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Ključne reči:
zgrade; latentna toplota;
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NUMERIČKA STUDIJA SKLADIŠTENJA LATENTNE TOPLOTE I POTENCIJALA UŠTEDE ENERGIJE KOD PCM ZIDOVA

Key words:
PCM; buildings; latent heat;
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NUMERICAL STUDY ON LATENT HEAT STORAGE AND ENERGY SAVING POTENTIAL OF PCM WALLS

Alper KARAGÖZ* *Mechanical Engineering Department, Engineering Faculty,*
Kocaeli University, Kocaeli, Türkiye
Müslüm ARICI* *Mechanical Engineering Department, Engineering Faculty,*
** muslumarici@kocaeli.edu.tr* *Kocaeli University, Kocaeli, Türkiye,*
ORCID: 0000-0002-3397-2215
Ahmet YÜKSEL *Yalova University, Yalova Vocational School, Electric and Energy Department,*
Yalova, Türkiye
ORCID: 0000-0002-0472-0342
Ruitong YANG *School of Architecture and Civil Engineering,*
Northeast Petroleum University, Daqing, China,
ORCID: 0000-0002-8442-0445

Cilj ove studije je numeričko ispitivanje efekata različitih tipova materijala sa promenom faze (PCM), njihovih debljina i položaja unutar spoljnog zida na skladištenje latentne toplote i, posledično, na uštede energije za grejanje i hlađenje u stambenim zgradama. Analizirana su tri različita tipa PCM-a i upoređena sa fazno stabilizovanim materijalom (PSM), koji poseduje identične toplotne osobine, ali ne prolazi kroz faznu tranziciju, kako bi se izolovao i kvantifikovao specifičan doprinos latentne toplote. Pored toga, izvršena su poređenja sa konvencionalnim zidom bez PCM-a, što je omogućilo procenu doprinosa latentne toplote i ukupnog efekta na toplotnu inerciju.

Analize su sprovedene u klimatskim uslovima Istanbula, Turska, koji je klasifikovan kao Csa (mediteranska klima sa vrelim letima) prema klasifikaciji Köppen-Geiger. Ova studija obuhvata ne samo godišnje i mesečne analize, već i dnevne i časovne procene, omogućavajući dublje razumevanje prolaznog toplotnog ponašanja i toplotne inercije PCM-a.

Nalazi naglašavaju značaj optimizacije tipa PCM-a, njegove debljine i položaja u projektovanju omotača zgrade radi maksimiziranja energetske efikasnosti. Rezultati pokazuju da postavljanje PCM-a bliže unutrašnjoj površini obezbeđuje najefikasnije korišćenje latentne toplote i najveće uštede energije, pri čemu PCM RT18 debljine 30 mm smanjuje godišnju potrošnju energije za grejanje i hlađenje do 3,7% u poređenju sa referentnim slučajem.

Povećanje debljine PCM-a od 1 mm do 30 mm generalno je smanjilo ukupnu godišnju potrošnju energije (u proseku za 2,5%), ali odgovor na opterećenje hlađenja nije bio konzistentan. Na primer, kada je RT18 postavljen bliže spoljašnjoj površini, sloj od 1 mm imao je istu potražnju za hlađenjem kao referentni slučaj, dok je sloj od 18 mm povećao potražnju za 1% zbog odloženog oslobađanja toplote tokom perioda maksimalnog hlađenja. U nekim slučajevima, kao što je kada su PCM RT21 i RT25 postavljeni bliže spoljašnjoj površini, efekat latentne toplote bio je zanemarljiv, rezultirajući gotovo istim ukupnim godišnjim opterećenjem kao u referentnom slučaju. Štaviše, kada su

PCM-ovi postavljeni bliže unutrašnjoj površini, doprinos latentne toplote ostao je dosledno pozitivan kroz sve debljine.

The goal of this study is to numerically investigate the effects of different phase change material (PCM) types, thicknesses, and placement positions within the external wall structure on latent heat storage and, consequently, on heating and cooling energy savings in residential buildings. Three different PCM types were analyzed and compared with a phase stabilized material (PSM), which possesses identical thermal properties but does not undergo phase transition, to isolate and quantify the specific contribution of latent heat. In addition, comparisons with a conventional wall without PCM were carried out, enabling the evaluation of both latent heat contribution and the overall effect on thermal inertia. The analyses were conducted under the climatic condition of Istanbul, Turkey, which is classified as a Csa (hot-summer Mediterranean) climate according to the Koppen-Geiger classification. This study addresses not only annual and monthly analyses but also daily and hourly assessments, enabling a deeper understanding of the transient thermal behavior and thermal inertia of PCMs. The findings underline the importance of optimizing PCM type, thickness, and placement in building envelope design to maximize energy efficiency. The results reveal that placing PCM closer to the inner surface provides the most effective latent heat utilization and the highest energy savings, with 30mm RT18 reducing annual heating and cooling energy demand by up to 4% compared to the base case. While increasing PCM thickness from 1 mm to 30 mm generally reduced total annual energy demand (by 2.5% on average), the cooling load response was not consistent. For instance, when RT18 was placed near the outer surface, a 1 mm layer has same cooling demand as base case while an 18 mm layer increased it by 1% due to delayed heat release during peak cooling periods. For some cases, such as when RT21 and RT25 PCMs were positioned near the outer surface, the latent heat effect was negligible, resulting in nearly the same total annual load as the reference case. Moreover, when PCMs were placed closer to the inner surface, the latent heat contribution remained consistently positive across all thicknesses.

1. Introduction

Buildings account for approximately 30% of the final global energy consumption, according to recent data report of International Energy Agency. This share includes operational needs in built environment such as heating, cooling, lighting, and household appliance usage. In the same year, the direct CO_2 emissions from buildings reached 3 gigatons while the indirect emissions were up to 6.8 gigatons [1]. Therefore, reducing energy consumption in buildings has become a prominent research focus in recent years, driven by environmental concerns, sustainability, and economic efficiency targets.

