and properties of PCM that can be utilized are presented, focusing on the utilization of PCM on roofs and exterior walls. Kamel et al. (2022) investigated the effect of PCM integrated into a wall on the cooling energy consumption of a building. The performance of the PCM has been determined for different locations, thicknesses and wall directions. It has been calculated that using the appropriate PCM type and suitable location can reduce the average cooling energy consumption by 38.14%. Park et al. (2023), artificial marble was produced with microencapsulated PCM and its effects on energy saving were analyzed by conducting field tests in a standard apartment building. The thermal performance of the system in winter seasons was examined and it was determined that the energy consumption of the heating system decreased by 27.7%.

In this study, the utilization of different PCMs in the building envelope was investigated by defining real environmental conditions in the virtual environment in order to enhance the thermal comfort in Mediterranean climate in summer and winter conditions. Temperature distributions with and without PCM conditions are extracted and given comparatively.

2. MATERIALS AND METHODS

In this study, solar heating of a one-room house was investigated numerically by using insulation and phase change materials. For this, a one-room house with a width, length and height of 5x7x3 m, respectively, was designed with a single door and 4 windows and presented in Figure 1. Each window is 2x1 m in size and there are 4 windows in total and the door is 1x2 in size. Three-dimensional solar position was defined over the z-axis for heating and meteorological data were defined from the ASHRAE database for Adana Turkey in 2011.

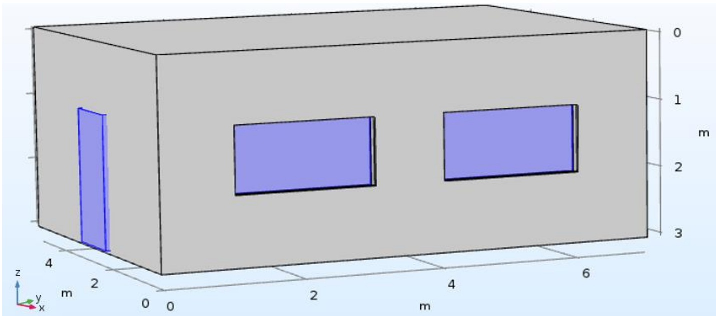


Figure 1:
Model of single room house

This study was carried out by 3D modeling, so the upper part of the house is defined as a (+z axis) air where the sun rises and sets between -x to +x axis from east to west, the sun's rays are constantly changing as in the real world. the sun rises from one side of the Windows (x) and sets from where the other windows are (-x). The side of the door (y) indicates the north and south parts.

Commercial software COMSOL Multiphysics was used for numerical calculation. Numerical methods were determined for radiation, conduction, convection methods for direct heating of the house and other heat interactions. Consider an object P, located on a surface with emissivity ε, reflectivity ρ, absorptivity α, refractive index n, and temperature T. The object is assumed to be opaque, and this is true for most solid objects. The total amount of flux arriving at the P object is called radiation and is denoted by G. The total luminous flux emitted from the object P is called radiosity and is denoted by J and radiosity is the sum of the reflected and emitted radiation and is shown as Equation 1 (COMSOL, 2022):

$$J = \rho G + \varepsilon n^2 \sigma T^4 \tag{1}$$

Surface properties are important for radiation, and emission and absorption. The radiosity method was selected in the module. The balance of radiant intensity, which includes all these contributions, can now be formulated as Equation 2 (COMSOL, 2022; Modest, 2003; Sogukpinar, 2021; Sogukpinar and Bozkurt, 2020)

$$\Omega \cdot \nabla I(\Omega) = \kappa I_b(T) - \beta I(\Omega) + \frac{\sigma s}{4\pi} \int_{4\pi} \mathrm{I}(\Omega')\varphi(\Omega', \Omega)\mathrm{d}\Omega' \tag{2}$$

Radiation intensity can be defined for any direction Ω due to the continuous properties of angular space. In addition to the conductive heat flux, the radiant heat flux is also taken into account to incorporate the radiation in the calculated medium and is implemented using following Equation 3 (Sogukpinar, 2019; 2020a; 2020b).

