Renew. Energy Environ. Sustain. **6**, 38 (2021)
© Q. Al-Yasiri and M. Szabó, Published by EDP Sciences, 2021
https://doi.org/10.1051/rees/2021040

Renewable Energy and Environmental Sustainability

Available online at:
www.rees-journal.org

Review Article Open Access

Paraffin As a Phase Change Material to Improve Building Performance: An Overview of Applications and Thermal Conductivity Enhancement Techniques

Qudama Al-Yasiri[1,2,3,*] and Márta Szabó[2]

[1] Doctoral School of Mechanical Engineering, Hungarian University of Agriculture and Life Sciences, Páter K. u. 1, Gödöllő 2100, Hungary
[2] Department of Building Engineering and Energetics, Institute of Technology, Hungarian University of Agriculture and Life Sciences, Páter K. u. 1, Gödöllő 2100, Hungary
[3] Department of Mechanical Engineering, Faculty of Engineering, University of Misan, Al Amarah City 62001, Misan Province, Iraq

Received: 29 June 2021 / Received in final form: 4 October 2021 / Accepted: 5 October 2021

Abstract. In recent years, phase change materials (PCMs) have increasingly received attention in different thermal energy storage and management fields. In the building sector, paraffin as a phase change material (PPCM) has been introduced as an efficient PCM incorporated in a building envelope, which showed remarkable results. However, the poor thermal conductivity of PPCM is still the topmost drawback in experimental and numerical investigations. In this paper, a general assessment of paraffins, their common uses and applications, have been presented with a particular focus on their potential in building envelope applications. Moreover, the general and desired properties of PPCM are highlighted and evaluated. The primary practical limitation of PPCM of poor thermal conductivity and their effect on PPCM performance is presented and discussed. Correspondingly, the popular techniques applied to improve the poor thermal conductivity are presented and discussed in four categories: the dispersion of nanoparticles, expanded graphite, metallic foam, and extended surfaces technique (fins). All in all, the analysed research works indicated that PPCM based building envelope applications could remarkably improve the thermal performance of buildings in terms of thermal load reduction, energy-saving and thermal comfort. Furthermore, the adoption of enhancement techniques is essential to improve the thermal performance of PPCM in building applications for better utilisation. This review provides a clear vision for the newcomers and interested parties about the main application aspects of PPCM in the building sector for further investigations towards technology commercialisation.

1 Introduction

Building energy consumption is maximising year after year due to population, urbanisation, and people's lifestyle. The increased greenhouse gas (GHG) emissions and climate change risks have drawn attention to adopting alternative energy sources [1,2]. Buildings are globally known as the biggest consumer of energy and the main responsible for GHG emissions. According to the International Energy Agency, the GHG emissions will be doubled by 2050 unless serious changes in the energy sources pattern being taken [3]. In this regard, researchers and responsible parties are working to develop systems and technologies for low or zero energy buildings.

Among modern technologies, phase change materials (PCMs) have been introduced as a revolutionary solution for many thermal applications over the last four decades [4]. PCMs are used for plastering mortars [5,6], concrete [7–9], bricks [10–14], walls [15–17], roofs [18–20], floors [21,22], windows and glasing elements [23–26].

PCMs can moderate the thermal energy through the building envelope under various climate conditions thanks to their high potential of storing and releasing heat energy during phase transition. PCM can be mixed with construction materials in hot climates and act as a heat barrier against the heat coming from outdoor towards indoor to decrease the high cooling load concerns [27,28]. In contrast, they also can work as a heat supplier under cold climates, which decrease the heating loads [29,30].

---

[*] e-mail: qudamaalyasiri@uomisan.edu.iq

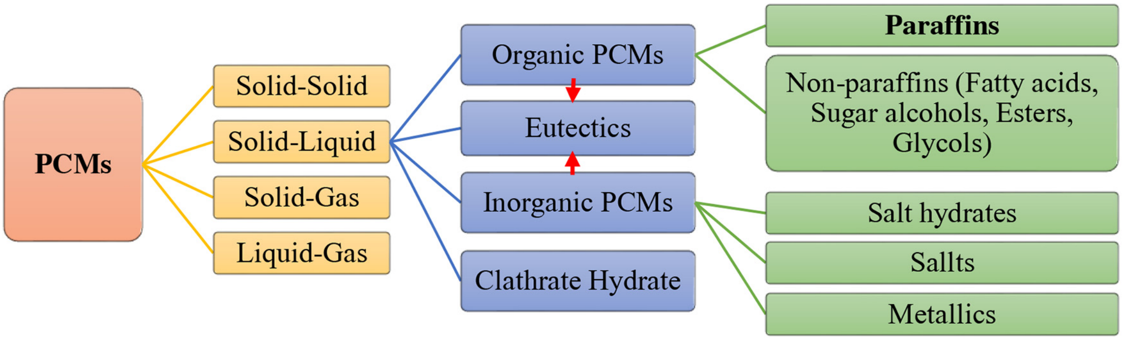


Fig. 1. Classification of PCMs [32].

Table 1. General properties of paraffins [34].

Property	Description/Value
Chemical formula	C_nH_2n+2
Appearance	Depends on the paraffin source and composition
Boiling point	$> 370\,°C$
Density	$\sim 900\,kg/m^3$
Specific heat capacity	2.14–2.9 J/gK

Among many PCM types, paraffin has mostly adapted for many sectors, particularly in the building sector. PPCM is classified as an organic PCM with great flexibility in building applications than other PCM categories shown in Figure 1 [31]. Furthermore, their abundant accessibility with low cost and safe operation makes them an excellent option for many building energy advances.

This paper focuses on the potential of paraffin in the building envelope applications, the most widely used PCM in this regard. To reach that, a general outlook of paraffin types, their uses and applications were highlighted in the following section. The third section analyses and discusses the main thermal improvements earned from incorporating PPCM in buildings. Following that, the most spread techniques used to improve the poor thermal conductivity of PPCM are introduced dealing with the recent investigations in this area of research. Finally, several conclusions are drawn from the analysed studies and presented for further researches in the future.