Thermal inertia, which refers to building material's ability to absorb, store, and slowly release heat, plays a critical role in regulating indoor temperature fluctuations and reducing heating and cooling loads [2]. However, the impact of thermal inertia is not always beneficial, as it strongly depends on factors such as building structure, occupancy schedule, and climatic conditions. Therefore, it can either enhance or hinder energy performance of the building depending on these factors. However, when a periodic heating schedule was applied, the same thermal inertia became a disadvantage due to its delayed thermal response [3]. On the other hand, in an experimental study [4] conducted in residential buildings, it showed that higher thermal inertia can be beneficial. Specifically, replacing lightweight timber frame walls with cellular concrete reduced the total duration of indoor temperatures above 28 °C from 18.6 days to only 8 hours, while maintaining average indoor air temperatures below 26 °C for nearly 20 days compared to less than 12 days in lightweight buildings.

Phase change materials (PCMs), which enhance thermal inertia through phase transition, are increasingly employed in buildings to improve thermal comfort and reduce energy consumption owing to their high latent heat storage capacity [5]. In many studies, the thermal properties of structural elements have been shown to significantly affect PCM performance. A recent review highlighted that PCM integration into building walls can delay phase change by 2–7 hours depending on orientation, while reducing maximum heat flow and heating energy requirements by up to 50% and 32%, respectively; overall HVAC energy demand was also reduced by 20–30%, resulting in significant energy cost savings [6]. More specifically, a quantitative study by Guarino et al. [7] for Montreal and Palermo showed that PCM usage reduced annual heating and cooling loads by 12% in Montreal, and when combined with night ventilation, energy efficiency improved by up to 16%. Similarly, a case study on PCM thermal storage in a solarium located in a cold climate demonstrated a 17.4% annual reduction in heating demand, with heat release delayed by 6–8 hours at night, effectively reducing daily indoor temperature fluctuations [8]. Arıcı et al. [9] conducted a numerical study to investigate the effects of different PCM placement position, melting temperatures and thicknesses under various climate conditions. Their findings indicate that the optimal melting temperature, placement or PCM thickness vary significantly depending on the climatic region. In an experimental study, Kuznik and Virgone [10] analyzed three different climate scenarios in a controlled environment to evaluate the effect of PCM wallboards on indoor thermal comfort. The results indicated that PCM wallboards significantly reduced indoor air temperature fluctuations and improved comfort by lowering the peak room temperature by up to 4.2 °C compared to conventional wallboards. Similarly, Castellón et al. [11] conducted an experimental study in Lleida using small house-sized test cubicles with different external wall configurations. The cubicle containing PCM exhibited approximately 15% lower heating and cooling loads compared to the non-PCM cubicle over a one-week period in August.

This study aims to numerically investigate the effects of different PCM types, PCM thicknesses and placement positions within the external wall structure on latent heat storage and, consequently, on heating and cooling energy savings in residential buildings. Different PCM types were analyzed and compared with a Phase Stabilized Material (PSM) to isolate the influence of latent heat. The analyses were conducted using DesignBuilder under the climatic condition of Istanbul, Turkey. Furthermore, PSM, which has identical thermal properties to PCM but does not undergo phase transition, was used as a reference to isolate the impact of latent heat. While several studies have investigated the impact of PCM type, thickness, and placement on building energy performance, the present work provides additional insights by analyzing the short-term thermal behavior at daily and hourly scales. This approach allowed the identification of both beneficial and adverse roles of PCM integration and additionally highlights the influence of phase-change–induced variations in thermal inertia (as evidenced by the PCM–PSM comparisons). Although similar topics have been addressed in previous research, the combined focus on transient dynamics and the role of changing inertia highlights aspects that have received limited attention in literature.

2. Method

2.1. Building Model

The simulations were performed using DesignBuilder with the EnergyPlus engine. The modeling studies were conducted on a single-story residential building with a total floor area of 120 m² and 2.8 m height (Fig. 1). The building included three bedrooms, a living room, a kitchen, and two bathrooms. Various wall constructions and PCM application scenarios were defined for the external envelope. Two wall types as seen at Fig. 2, PCM or PSM close to outer or external surface, were modeled, each with different thicknesses of PCM and PSM layers and a reference wall which doesn't contain either PCM or PSM.

- The internal wall structure was kept constant across all scenarios and consisted of a 0.135 m thick firebrick layer, covered on both sides with 0.02 m thick plaster. The roof and ground floor assemblies were modeled with a thermal transmittance (U-value) of 0.5 W /m^2 ·K and windows were defined as double-glazed units with a U-value of 1.8 W/m^2·K according to TS825 [12] Thermophysical properties of the materials used in exterior wall types are given in Table 1.