$$\rho C_P \left(\frac{\partial T}{\partial t} + \mathbf{u}.\nabla T\right) + \nabla.\mathbf{q} = \kappa(G - 4n\sigma T^4) + \alpha_p T \left(\frac{\partial p}{\partial t} + \mathbf{u}.\nabla p\right) + \tau.\nabla\mathbf{u} + Q \tag{3}$$

ρ is the density of the medium, which can be solid, liquid and gas. C_P is the specific heat capacity coefficient, T is temperature, q is heat flux, Q is heat, n is Refractive index, α_p Coefficient of thermal expansion in a fluid, p is Contact pressure, τ is optical thickness, **u** is fluid velocity vector. The discrete coordinates method (or SN approximation) allows discretization of angular space as n = N(N + 2) in 3-dimensional space. The following Equation 4 was used to discretize in 3D (Fiveland, 1991).

$$S_{\mathrm{i}}.\nabla I_{\mathrm{i}} = \kappa I_b(T) - \beta I_{\mathrm{i}} + \frac{\sigma_s}{4\pi}\sum_{j=1} w_j I_j \emptyset\,(S_j, S_{\mathrm{j}}) \tag{4}$$

Discrete ordinate method was used and refractive index was set as 1, and performance index was taken as 0.4. For the ambient data, Meteorological data set ASHRAE 2013 was implemented for Adana Turkey. In order for the sun's rays to penetrate into the room through the windows, the radiation in participation media interface was implemented. For the mesh distribution COMSOL mesh module was preferred and, 348.153 tetrahedral mesh was created. Mesh distribution is seen in Figure 2. The PARDISO solver was preferred for the study for high performance, robustness, multiprocessors memory and efficient use (Sogukpinar, 2019; PARDISO, 2022).

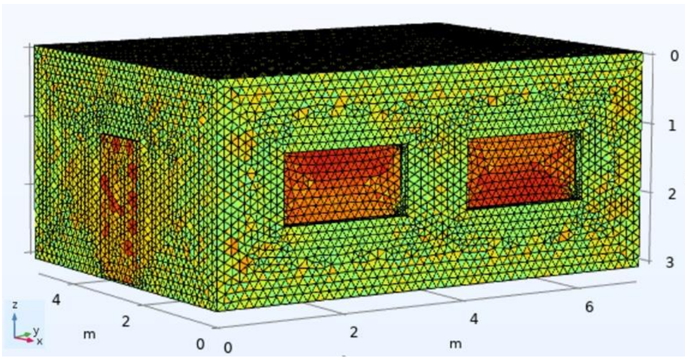


Figure 2:
Mesh distribution

3. PHASE CHANGE MATERIALS

PCM is a substance used for heat storage to absorb or releases a certain amount of energy to provide useful heating or cooling by phase change. In general, phase change usually occurs in two basic states of matter, solid and liquid. Phase change material's temperature transition interval is shown in Figure 3 (COMSOL, 2022).

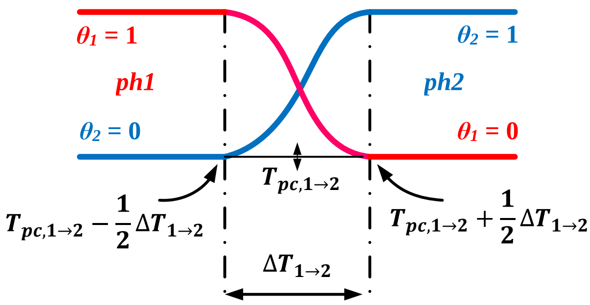


Figure 3:
Model of the phase change temperature transition interval

It is observed that each transformation process occurs smoothly over a temperature range between $T_{pc,1\rightarrow 2} - \frac{1}{2}\Delta T_{1\rightarrow 2}$ and $T_{pc,1\rightarrow 2} + \frac{1}{2}\Delta T_{1\rightarrow 2}$ and the total per unit volume of heat is released. The phase change temperature between phase 1 and phase 2 $T_{pc,1\rightarrow 2}$, must be set to define the midpoint of the first pass temperature range. The density of the phase change material is shown by the following Equation 5 (COMSOL, 2022):

$$\rho = \theta\rho_{ph1} + (1-\theta)\rho_{ph2} \tag{5}$$

In this equation, ph1 and ph2 are the material of phase 1 and phase 2 of a phase change material, and enthalpy is expressed Equation 6 (COMSOL, 2022):

$$H = \frac{1}{\rho}(\theta\rho_{ph1}H_{ph1} + (1-\theta)\rho_{ph2}H_{ph2}) \tag{6}$$