2 Paraffin

2.1 General overview

Paraffin (also called alkane) is an organic, colourless, odourless and chemically based material derived mainly from petroleum waste products. Paraffin is a mixture of hydrocarbons and generally has a melting temperature ranged from sub-zero to above 100 °C [33]. Table 1 lists other common properties of paraffin.

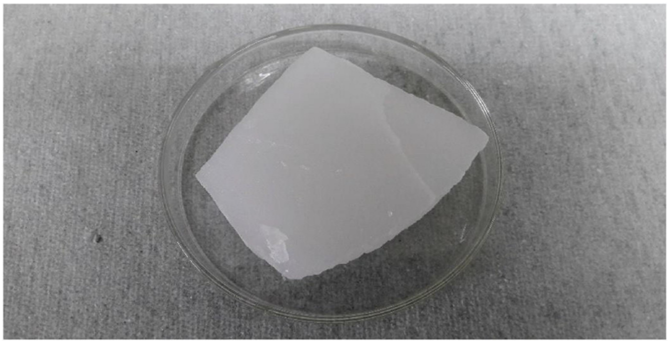


Fig. 2. Paraffin wax appearance.

Paraffins are mainly classified according to the number of carbon atoms in the crystal structure. Paraffin has a gaseous state under room conditions with 1–4 carbon atoms and is known as pure alkanes. Paraffin with 5–17 carbon atoms is usually in a liquid state at room temperature, and those with more than 17 are waxes. Solid waxes are a mixture of saturated hydrocarbons and are naturally linear, iso branched, or cycloalkanes [35]. Figure 2 shows the typical solid-state paraffin wax available in the local markets.

2.2 Uses and applications of paraffin

Paraffins have been used in different sectors such as the commercial sector (candle-making, paintings, coatings, crayons, surf-waxes, etc.), medical sector (cosmetics,

Table 2. Thermal properties of paraffin types suitable for building applications [75].

Paraffin	Melting temperature (°C)	Latent heat (kJ/kg)	Density (kg/m^3)	Thermal conductivity (W/m K)
n-Hexadecane (C16)	18	237	770	0.2
n-Heptadecane (C17)	22	213	760	0.145
Paraffin C16-C18	20–22	152	–	–
Paraffin C13-C24	22–24	189	900	0.21
n-Octadecane (C18)	28	245	865	0.148
n-Nonadecane (C19)	32	222	830	0.22
RT 35 HC	35	240	880	0.2
n-Eicosane (C20)	37	246	–	–
n-Henicosane (C21)	40	200–213	778	–
Paraffin C16-C28	42–44	189	910	–
n-Docosane (C22)	44.5	249	880	0.2
n-Tricosane (C23)	47.5	232	–	–
Paraffin C20-C33	48–50	189	912	–

medical paths, therapy treatment) electrical sector (insulators, actuators, and thermostats) [36], mechanical sector (lubrication, fuels) [37]. They have been implemented successfully as PCMs in many heat energy storage-linked applications. Recently, PPCM is emerged with renewable energy applications to improve their utilisation. Specifically, they have been used in solar systems to store the heat and meet the heat supply mismatch and demand or release the heat from the solar system for better performance. Concisely, PPCMs are utilised in solar systems for the following benefits:

- In solar storage tanks to prolong the time of heat for later use in solar heating [38–43], solar domestic hot water [44], solar cooling and air-conditioning systems [45–50].
- To store solar heat to be used after sunset to extend water productivity in solar distillers [51–55] and enhance solar drying and other solar systems [56–59].
- To improve the efficiency of solar thermal collectors such as solar air heaters [60], flat plate solar collectors [61], evacuated tube solar collectors [62] and concentrated solar collectors [63,64] after sunset.
- To store and later release non-desired heat in photovoltaic/thermal systems working in hot weather conditions to enhance their efficiency [65–70].
- To manage the heat and improve the heat sink in electric and electronic devices [71–74].

PPCM incorporated into the building envelope showed remarkable improvements by shaving and shifting the peak load and building energy and thermal comfort improvements.

Among the thermo-physical properties of PPCM, the melting temperature represents its key property in a specific application. Therefore, paraffin that has low and medium melting temperatures is preferred for building applications. Table 2 lists the main thermo-physical properties of different paraffin types that are suitable for building applications.

3 PPCM for building performance improvement

PPCMs have a great potential to improve building energy performance thanks to their high latent storage capacity and other desired characteristics. These improvements presented as cooling/heating load reduction, decrement of daily temperature fluctuations, thermal management of building elements, reduction of indoor surface temperatures, energy savings and thermal comfort improvement [16,76].

PPCM is commonly incorporated into building elements in different methods: *direct mixing*, *impregnation*, *encapsulation*, and shape-stabilised. In *direct mixing* and *impregnation* methods, PPCM is combined directly with the building materials such as concretes and mortars either by direct addition or immersing. However, in these methods, PPCM is suffering from leakage during the melting phase, which influences the compatibility of building elements. *The encapsulation* method has been introduced to solve leakage and enhance the thermal conductivity of PPCM. In this method, PPCM is contained in special covering material either at micro-size (micro-encapsulation) or larger (macro-encapsulation). In both encapsulation techniques, PPCM performs better and can be installed with building materials efficiently and safely [77]. The *shape-stabilised* method is the most advanced method where the PPCM includes an inside carrying matrix of stable shape during melting and solidification, which provides high thermal stability and cycle durability. The complexity of manufacturing and high cost are the main disadvantages of this method.

Researchers have investigated the potential of PPCM in building construction elements and reported remarkable advantages in building performance. Table 3 shows the main improvements of PPCM incorporated building envelope materials of various melting temperatures, incorporation methods and building applications.

Table 3. Thermal improvements of PPCM incorporated building envelope.