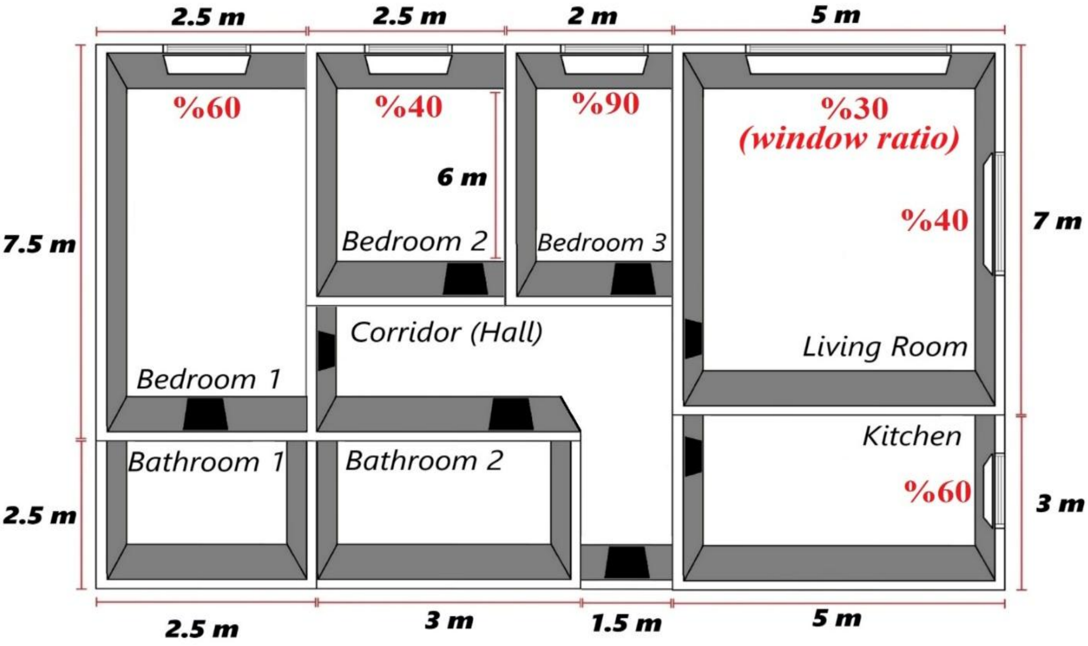
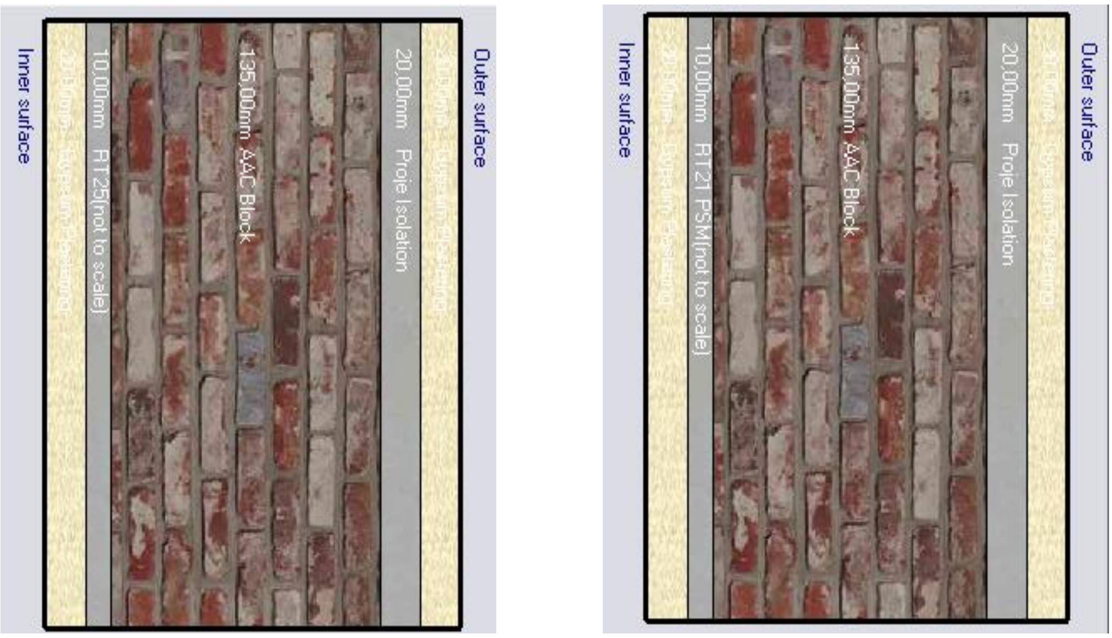


Figure 1. Floor plan of the simulated residential building

Table 1. Thermophysical properties of the materials of the outer wall

Material	λ [W/m·K]	ρ [kg/m^3]	c_p [J/kg·K]
Gypsum Plastering	0.4	1000	1000
Insulation	0.038	32	840
Autoclaved aerated concrete	0.11	2800	896
RT18 PSM	0.2	880	2000
RT21 PSM	0.2	840	2000
RT25 PSM	0.2	840	2000

Given the extensive number of wall configurations analyzed in this study (96 PCM and PSM cases and reference wall), only two representative wall assemblies are illustrated in Fig. 2. One includes a sample PCM and the other its equivalent PSM counterpart, both applied with 10 mm thickness. These figures aim to demonstrate the relative position of the PCM/PSM layer within the wall structure. All other configurations follow the same placement logic with varying thicknesses and material types.



(a) Wall section with PCM layer *(b) Wall section with equivalent PSM layer*

Figure 2. Cross-sectional configurations of external wall layers

2.2. Climate conditions

Istanbul was selected as the representative location for the energy performance analysis due to its temperate climate characteristics. For the climatic input data, IWEC (International Weather for Energy Calculations) weather file for Istanbul (WMO#170600) was used. This dataset represents a typical meteorological year generated from 30 years (1961–1990) of measured weather data, as published by ASHRAE (2001) [13]. Typical Meteorological Year files were utilized to ensure consistency and reliability of climatic inputs throughout the annual simulation period.