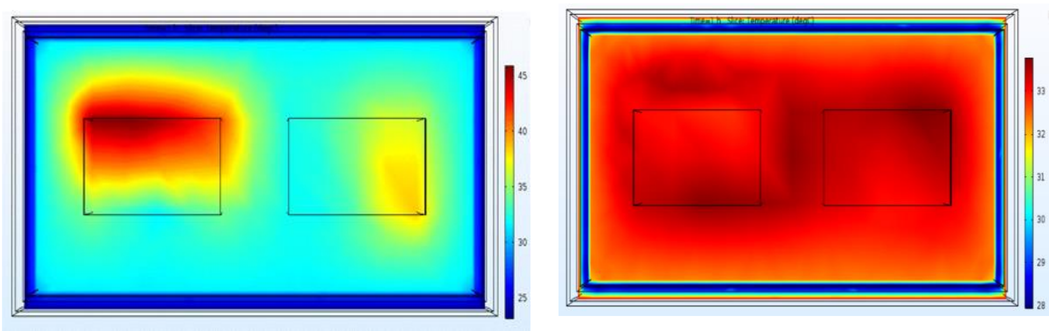
After some derivation and formal transformations and calculations, the specific heat capacity is expressed by Equation 7 (COMSOL, 2022):

$$C_p = \frac{1}{\rho}(\theta_1\rho_{ph1}C_{p,ph1} + \theta_2\rho_{ph2}C_{p,ph2}) + (H_{ph2} - H_{ph1})\frac{d\alpha_m}{dT} \tag{7}$$

α_m is a mass equation defined from the functions θ_1 and θ_2. In this study, decanoic acid and Paraffin C_{13}-C_{24} were selected as phase change materials. The main reason in using different materials is that the phase change temperature range of decanoic acid is suitable for summer, while the other material is more suitable for winter.

4. RESULTS AND DISCUSSION

For this study, a 5x7x3 m model house was designed and 1 cm phase change material was applied to the inside wall surface, and the outside was covered with 5 cm thick insulation material. One of the main indicators for PCM is the phase change temperature, and different types were used in winter and summer. While Paraffin C13-C24 type material was used for winter, Deconoic acid was preferred for summer. The thermophysical properties of phase change materials were taken from Zalba et al. (2003) and simulated. The instantaneous cross-sectional temperature distribution in the room at different times during the day in July is given in Figure 4. In Figure 4(a), the temperature distribution when the sun rays enter through the window is given, and in Figure 4(b) the temperature distribution is given for the moment when the sun rays do not come in.

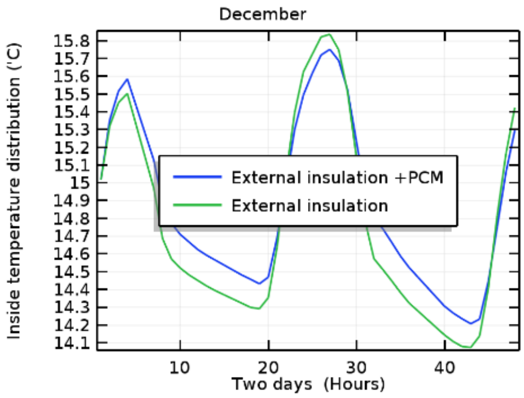


a. *b.*

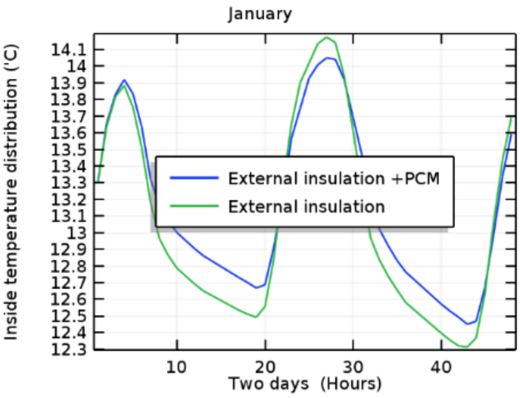
Figure 4:

*Instant room temperature distribution during the day; **a.** the moment the sun's rays come in through the window, **b.** the moment they don't*

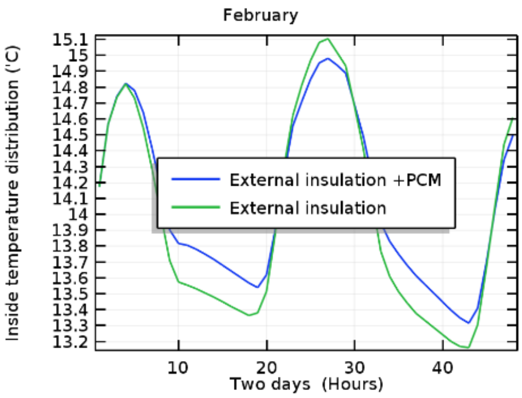
The average temperature in the room was calculated hourly for the 15th day of each month for the winter months is given in Figure 5. The numerical calculation was performed by defining only the externally insulated state and both external insulation and internal phase change material, and the results are presented in Figure 5(a), Figure 5(b), Figure 5(c). Although the temperature distributions for each winter month are similar, the differences differ depending on the angle of inclination of the earth to the sun and sunshine duration. After the temperature was lowest in January, it rose again in February. Since the simulation was carried out only with the effect depending on the sun rays, the temperature in the room increased during the hours of the sun, and the room temperature decreased in the hours when there was no sun. Therefore, the direct heating effect of the sun is observed in the study. The effect of PCM was investigated when the room temperature started to increase, PCM started to store energy and the maximum temperature of the room was calculated lower than compared to insulated case only. When the room temperature started to decrease and the temperature of the environment began to decrease below the temperature of the phase-change material, energy was supplied to the room with the phase change, and it succeeded in making the room temperature higher than in the insulated state case. According to the simulation results, the sun is not likely to keep the room in normal temperature conditions under Adana climatic conditions, and the room needs extra heating.



a.



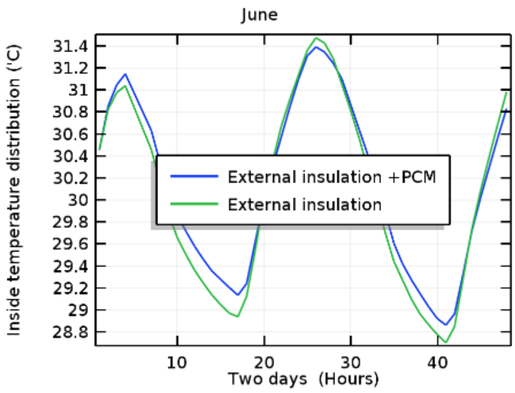
b.



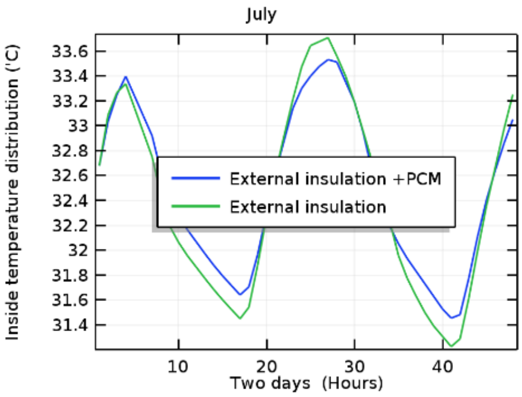
c.

Figure 5:
*Daily temperature distribution of the model house in winter; **a.** December **b.** January **c.** February (simulation was started at 00:00 AM)*