Composition (PCM melting temperature, °C)	Incorporation method	Construction element	Main findings and remarks	Ref.
Paraffin (44)/ Concrete	Direct mixing	Foam concrete	• The thermal storage capacity of composite PPCM/concrete is enhanced over conventional concrete • Composite PPCM/concrete with 45% PPCM content had the best stable structure considering the thermal performance and leakage issues.	[78]
Paraffin (44)/expanded graphite/ Cement	Direct mixing	Building outer surfaces and sandwiched middle enclosures of walls	• Foamed cement blocks of 30% PPCM content have the best thermal energy storage performance and efficiently maintain the indoor temperature.	[79]
Paraffin Wax (58.5)/ Conical concrete holes	Direct mixing	Walls	• The cooling load was reduced by 9%. Moreover, an energy-saving of 31% and a time lag of 184 min were obtained.	[80]
RT28 (28)/ Concrete	Impregnation	Autoclave aerated concrete	• The thermal storage capacity of concrete improved with 40% PPCM impregnation • Two-thirds of PPCM/concrete is appropriate to ensure the optimal thermal performance of PPCM and prevent leakage upon melting.	[81]
Micronal 5038X (26) and Micronal 5040X (23)/ Cement mortar	Micro-encapsulation	Internal and external wall applications	• The comfort period increased by about 15% during the entire year by mixing 15 wt% of PPCM with cement mortar.	[82]
Paraffin (27-29)/ Extruded polystyrene/ gypsum	Macro-encapsulation (high-density polyethene spheres)	Wallboard	• The internal wall surface temperature was reduced by 21.4% and 23.9% during summer and winter • Annual average energy-saving of 23.1% was achieved.	[83]
Paraffin wax (44) incorporated separately	Macro-encapsulation (aluminium pipes, rectangular cross-section)	Walls and ceiling	• Cooling load reduction up to 20.9% and a maximum electricity saving of 1.35 Dollars/Day m^3 were obtained.	[84]
RT27 (27.5) incorporated separately	Macro-encapsulation (copper pipes, circular cross-section)	Walls	• Energy-saving of 63.81W-hr/m^2 and a time delay of 116min was achieved • Maximum heat flux reduced by 22.45% • A maximum energy saving of 32.67W-hr/m^2 was obtained.	[85]
RT-21 (21-22)/ Pre-fabricated concrete slab	Macro-encapsulated (circular aluminium tubes)	Ceiling	• Energy-saving of 25% and 40% achieved during severe and mild winter conditions.	[86]
Paraffin (23-27) incorporated separately into the interior	Shape-stabilized	Walls	• An average annual energy-saving of 5% was obtained • The peak temperature in summer was reduced by 4.1 °C.	[87]

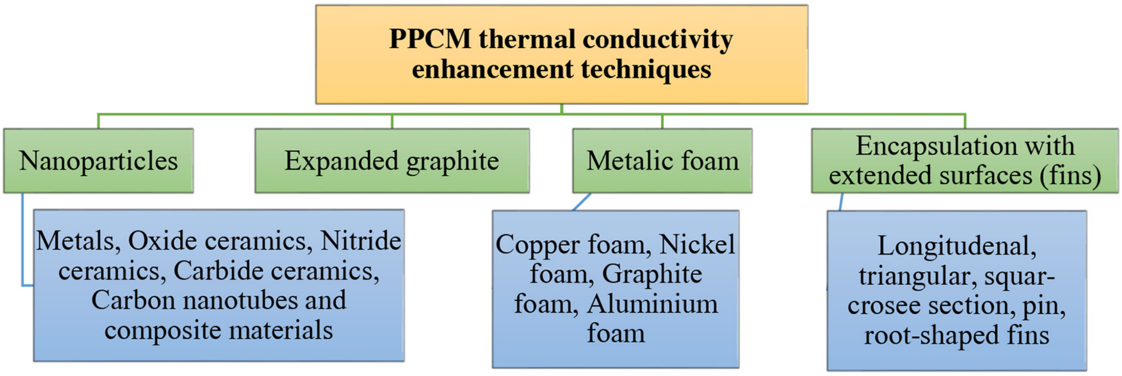


Fig. 3. Techniques to enhance PPCM poor thermal conductivity.

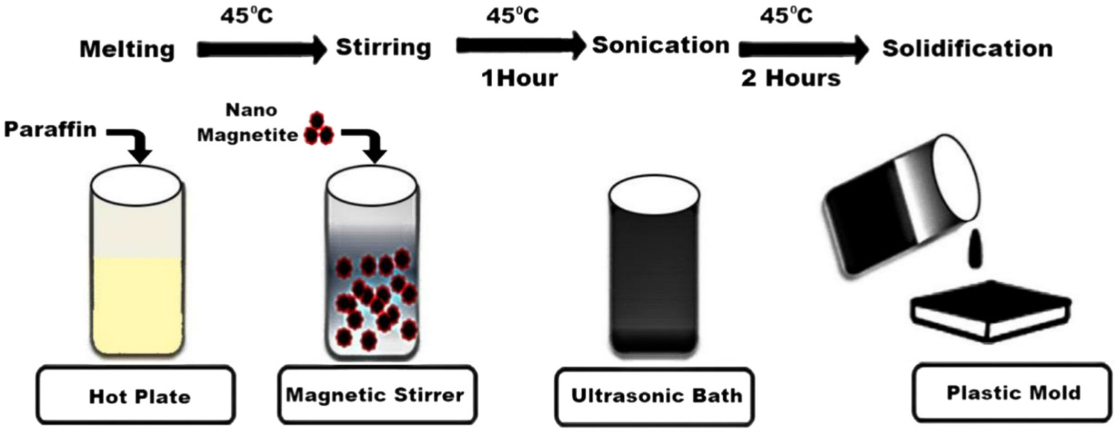


Fig. 4. Preparation procedure of NPs-PPCM [51].