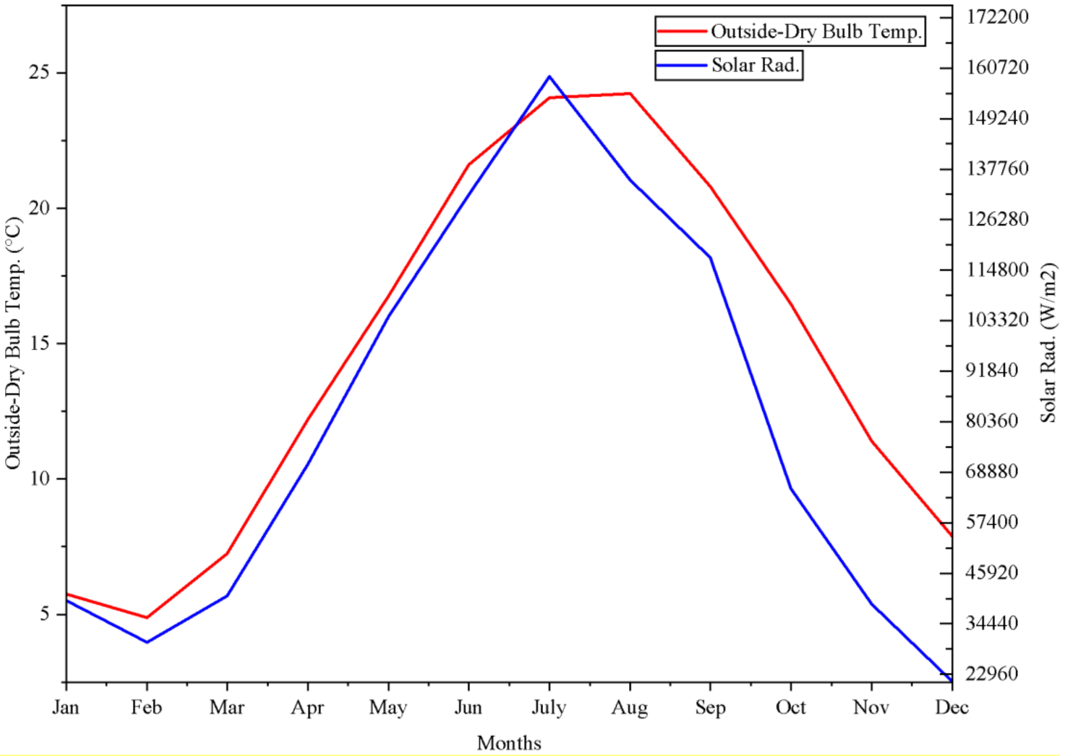


Figure 3. Outside dry-bulb temperature and solar radiation

2.3. Application strategy for PCM and PSM

The PCMs used in the simulations were modeled with varying thicknesses. To isolate the effect of latent heat, a PSM with identical thermophysical properties to the PCM but without phase transition was used for comparison. The thermophysical properties of PCMs [14] are presented in Table 2.

Table 2. Thermophysical properties of PCM

PCM	*Melting Temp. [°C]*	*λ [W/m·K]*	*c_p [J/kg·K]*	*ρ_L [kg/m³]*	*ρ_S [kg/m³]*	*Heat Storage Capacity [J/kg]*
RT18	18	0.2	2000	770	880	150000
RT21	21	0.2	2000	770	840	165000
RT25	25	0.2	2000	760	840	180000

2.4. Simulation cases

Simulation cases consisted of 96 different scenarios. Variable parameters were as follows:

- Type of material used (PCM or PSM)
- PCM or PSM thickness (ranging between 1-30 mm by 2 mm increment)
- Three different types of PCM (RT18, RT21, and RT25)
- Two different PCM or PSM placement positions (inner side of the wall and outer side of the wall)

3. Results and discussion

This study presented a comprehensive evaluation of the simulation outcomes obtained for various PCM types, thicknesses (1 mm to 30 mm), and placement configurations within the external wall assembly, alongside their comparison with the corresponding PSM cases under Istanbul's climatic conditions. The analysis focused on quantifying the influence of thermal inertia and latent heat storage capacity on heating and cooling energy demands, thereby identifying the most energy-efficient configuration among the scenarios considered.

3.1. Effect of PCM characteristics on energy performance

Figs. 4 and 5 collectively illustrate the influence of PCM type, thickness, and placement position on the annual heating and cooling energy demands of the reference building. Fig. 6 illustrates the variation of latent heat contribution with respect to PCM thickness and placement position for different PCM types. The results demonstrate that both the material properties and the design parameters of PCM integration play a decisive role in shaping the overall thermal performance of the building envelope. Fig. 4 presents the heating and cooling demands as a function of PCM thickness for different material types, while Fig. 5 summarizes the total annual energy demand (heating and cooling) to enable direct comparison of overall effectiveness. RT18 provided the highest overall energy savings, achieving a 4.5% reduction in heating demand compared to reference wall at 30 mm thickness when placed near the interior surface. Conversely, while RT18 recorded a cooling demand of 2478 kWh under the same thickness and installation conditions, RT25 exhibited the lowest value of 2387 kWh, suggesting its greater effectiveness in reducing cooling loads. In contrast, while RT18 achieved the lowest heating demand of 8618 kWh, RT25 showed the highest value of 8768 kWh under the same conditions, indicating that RT18 was more effective in reducing heating loads. Considering that heating demand is the dominant factor under these climatic conditions, RT18 emerges as the more favorable choice overall.

The effect of thickness is illustrated in Fig. 5, where increasing PCM layer thickness generally enhances latent heat utilization. Comparisons with the PSM reference wall confirm that thicker layers improve the contribution of latent heat storage, especially when applied closer to the interior surface. However, exterior placement introduces more complex behavior: while greater thickness reduces heating loads, it may also increase cooling loads depending on the material properties and outdoor thermal interactions. For example, RT21 with 12 mm thickness near the exterior surface produced the highest annual cooling demand (2518 kWh).

Placement position emerged as a critical factor across all cases. Interior placement consistently produced stronger and more stable latent heat effects (Fig. 6), enabling effective charging and discharging cycles in response to indoor conditions. The best-performing configuration was RT18 with thickness 30 mm near the interior surface, achieving 4% annual energy saving compared to the reference wall. By contrast, exterior placement does not provide a meaningful reduction and instead results in minor fluctuations around the Reference Wall (Fig. 4d), with all variations remaining below 1%, except for RT21, which shows a slight positive deviation, only beyond approximately 22 mm of PCM thickness. It should also be noted that the apparent differences in the figure partly stem from the narrow axis range, and the actual performance variations are negligible. This was because the PCMs often remain above their phase change temperature range in summer and thus cannot activate latent heat storage.