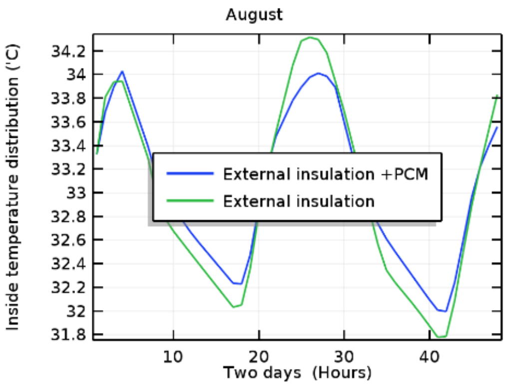
For the summer months, the average temperature in the room was calculated numerically. The temperature changes are seen in Figure 6. Phase change material tries to balance the room temperature to some extent, brakes the temperature increase a little while the room is warming up, and tries to keep the temperature at a certain level when the room is cooling. It is seen that by utilizing suitable PCMs, it can keep the room temperature at a slightly lower level during the daytime in summer, and it will be effective in temperature balancing like a natural air conditioner. Again, by applying suitable phase change materials, room temperature can be kept at a slightly higher level in winter night and this would be effective in temperature balancing like a natural heater.



a.



b.



c.

Figure 6:

Daily temperature distribution of the model house in Summer ***a.*** *June* ***b.*** *July* ***c.*** *August (simulation was started at midnight at 00:00 AM)*

5. CONCLUSION

In this study, the effect of PCMs on room temperature for winter and summer months was investigated numerically by defining real environmental conditions in the virtual environment. First, 1 cm thick PCM is defined on the inner wall of a one-room house, the outer surface of which is insulated using 5 cm thick insulation material. 3D solar position was defined and real-time sunlight entered through the windows at different times of the day according to the viewpoint of the sun from the windows and the room was heated by radiation and by conduction through walls.

Study shows that PCM absorbs heat by changing its state depending on the heat storage capacity as the room temperature increases, and it ensures that the room is slightly below the maximum temperature also while the room temperature decreases, it keeps the temperature of the room at a certain level by giving out the heat. It has been observed that the application of PCMs with suitable thermal properties to the walls reduces the fluctuations in indoor temperature in summer and winter months. Thus, it is understood that PCMs will contribute to thermal comfort as well as energy savings.

As a result, PCMs can be utilized as a natural air conditioner in the summer, as well as a natural heater at night in the winter. On the other hand, smart bricks can be produced that can absorb all the heat transmitted from the inside to the outside by using different PCMs in a way that the melting temperature of PCMs would decrease gradually from the inside to the outside.

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NOMENCLATURE

$I(\Omega)$	Radiative intensity at a given position following the Ω direction (W/(m^{2}sr))
$I_b(T)$	Blackbody radiative intensity (W/(m^{2}sr))
Nr	Refractive index (*dimensionless*)
n	Outward normal vector (*dimensionless)*
q_r	Heat flux striking the wall (W/m^3)
κ	Absorption coefficients (1/m)
β	Extinction coefficients (1/m)
σs	Scattering coefficients (1/m)
$\varphi(\Omega', \Omega)$	Scattering phase function (dimensionless)
σ	Stefan-Boltzmann constant (J/K)
ρ	Density (kg/m^3)
K_Ω	Kinetic energy (J)
E_Ω	Internal energy (J)
P_{ext}	Mechanical power of forces (W)
Q_{exch}	Heat exchanged rate (W)
Cp	Specific heat capacity at constant pressure (J/(kgK))
T	Absolute temperature (K)
u	Velocity vector (m/s)
τ	Cauchy stress tensor deviatoric (Pa)
q	Heat flux by conduction (W/m^2)
p	Pressure (Pa)
PCM	Phase Change Material
S	Strain-rate tensor (1/s)
Q	Heat sources other than viscous heating (W/m^3)

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Haci Sogukpinar: Designed and performed the system.

Ismail Bozkurt: Evaluated data and wrote the paper.

REFERENCES

1. Alqallaf, H.J. and Alawadhi, E.S. (2013). Concrete roof with cylindrical holes containing PCM to reduce the heat gain, *Energy and Buildings,* 61, 73–80. http://dx.doi.org/10.1016/j.enbuild.2013.01.041

2. Al-Yasiri, Q, Szabo, M. (2021). Incorporation of phase change materials into building envelope for thermal comfort and energy saving: A comprehensive analysis, *Journal of Building Engineering,* 36, 102122. https://doi.org/10.1016/j.jobe.2020.102122

3. Ascione, F., Bianco, N., de'Masi, R.F., de'Rossi, F., Vanoli, G.P. (2014). Energy refurbishment of existing buildings through the use of phase change materials: Energy savings and indoor comfort in the cooling season, *Applied Energy*, 113, 990–1007. http://dx.doi.org/10.1016/j.apenergy.2013.08.045

4. Castell, A., Farid, M.M. (2014). Experimental validation of a methodology to assess PCM effectiveness in cooling building envelopes passively, *Energy and Buildings,* 81, 59–71. http://dx.doi.org/10.1016/j.enbuild.2014.06.011

5. Fiveland, W.A. (1991). The selection of discrete ordinate quadrature sets for anisotropic scattering, *Fundamentals of Radiation Transfer*, HTD, vol. 160, ASME.