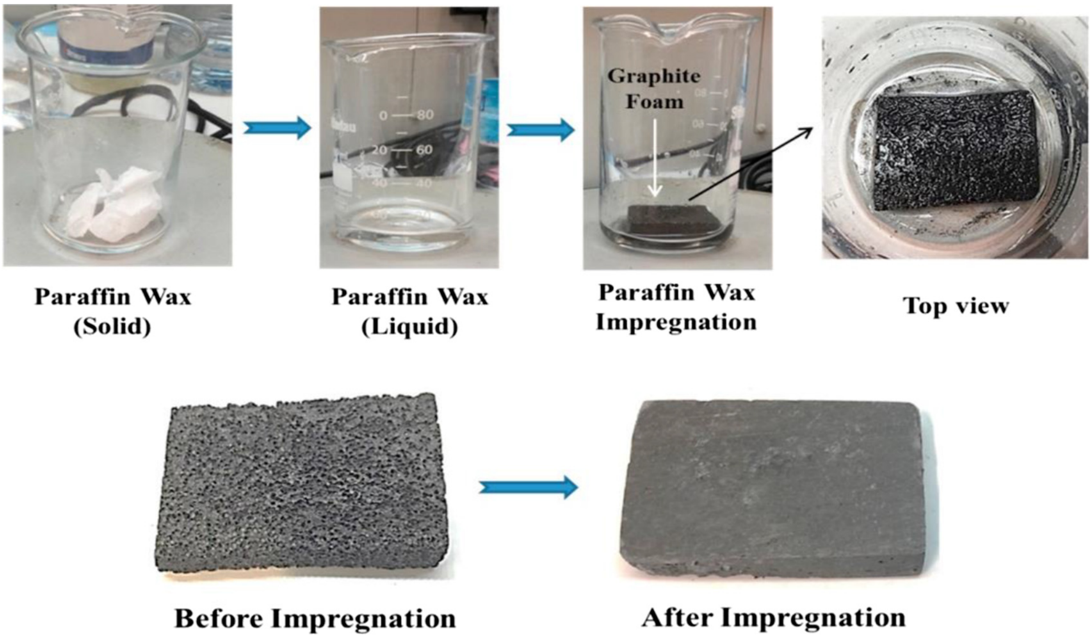


Fig. 5. PPCM-EG preparation steps [105].

4 Enhancement techniques for PPCM poor thermal conductivity

PPCM has many preferred properties that make it an outstanding choice in building applications. The primary desired properties are (i) availability with low-cost, (ii) relatively high latent heat, (iii) no sub-cooling, (iv) non-toxic, (v) non-corrosive, (vi) eco-friendly, (vii) low volumetric change during phase transition and (viii) chemically stable with no segregation over long-term service [88,89]. Notwithstanding the exciting improvements of using PPCM in building elements, the poor thermal conductivity is the main limitation reported by the researchers in this regard. Moreover, like other PCMs, PPCMs are suffering from crystallisation over many rounds of melting/solidification. However, paraffins are stable materials, and the crystallisation phenomenon rarely occurs after many working cycles [90]. More details about paraffin crystallisation can be found in [91,92].

PPCMs are generally renowned for their poor thermal conductivity, which prolongs melting and solidification and impacts thermal performance. In general, the thermal conductivity of PPCMs can be enhanced using different methods such as dispersion of conductive nanoparticles, the addition of expanded graphite, using metallic foams and encapsulation with extended surface techniques (Fig. 3).

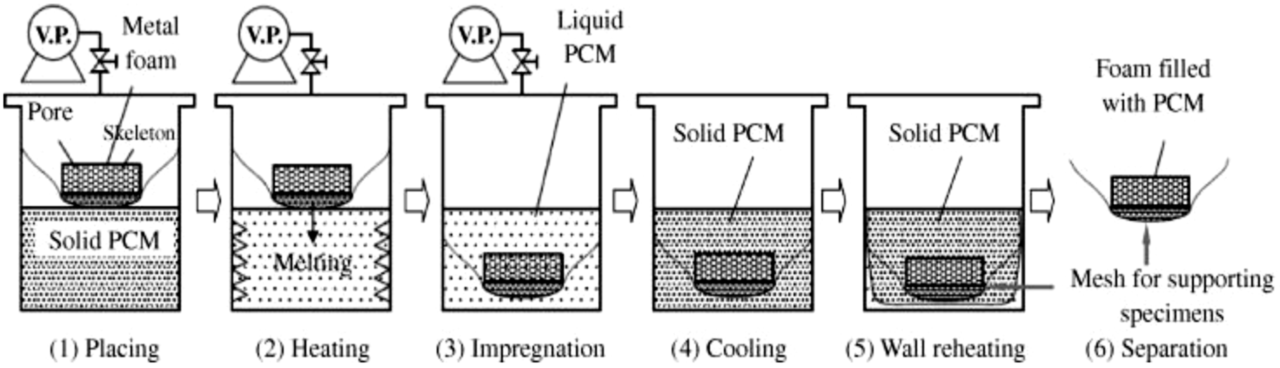
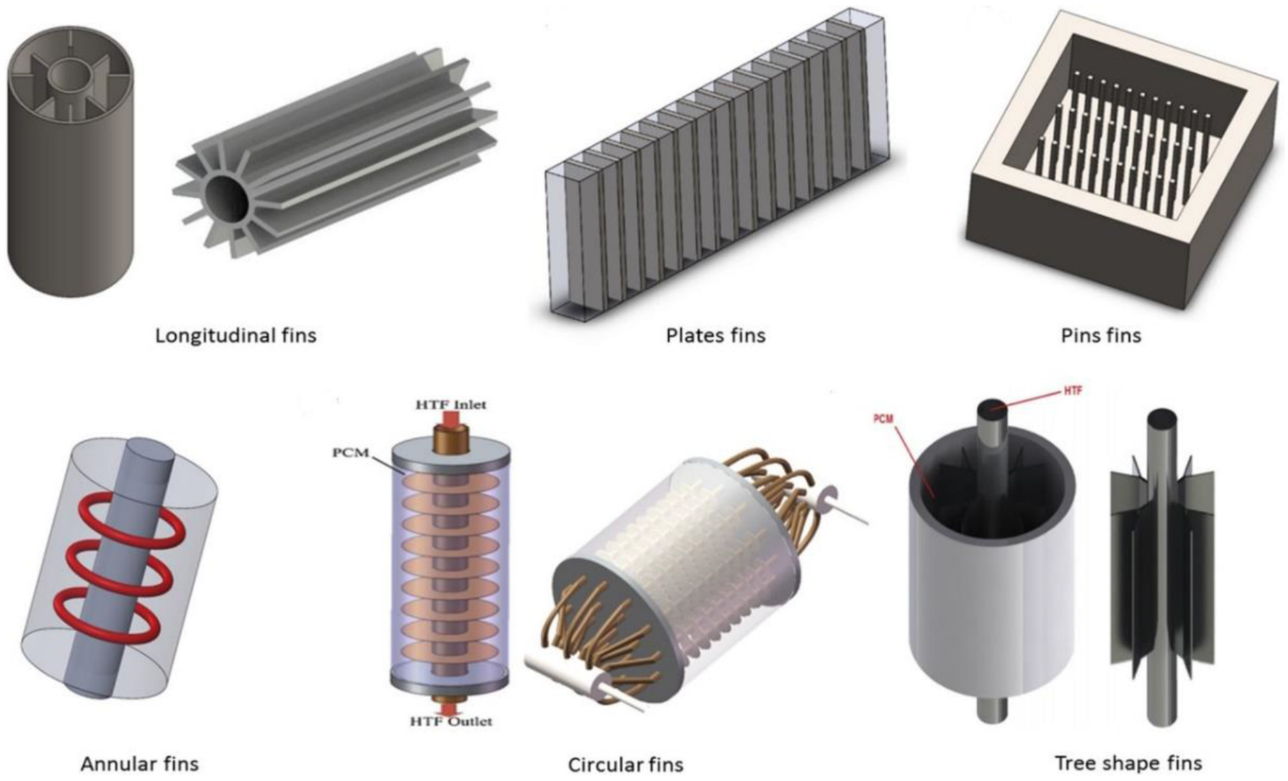