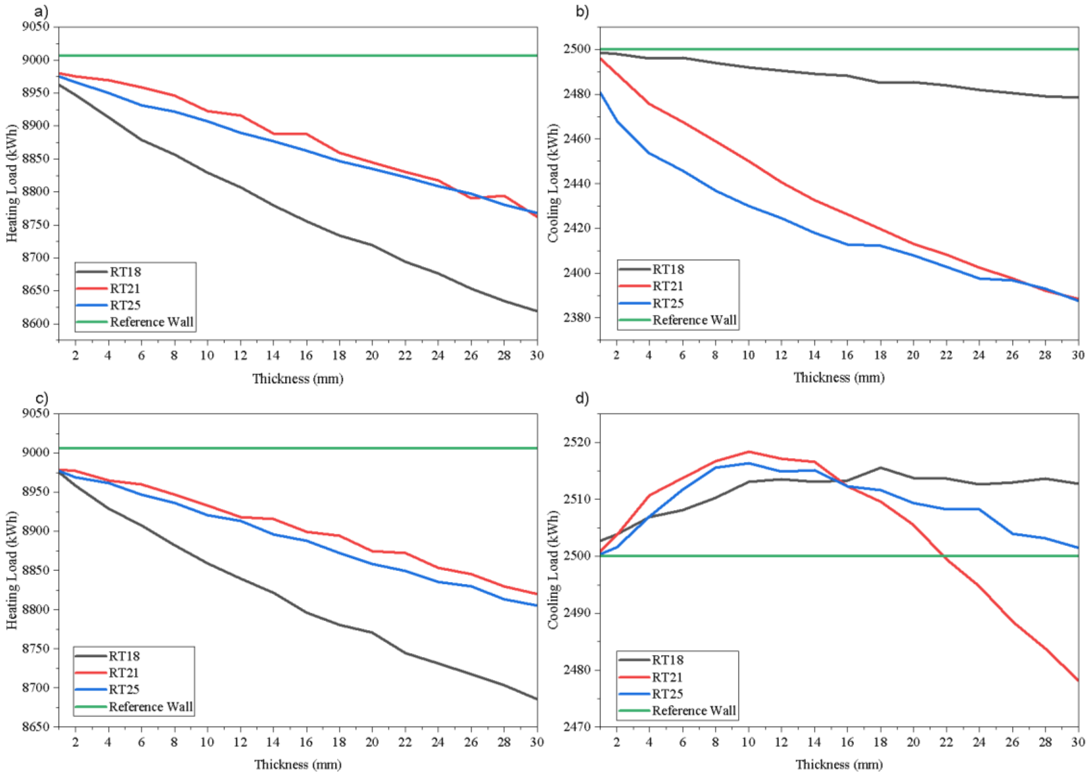


Figure 4. Annual heating and cooling loads for different PCM types and thicknesses compared with reference wall: a) heating load – PCM positioned close to the internal surface, b) cooling load – PCM positioned close to the internal surface, c) heating load – PCM positioned close to the external surface, d) cooling load – PCM positioned close to the external surface

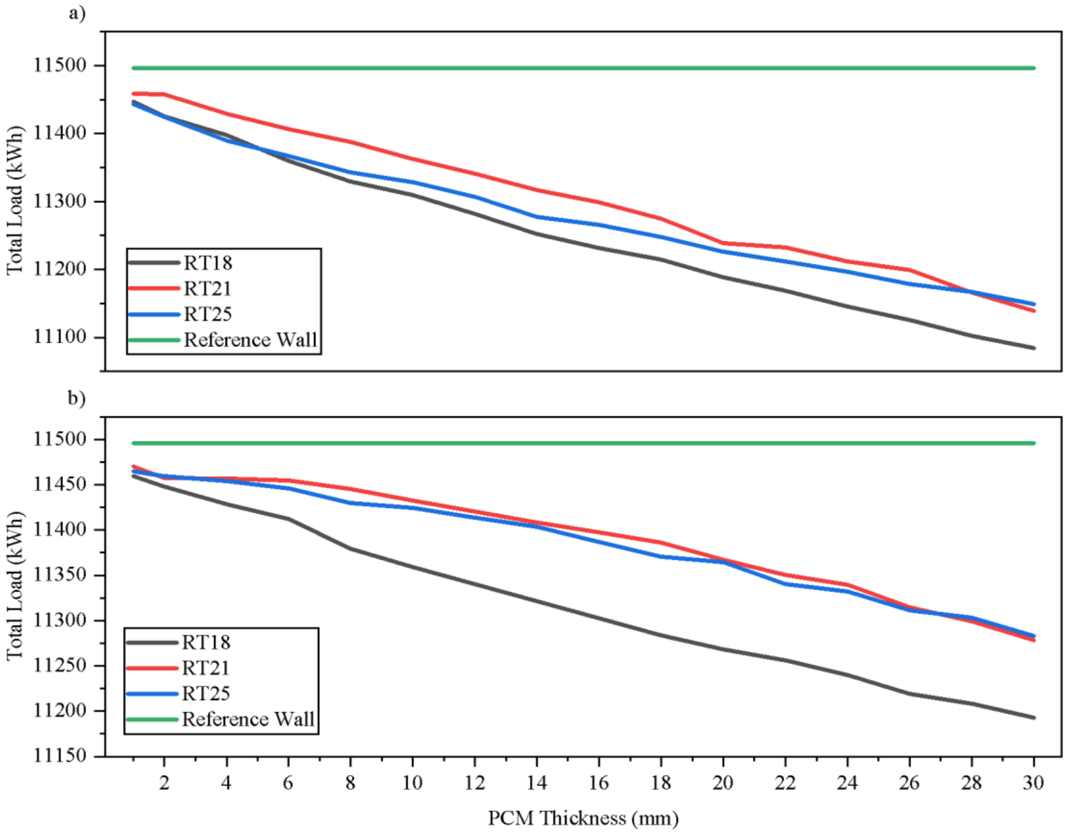


Figure 5. Annual total of heating and cooling loads for different PCM types and thicknesses a) PCM positioned close to the internal surface, b) PCM positioned close to the outer surface