6. Heat Transfer Module, COMSOL. https://www.comsol.com [accessed 30 February 2022]

7. Jayalath, A., Aye, L., Mendis, P., Ngo, T. (2016). Effects of phase change material roof layers on thermal performance of a residential building in Melbourne and Sydney, *Energy and Buildings*, 121, 152–158. http://dx.doi.org/10.1016/j.enbuild.2016.04.007

8. Jamil, H., Alam, M., Sanjayan, J., Centre, J.W. (2016). Investigation of PCM as retrofitting option to enhance occupant thermal comfort in a modern residential building, *Energy and Buildings*, 133, 217–229. http://dx.doi.org/10.1016/j.enbuild.2016.09.064

9. Kamel, J.A., Mina, E.M., Elsabbagh, A.M. (2022). Implementation of phase change material for cooling load reduction: a case study for Cairo, Egypt, *International Journal of Air-Conditioning and Refrigeration*, 30, 13. https://doi.org/10.1007/s44189-022-00013-5

10. Modest, M.F. (2003). *Radiative Heat Transfer*, 2nd ed., Academic Press, San Diego, California.

11. Panayiotou, G.P., Kalogirou, S.A., Tassou, S.A. (2016). Evaluation of the application of Phase Change Materials (PCM) on the envelope of a typical dwelling in the Mediterranean region, *Renewable Energy*, 97, 24–32. http://dx.doi.org/10.1016/j.renene.2016.05.043

12. Pardiso, "Parallel Sparse Direct and Multi - Recursive Iterative Linear Solvers", User Guide Version 6.0, https://pardiso-project.org [accessed 30 February 2022]

13. Park, B., Cheong, C.H., Park, D.Y., Ryu, S.R. (2023). Effects of microencapsulated phase change material on indoor thermal comfort and energy consumption, *Case Studies in Thermal Engineering*, 41, 102681. https://doi.org/10.1016/j.csite.2022.102681

14. Pirasaci, T. (2020). Investigation of phase state and heat storage form of the phase change material (PCM) layer integrated into the exterior walls of the residential-apartment during heating season, *Energy*, 207, 118176. https://doi.org/10.1016/j.energy.2020.118176

15. Sogukpinar, H. (2021). A new perspective to the conventional solar pond technology to increase the thermal efficiency, *Environmental Progress & Sustainable Energy*, 40(1), 13467. https://doi.org/10.1002/ep.13467

16. Sogukpinar, H., Bozkurt, I. (2020). Investigation of saturation temperature in solar pond for different sizes, *Thermal Science*, 24(5 Part A), 2905-2914. https://doi.org/10.2298/TSCI181222161S

17. Sogukpinar, H. (2019). Seasonal temperature variation of solar pond under Mediterranean condition, *Thermal Science*, 23(6 Part A), 3317-3326. https://doi.org/10.2298/TSCI180518060S

18. Sogukpinar, H. (2020). Effect of hairy surface on heat production and thermal insulation on the building. *Environmental Progress & Sustainable Energy*, 39(6), 13435. https://doi.org/10.1002/ep.13435

19. Sogukpinar, H. (2020). Numerical study for estimation of temperature distribution in solar pond in diverse climatic conditions for all cities of Turkey. *Environmental Progress & Sustainable Energy*, 39(1), 13255. https://doi.org/10.1002/ep.13255

20. Zalba, B., Marin, J.M., Cabeza, L.F., Mehling, H. (2003). Review on thermal energy storage with phase change: materials, heat transfer analysis and applications, *Applied Thermal Engineering*, 23(3), 251-283. https://doi.org/10.1016/S1359-4311(02)00192-8