Fig. 6. Preparation steps of PPCM-metal foam [108].



Longitudinal fins

Plates fins

Pins fins

Annular fins

Circular fins

Tree shape fins

Fig. 7. Different types of finned encapsulation containers [111].

In recent years, *nanoparticles* (NPs) have been introduced as an effective technique to increase the thermal conductivity of the base fluid in many applications [24,93]. NPs can considerably improve the thermal conductivity and heat storage capacity of paraffin with no significant improvement in its melting temperature [94]. Researchers have deeply investigated the poor thermal conductivity of paraffin, and immersion of NPs is a superior technique in this regard [95]. Different NPs with various concentrations have been studied and indicated remarkable enhancement [96,97]. The main advantage of dispersing NPs with PPCMs is shortening heat charging/discharging time, which are the core of thermal energy storage systems [98]. Nevertheless, several limitations are reported, such as long-term degradation and optimal nano concentration to fulfil the desired properties, homogeneity issues/concerns, and cost consideration [99]. Preparation of PPCM-NPs is usually done using the same methods used to prepare nanofluids, such as sonication, magnetic stirrer, and so on [100,101]. However, stable PPCM-NPs is still one of the most challenging tasks, even in recent literature studies [102]. Figure 4 shows the main preparation steps of PPCM-NPs.

Expanded graphite (EG) is a novel technique used to enhance PPCM thermal conductivity. It is a worm-like network pore structure at a micrometric scale with high thermal conductivity, large volume and specific surface area [103]. EG is usually used as a supporting material for PPCM in which the thermal conductivity of PPCM increases as the mass fraction of EG increases [104]. Figure 5 shows the main steps followed to prepare PPCM-EG.

Table 4. PPCM thermal conductivity improvements.

Enhancement technique	Composition	Enhancement of thermal conductivity	Ref.
NPs	Paraffin/expanded perlite (49.5 and 47.5) loaded with 1 and 5% wt. of graphene nano-platelets	Thermal conductivity of paraffin-expanded perlite-graphene nano-platelets (5%) enhanced by 1.66 and 2.5 times faster than paraffin/expanded perlite/graphene nano-platelets (1%) and paraffin alone, respectively.	[112]
NPs	Paraffin/ethylene-vinyl acetate (EVA)/graphene nanocomposites (0.7, 1.5, 3.6 and 7.0% wt.)	PCM with graphene of 0.7% had the highest thermal conductivity enhancement among all nanocomposites.	[113]
NPs	Paraffin/ multi-walled carbon nanotubes and activated carbon	Paraffin/multi-walled carbon nanotube and paraffin/activated carbon composites' thermal conductivity are improved by 34.1% and 39.1%, respectively, compared with pure paraffin.	[114]
NPs	Paraffin/ graphene oxide and graphene nano-plates	The thermal conductivity of PPCM based graphene oxide and graphene nano-platelets was enhanced by up to 360%.	[115]
NPs	Paraffin/AL_2O_3, ZrO_2 and SiC nanoparticles with 0%, 0.1%, 0.5%, 1%, 2%, 3%, 4% and 5%.	Adding 1% of nano-Al_2O_3, nano-ZnO_2 and nano-SiC to paraffin wax enhanced its thermal conductivity by 3.3%, 1.8% and 4.2%, respectively.	[116]
NPs	Organic montmorillonite (OMMT)/paraffin/grafted multi-walled nanotube (MWNT)	OMMT/paraffin/ MWNT composite's thermal conductivity is higher than that of the OMMT/paraffin and paraffin by 34% and 65%, respectively.	[117]
NPs	Paraffin/ Fe_2O_3 (1%, 2%, 3%, 4 % and 5% wt. concentrations)	The paraffin/ Fe2O3 composite's thermal conductivity was improved over the paraffin alone by up to 30% at 3% Fe_2O_3 concentration.	[118]
EG	Paraffin/EG (15%)	The thermal conductivity of paraffin/EG is higher by 6.5 times that of pure paraffin thermal conductivity.	[119]
NPs + EG	Paraffin (90.6%) + expanded graphite + carbon fibers (1%)	The thermal conductivity of gypsum mortar increased by 36.0% with the addition of 1% carbon fibers.	[120]
NPs + EG	Paraffin/ Cu, Al, Ni, and Fe/ EG	The highest thermal conductivity obtained for paraffin/EG11%/Cu1.9% was nine times pure paraffin.	[121]
Metallic foam	Paraffin/graphite foam composite	The paraffin/graphite foam composite's thermal conductivity in solid and liquid phases was higher by 980% and 1530% than pure paraffin wax.	[105]
Metallic foam	Paraffin /copper foam metal composite	The thermal conductivity and heat storage time improved by 40%.	[122]
Metallic foam	Paraffin (62%)/TiO_2 foam	The thermal conductivity of paraffin composite was higher by about five times that of pure paraffin.	[123]
Metallic foam	Paraffin/copper and nickel foams	The thermal conductivity of paraffin increased by 376% using copper foam against 205% for nickel foam.	[124]
NPs + metallic foam	Paraffin/ polystyrene-carbon nanotubes/PolyHIPE foam	Thermal conductivity of the composite paraffin increased by 62% compared with pure paraffin	[125]

Table 4. (continued).