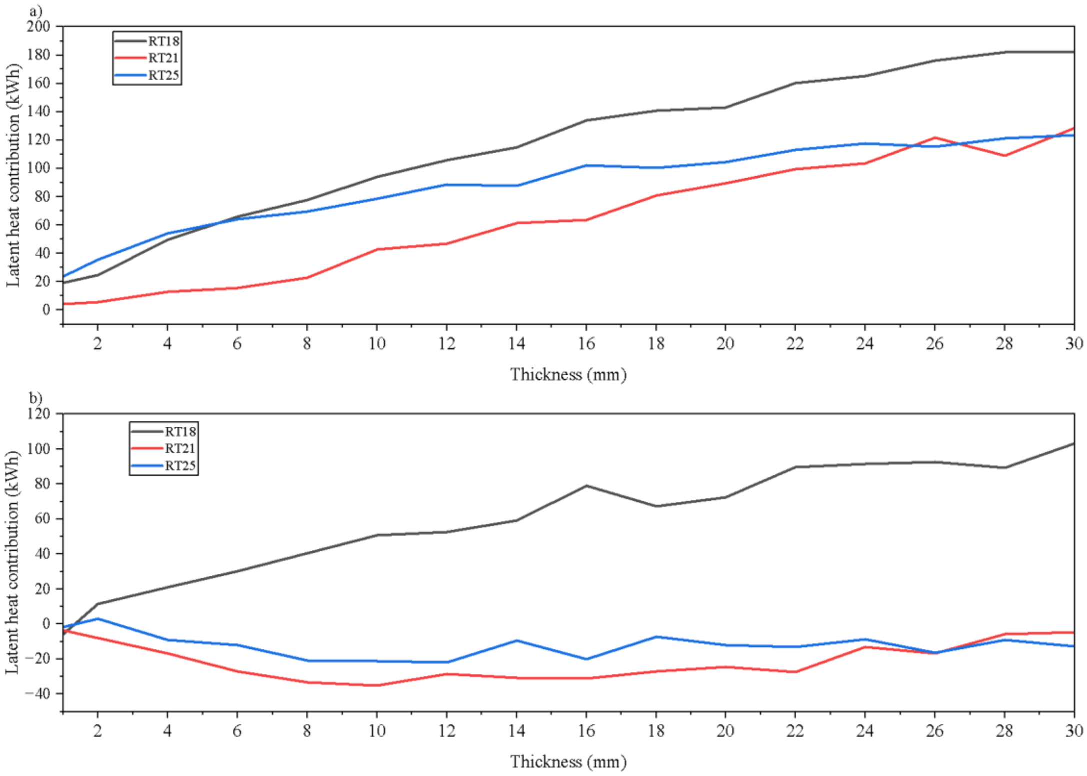


Figure 6. Latent heat contribution of PCM with respect to thickness for different placement positions: a) PCM placed near the inner surface, b) PCM placed near the outer surface

3.2. Monthly, daily, and hourly performance analyses

Fig. 7 presents the monthly latent heat effect of the 28 mm RT18 layer placed near the interior surface, calculated as the difference between the PCM-integrated wall and the corresponding PSM configuration. The results reveal that the latent heat contribution is positive during most of the year, while its influence diminishes in the summer months (June–September). This case was specifically selected because RT18 (28 mm, near the exterior surface) remained entirely in the liquid phase during the summer, while simultaneously exhibiting the largest PCM–PSM difference in terms of cooling load.

The reason for this seasonal variation can be explained with reference to Fig. 8. As shown, the temperature remains consistently above the solidification range of RT18, preventing the material from releasing stored heat. Fig. 8 further supports this observation by depicting the annual variation of interior and exterior wall surface temperatures together with the PCM phase change range. This figure demonstrated that the PCM undergoes phase transitions primarily during the spring and autumn months, while in summer the exterior surface temperature remains above the melting point, keeping the PCM predominantly in the liquid phase. Consequently, latent heat storage was not activated between June and September, which was observed on Fig. 7. Minor deviations between PCM and PSM were attributed to density differences between the solid and liquid phases of the material.

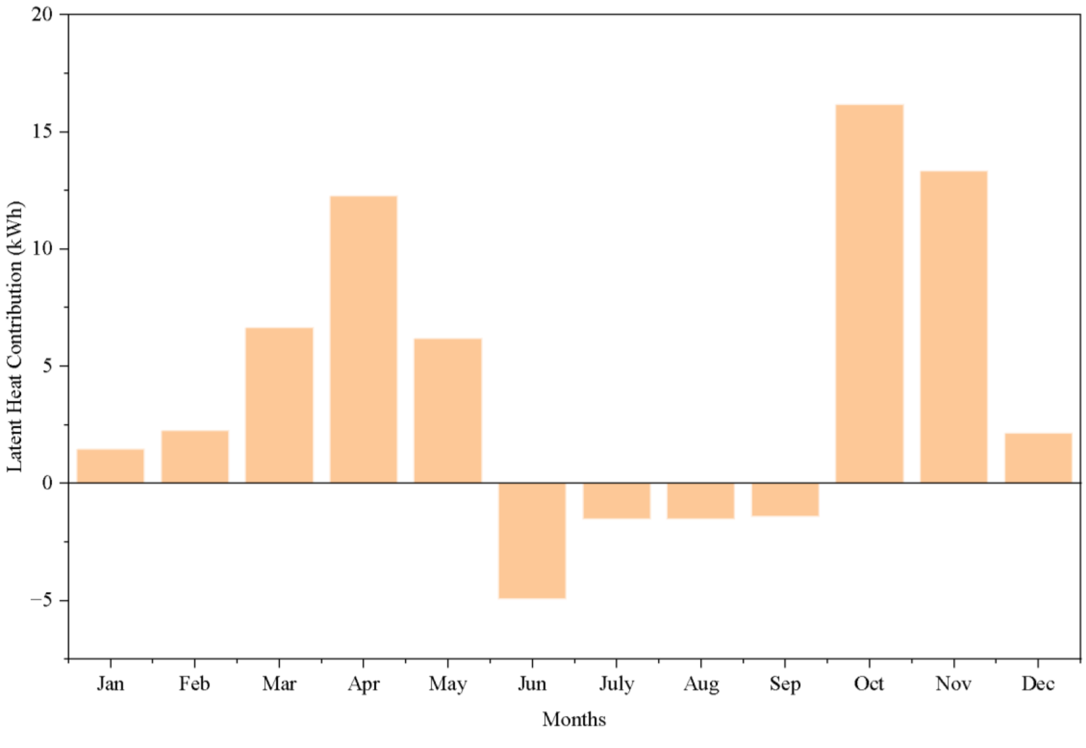


Figure 7. Latent heat contribution of RT18 with 28mm thickness and placed close to outer surface

To provide a more detailed perspective, Fig. 9 presents the hourly variation of the exterior wall surface temperature on the 9th of June. In this figure, the phase change ranges of RT18, RT21, and RT25 at 30mm thickness are superimposed on the temperature profile to illustrate their interaction with the wall surface conditions. The results indicated that the exterior surface temperature consistently remains above the phase change interval of RT18 throughout the entire day, preventing any solidification–melting cycles. In contrast, RT21 and RT25 exhibit limited phase change activity, as their transition ranges were only encountered during the nighttime and early morning hours (approximately 19:00–08:00). For the rest of the day, their phase transition was suppressed due to higher surface temperatures. This finding under summer conditions highlighted that latent heat storage was largely inactive for RT18 and only partially activated for RT21 and RT25, which was consistent with the seasonal behavior discussed in Figs. 7. This observation was also supported by Fig. 4, where RT18 exhibits higher cooling loads than RT21 and RT25 at increased thicknesses.

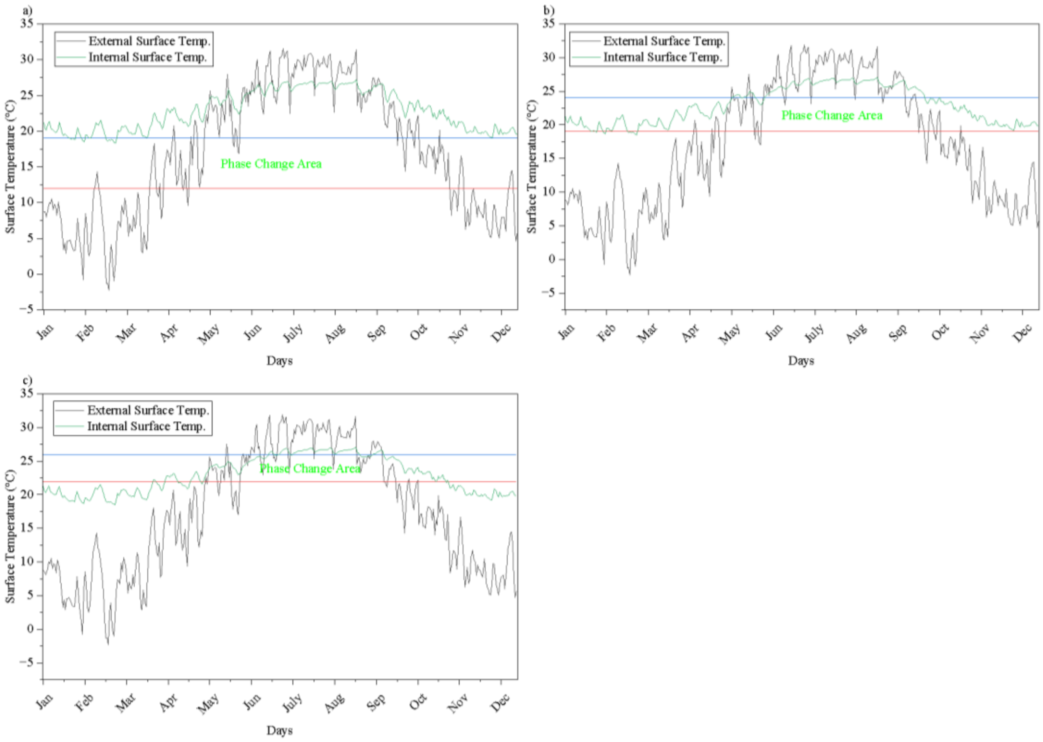


Figure 8. Comparison of annual external wall surface temperature and PCM phase change temperature range a) RT18, b) RT21, c) RT25