Enhancement technique	Composition	Enhancement of thermal conductivity	Ref.
Fins	Paraffin (RT82)/ longitudinal and triangular copper fins	The thermal conductivity of paraffin was improved using triangular fins by 18% compared with longitudinal fins.	[126]
Fins	Paraffin/ Pin fins (square section-area of 1, 2 and 3 mm thickness)	The thermal conductivity and thermal performance of paraffin were enhanced by 4.3 at fins of 2 mm thickness.	[127]
NPs + Fins	Paraffin(n-Octadecane)/ horizontal radial copper fins/ Al_2O_3 (1%–5% concentration)	The best thermal conductivity of paraffin was obtained at 3-fins and 5% NPs concentration, in which the melting time shortened by 28.3%.	[128]
NPs + Fins	Paraffin/ graphene nano-platelets (1%, 3% and 5% concentration)/ Fins (longitudinal, circular and wire-wound)	The optimal thermal performance of PPCM was achieved with 1% graphene nanoplates and wire-wound fins. The melting time was reduced from 23.5 h to only 1.02 h compared with the PPCM without thermal enhancement.	[129]

Metallic foam is another essential technique used to enhance the thermal conductivity of PPCM. What makes metallic foams a great option is their high porosity, stable thermo-physical properties, good mechanical strength and high thermal conductivity of base materials. Furthermore, their long term stability and low density are the superior advantages that make them preferable more than NPs [106]. In general, metallic foams' effectiveness depends on the type of foam material, pore size and pore density [107]. Incorporating as much as possible of PPCM inside metallic foam with no leakage is an important task. Therefore, the proper procedure should be followed to gain the best utilisation of PPCM storage capacity with maximum content (Fig. 6).

Encapsulation using finned containers (external and/or internal fins) can also significantly enhance the thermal conductivity of PPCM. This technique is an economical option and has shown notable enhancement using high thermal conductivity materials such as copper, aluminium and stainless steel. Using fins accelerate the melting and solidification processes, which shorten the time to reach the complete cycle. The thermal performance of PPCM is influenced by different parameters of fins such as their type, dimensions, spacing and number of fins [109,110]. Figure 7 shows the main shapes and designs of fins used for PPCM thermal conductivity enhancement purposes.

Many studies considering the enhancement of PPCM thermal conductivity are reported in the literature, and the recent ones are shown in detail in Table 4.

5 Conclusion

This paper introduced PPCM as an advanced solution to improve buildings' thermal energy, which showed exciting results. PPCM has shown a bright potential in the building industry thanks to their availability worldwide and desired properties. Several conclusions can be drawn from the analysed studies, as follows:

- PPCM can effectively improve the energy of building under different locations for heating and cooling purposes. Further, PPCMs have a wealth future in building applications mainly because of their low cost, a vast range of latent heat storage capacity, and high flexibility to incorporate different methods and techniques.
- The poor thermal conductivity represents the main drawback of PPCM, which results in incomplete charging/discharging phases and significantly influences the building's thermal performance.
- Among other enhancement technologies, the dispersion of NPs is the most booming technology nowadays, which can enormously enhance the thermal properties of PPCM. Investigating new NPs and their optimal concentrations in PPCM are still under research.
- Despite the limited amount of PPCM allowed to avoid leakage, EG is an excellent technique to enhance its thermal conductivity. However, few investigations with building applications can be found in the literature.
- The inserting of metallic foams is a competitive option against NPs to enhance PPCM thermal conductivity. Nonetheless, these foams are limited to a few materials such as aluminium, nickel, and copper; hence, investigating new materials is still out of view.
- Fins are a crucial and economical option that can positively influence the melting/solidification time of PPCM. Some studies reported significant results mostly done numerically. More experimental studies are required to specify the optimal parameters (material type, shape, number, etc.).

- The combination of more than one enhancer, for instance, fins and NPs, seems to be the best option in this regard. However, system complexity and economic feasibility should be considered accordingly.
- Other enhancers of PPCM thermal conductivity are required in future researches considering the cost, performance improvement and ease of incorporation.

Acknowledgments. This work was supported by the Stipendium Hungaricum Scholarship Programme and the Mechanical Engineering Doctoral School, Hungarian University of Agriculture and Life Sciences, Gödöllő campus, Hungary.

References

1. IEA, *The Future of Cooling: Opportunities for Energy-Efficient Air Conditioning* (Internal Energy Agency, 2018)
2. Q. Al-Yasiri, G. Géczi, Global warming potential: causes and consequences, Acad. Lett. 3202 (2021)
3. IEA, *CO2 Emissions from Fuel Combustion* (International Energy Agency, 2020)
4. G. Alva, Y. Lin, G. Fang, An overview of thermal energy storage systems, Energy **144**, 341–378 (2018)
5. N. Essid, A. Eddhahak-Ouni, J. Neji, Experimental and numerical thermal properties investigation of cement-based materials modified with PCM for building construction use, J. Archit. Eng. **26**, 1–9 (2020)
6. P. Sukontasukkul, T. Sutthiphasilp, W. Chalodhorn, P. Chindaprasirt, Improving thermal properties of exterior plastering mortars with phase change materials with different melting temperatures: paraffin and polyethylene glycol, Adv. Build. Energy Res. **13**, 220–240 (2019)
7. A. Adesina, Use of phase change materials in concrete: current challenges, Renew. Energy Environ. Sustain. **4**, 9 (2019)
8. U. Berardi, A.A. Gallardo, Properties of concretes enhanced with phase change materials for building applications, Energy Build. **199**, 402–414 (2019)
9. P. Sukontasukkul, E. Intawong, P. Preemanoch, P. Chindaprasirt, Use of paraffin impregnated lightweight aggregates to improve thermal properties of concrete panels, Mater. Struct. **49**, 1793–1803 (2016)
10. E. Tunçbilek, M. Arıcı, S. Bouadila, S. Wonorahardjo, Seasonal and annual performance analysis of PCM-integrated building brick under the climatic conditions of Marmara region, J. Therm. Anal. Calorim. **141**, 613–624 (2020)
11. Q. Al-Yasiri, M. Szabó, Thermal performance of concrete bricks based phase change material encapsulated by various aluminium containers: an experimental study under iraqi hot climate conditions, J. Energy Storage **40**, 102710 (2021)
12. K. Kant, A. Shukla, A. Sharma, Heat transfer studies of building brick containing phase change materials, Sol. Energy **155**, 1233–1242 (2017)
13. M. Mahdaoui, S. Hamdaoui, A. Ait Msaad, T. Kousksou, T. El Rhafiki, A. Jamil, M. Ahachad, Building bricks with phase change material (PCM): thermal performances, Constr. Build. Mater. **269**, 121315 (2021)
14. Q. Al-Yasiri, M. Szabó, Effect of encapsulation area on the thermal performance of PCM incorporated concrete bricks: a case study under Iraq summer conditions, Case Stud. Constr. Mater. **15**, e00686 (2021)
15. C. Nie, S. Deng, H. Guo, J. Liu, Effects of partially thermally active walls on simultaneous charging and discharging of paraffin wax in a square cavity, Energy Convers. Manag. **202**, 112201 (2019)
16. M. Arıcı, F. Bilgin, S. Nižetić, H. Karabay, PCM integrated to external building walls: an optimization study on maximum activation of latent heat, Appl. Therm. Eng. **165**, 114560 (2020)
17. E. Tunçbilek, M. Arıcı, M. Krajčík, S. Nižetić, H. Karabay, Thermal performance based optimization of an office wall containing PCM under intermittent cooling operation, Appl. Therm. Eng. **179**, 115750 (2020)
18. H.J. Akeiber, M.A. Wahid, H.M. Hussen, A.T. Mohammad, A newly composed paraffin encapsulated prototype roof structure for efficient thermal management in hot climate, Energy **104**, 99–106 (2016)
19. J. Yu, Q. Yang, H. Ye, J. Huang, Y. Liu, J. Tao, The optimum phase transition temperature for building roof with outer layer PCM in different climate regions of China, Energy Proc. **158**, 3045–3051 (2019)
20. Q. Al-Yasiri, M. Szabó, Experimental evaluation of the optimal position of a macroencapsulated phase change material incorporated composite roof under hot climate conditions, Sustain. Energy Technol. Assess. **45**, 101121 (2021)
21. J. Guo, B. Zou, Y. Wang, Y. Jiang, Space heating performance of novel ventilated mortar blocks integrated with phase change material for floor heating, Build. Environ. **185**, 107175 (2020)
22. Q. Yan, J. Zhang, C. Liu, Thermal storage performance of paraffin and fatty acid mixtures used in walls and floors, Mater. Res. Express **6**, 105522 (2019)
23. D. Li, B. Wang, Q. Li, C. Liu, M. Arıcı, Y. Wu, A numerical model to investigate non-gray photothermal characteristics of paraffin-containing glazed windows, Sol. Energy **194**, 225–238 (2019)
24. G. Zhang, Z. Wang, D. Li, Y. Wu, M. Arıcı, Seasonal thermal performance analysis of glazed window filled with paraffin including various nanoparticles, Int. J. Energy Res. **44**, 3008–3019 (2020)
25. D. Li, Y. Wu, C. Liu, G. Zhang, M. Arıcı, Energy investigation of glazed windows containing Nano-PCM in different seasons, Energy Convers. Manag. **172**, 119–128 (2018)
26. I. Vigna, L. Bianco, F. Goia, V. Serra, Phase change materials in transparent building envelopes: a strengths, weakness, opportunities and threats (SWOT) analysis, Energies **11** (2018)
27. Q. Al-Yasiri, M. Szabó, Case study on the optimal thickness of phase change material incorporated composite roof under hot climate conditions, Case Stud. Constr. Mater. **14**, e00522 (2021)
28. Q. Al-Yasiri, M. Szabó, Incorporation of phase change materials into building envelope for thermal comfort and energy saving: A comprehensive analysis, J. Build. Eng. **36**, 102122 (2021)
29. A. de Gracia, Dynamic building envelope with PCM for cooling purposes – proof of concept, Appl. Energy **235**, 1245–1253 (2019)