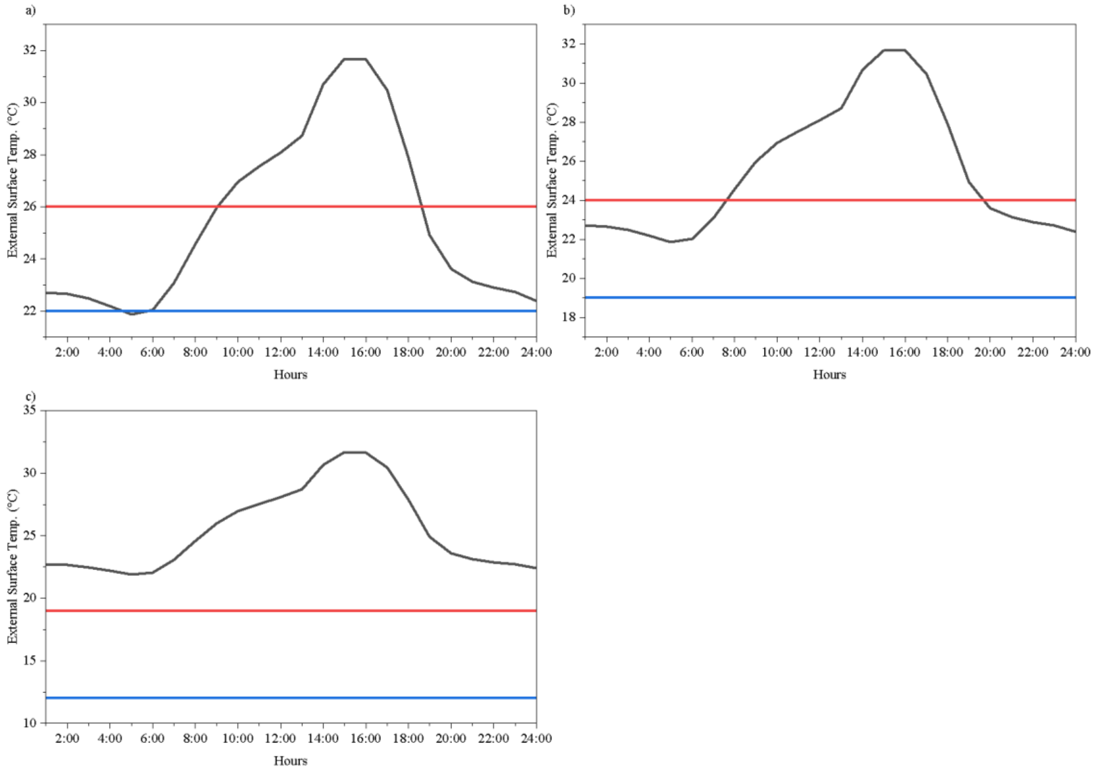


Figure 9. Hourly variation of exterior wall surface temperature on June 9, with phase change ranges of a) RT25, b) RT21, and c) RT18

4. Conclusion

This study examined the influence of different PCM types, thicknesses, and placement positions within the external wall structure of a residential building under Istanbul's climate (hot-summer Mediterranean). Numerical analyses were conducted on annual, monthly, daily, and hourly basis to evaluate heating and cooling loads, with particular emphasis on the role of PCM melting temperature, thickness, and location in the wall assembly.

- Placement near the inner surface provided the highest overall energy-saving potential, as RT18 achieved the maximum annual total saving of approximately 4% compared to the reference wall.
- When the PCM was placed near the outer surface, the cooling load showed almost no variation compared to the base case, with slight increase below 1%.
- Outer-surface placement still led to a net reduction in total load up to 3%, confirming that PCM can provide energy savings even under less favorable conditions.
- The findings emphasized the necessity of optimizing PCM melting temperature, thickness, and placement strategy in relation to the prevailing climate, since PCM can either mitigate or exacerbate cooling demand.
- Increasing thermal inertia initially caused a slight overheating effect; however, for the RT21 case, beyond a certain threshold, it started to enhance cooling performance.

It should also be noted that the findings are valid for the modeled wall/window composition (U-values), building mass, and the specific climatic conditions of Istanbul. Across all scenarios, PCM consistently contributed to reducing overall energy use, reinforcing its potential as a passive energy-saving technology in building envelopes. Future studies should extend the analysis to different building types (lightweight and heavyweight structures) and various climatic conditions to establish a more comprehensive understanding of PCM applications in buildings.

5. References

[1] *** International Energy Agency. (2023). World Energy Outlook 2023. IEA. https://www.iea.org/

[2] **Verbeke, S., & Audenaert, A.** (2018). Thermal inertia in buildings: A review of impacts across climate and building use. Renewable and Sustainable Energy Reviews, 82, 2300–2318. https://doi.org/10.1016/j.rser.2017.08.083

[3] **Karlsson, J., Wadsö, L., & Öberg, M.** (2013). A conceptual model that simulates the influence of thermal inertia in building structures. *Energy and Buildings, 60,* 146–151. https://doi.org/10.1016/j.enbuild.2013.01.017

[4] **Kuczyński, T., & Staszczuk, A.** (2020). Experimental study of the influence of thermal mass on thermal comfort and cooling energy demand in residential buildings. Energy, 195, 116984. https://doi.org/10.1016/j.energy.2020.116984

[5] **Wang, X., Li, W., Luo, Z., Wang, K., & Shah, S. P.** (2022). A critical review on phase change materials (PCM) for sustainable and energy efficient building: Design, characteristic, performance and application. Energy and Buildings, 260, 111923. https://doi.org/10.1016/j.enbuild.2022.111923

[6] **Shree, V., Dwivedi, A., Saxena, A., Pathak, S. K., Agrawal, N., Tripathi, B. M., Shukla, S. K., Kumar, R., & Goel, V.** (2025). A comprehensive review of harnessing the potential of phase change materials (PCMs) in energy-efficient building envelopes. Journal of Building Engineering, 101, 111841. https://doi.org/10.1016/j.jobe.2025.111841

[7] Guarino, F., Dermardiros, V., Chen, Y., Rao, J., Athienitis, A., Cellura, M., & Mistretta, M. (2015). PCM Thermal Energy Storage in Buildings: Experimental Study and Applications. Energy Procedia, 70, 219–228. https://doi.org/10.1016/j.egypro.2015.02.118

[8] Guarino, F., Athienitis, A., Cellura, M., & Bastien, D. (2017). PCM thermal storage design in buildings: Experimental studies and applications to solaria in cold climates. Applied Energy, 185, 95–106. https://doi.org/10.1016/j.apenergy.2016.10.046

[9] **Arıcı, M., Bilgin, F., Nižetić, S., & Karabay, H.** (2020). PCM integrated to external building walls: An optimization study on maximum activation of latent heat. Applied Thermal Engineering, 165, 114560. https://doi.org/10.1016/j.applthermaleng.2019.114560

[10] Kuznik, F., & Virgone, J. (2009). Experimental assessment of a phase change material for wall building use. Applied Energy, 86(10), 2038–2046. https://doi.org/10.1016/j.apenergy.2009 01.004

[11] Castellón, C., Castell, A., Medrano, M., Martorell, I., & Cabeza, L. F. (2009). Experimental Study of PCM Inclusion in Different Building Envelopes. Journal of Solar Energy Engineering, 131(4). https://doi.org/10.1115/1.3197843

[12] TSE, TS 825 – Thermal Insulation Requirements for Buildings, Turkish Standards Institution, Ankara, 2025.

[13] American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), *International Weather for Energy Calculations (IWEC Weather Files)*, Atlanta, GA: ASHRAE, 2001.

[14] Rubitherm GmbH. (2024). *Phase Change Materials (RT Series) – Technical Data Sheets.* Available at: https://www.rubitherm.eu/en/productcategory/organische-pcm-rt