30. Q. Al-Yasiri, M. Szabó, Performance assessment of phase change materials integrated with building envelope for heating application in cold locations, Eur. J. Energy Res. **1**, 7–14 (2021)
31. W. Lin, Z. Ma, H. Ren, J. Liu, K. Li, Solar thermal energy storage using paraffins as phase change materials for air conditioning in the built environment, in Paraffins (IntechOpen, 2019)
32. R. Zeinelabdein, S. Omer, G. Gan, Critical review of latent heat storage systems for free cooling in buildings, Renew. Sustain. Energy Rev. **82**, 2843–2868 (2018)
33. H. Mehling, L.F. Cabeza, Heat and Cold Storage with PCM (Springer, 2008), Vol. 308
34. W.R. Turner, D.S. Brown, D.V. Harrison, Properties of paraffin waxes, Ind. Eng. Chem. **47**, 1219–1226 (1955)
35. R. Gulfam, P. Zhang, Z. Meng, Advanced thermal systems driven by paraffin-based phase change materials – a review, Appl. Energy **238**(January), 582–611 (2019)
36. M. Lehto, R. Boden, U. Simu, K. Hjort, G. Thornell, J.-Å. Schweitz, A polymeric paraffin microactuator, J. Microelectr. Syst. **17**, 1172–1177 (2008)
37. I. Nakagawa, S. Hikone, Study on the regression rate of paraffin-based hybrid rocket fuels, J. Propuls. Power **27**, 1276–1279 (2011)
38. S.K. Mandal, S. Kumar, P.K. Singh, S.K. Mishra, H. Bishwakarma, N.P. Choudhry, R.K. Nayak, A.K. Das, Performance investigation of CuO-paraffin wax nanocomposite in solar water heater during night, Thermochim. Acta **671**, 36–42 (2019)
39. S. Bellan, A. Cordiviola, S. Barberis, A. Traverso, J. González-Aguilar, M. Romero, Numerical analysis of latent heat storage system with encapsulated phase change material in spherical capsules, Renew. Energy Environ. Sustain. **2**, 3 (2017)
40. T.-T. Nguyen, V. Martin, A. Malmquist, C.A.S. Silva, A review on technology maturity of small scale energy storage technologies, Renew. Energy Environ. Sustain. **2**, 36 (2017)
41. D. Das, U. Bordoloi, H.H. Muigai, P. Kalita, A novel form stable PCM based bio composite material for solar thermal energy storage applications, J. Energy Storage **30**, 101403 (2020)
42. H. Huang, Y. Xiao, J. Lin, T. Zhou, Y. Liu, Q. Zhao, Improvement of the efficiency of solar thermal energy storage systems by cascading a PCM unit with a water tank, J. Clean. Prod. **245**, 118864 (2020)
43. P. Rolka, T. Przybylinski, R. Kwidzinski, M. Lackowski, The heat capacity of low-temperature phase change materials (PCM) applied in thermal energy storage systems, Renew. Energy **172**, 541–550 (2021)
44. G. Dogkas, J. Konstantaras, M.K. Koukou, V.N. Stathopoulos, L. Coelho, A. Rebola, Evaluating a prototype compact thermal energy storage tank using paraffin-based phase change material for domestic hot water production, in *E3S Web of Conferences* (EDP Sciences, 2019), Vol. 116, p. 16
45. A.K. Alsharaa, Numerical simulation of packed bed cubical storage unit filled with spherical capsules of PCM, Wasit J. Eng. Sci. **6**, 39–50 (2018)
46. A.A.M. Omara, A.A.A. Abuelnour, Improving the performance of air conditioning systems by using phase change materials: a review, Int. J. Energy Res. **43**, 5175–5198 (2019)
47. E. Varvagiannis, A. Charalampidis, G. Zsembinszki, S. Karellas, L.F. Cabeza, Energy assessment based on semi-dynamic modelling of a photovoltaic driven vapour compression chiller using phase change materials for cold energy storage, Renew. Energy **163**, 198–212 (2021)
48. B. Nie, Z. Du, B. Zou, Y. Li, Y. Ding, Performance enhancement of a phase-change-material based thermal energy storage device for air-conditioning applications, Energy Build. **214**, 109895 (2020)
49. B. Nie, Z. Du, J. Chen, B. Zou, Y. Ding, Performance enhancement of cold energy storage using phase change materials with fumed silica for air-conditioning applications, Int. J. Energy Res. **45**, 16565–16575 (2021)
50. B. Nie, A. Palacios, B. Zou, J. Liu, T. Zhang, Y. Li, Review on phase change materials for cold thermal energy storage applications, Renew. Sustain. Energy Rev. **134**, 110340 (2020)
51. M.R. Safaei, H.R. Goshayeshi, I. Chaer, Solar still efficiency enhancement by using graphene oxide/paraffin nano-pcm, Energies **12**, 2002 (2019)
52. M.T. Chaichan, K.I. Abaas, H.A. Kazem, Design and assessment of solar concentrator distillating system using phase change materials (PCM) suitable for desertic weathers, Desalin. Water Treat. **57**, 14897–14907 (2016)
53. M.T. Chaichan, H.A. Kazem, Using aluminium powder with PCM (paraffin wax) to enhance single slope solar water distiller productivity in Baghdad – Iraq winter weathers, Int. J. Renew. Energy Res. **5**, 251–257 (2015)
54. M.T. Chaichan, H.A. Kazem, Water solar distiller productivity enhancement using concentrating solar water heater and phase change material (PCM), Case Stud. Therm. Eng. **5**, 151–159 (2015)
55. M.T. Chaichan, H.A. Kazem, Single slope solar distillator productivity improvement using phase change material and Al_2O_3 nanoparticle, Sol. Energy **164**, 370–381 (2018)
56. D.K. Rabha, P. Muthukumar, Performance studies on a forced convection solar dryer integrated with a paraffin wax-based latent heat storage system, Sol. Energy **149**, 214–226 (2017)
57. S. Ali, S.P. Deshmukh, An overview: applications of thermal energy storage using phase change materials, Mater. Today Proc. **26**, 1231–1237 (2020)
58. M. Mehrali, J.E. ten Elshof, M. Shahi, A. Mahmoudi, Simultaneous solar-thermal energy harvesting and storage via shape stabilized salt hydrate phase change material, Chem. Eng. J. **405**, 126624 (2021)
59. F.S. Javadi, H.S.C. Metselaar, P. Ganesan, Performance improvement of solar thermal systems integrated with phase change materials (PCM), a review, Sol. Energy **206**, 330–352 (2020)
60. Q.A. Jawad, A.M.J. Mahdy, A.H. Khuder, M.T. Chaichan, Improve the performance of a solar air heater by adding aluminum chip, paraffin wax, nano-SiC, Case Stud. Therm. Eng. 100622 (2020)
61. L. Owolabi Afolabi, H. H Al-Kayiem, T. B Aklilu, On the nano-additive enhanced flat plate solar collector integrated with thermal energy storage, Nanosci. Nanotechnology-Asia **7**, 172–182 (2017)
62. P. Felinski, R. Sekret, Experimental study of evacuated tube collector/storage system containing paraffin as a PCM, Energy **114**, 1063–1072 (2016)

63. R. Senthil, P. Sundaram, M. Kumar, Experimental investigation on packed bed thermal energy storage using paraffin wax for concentrated solar collector, Mater. Today Proc. **5**, 8916–8922 (2018)
64. K. Balasubramanian, A.K. Pandey, S. Shahabuddin, M. Samykano, T.M.R. Saidur, Phase change materials integrated solar thermal energy systems: global trends and current practices in experimental approaches, J. Energy Storage **27**, 101118 (2020)
65. E. Roslan, A. Razak, Performance effect of applying paraffin wax on solar photovoltaic backplate, Indones. J. Elec. Eng. Comp. Sci.(IJEECS) **14**, 375 (2019)
66. A.H.A. Al-Waeli, H.A. Kazem, J.H. Yousif, M.T. Chaichan, K. Sopian, Mathematical and neural network modeling for predicting and analyzing of nanofluid-nano PCM photovoltaic thermal systems performance, Renew. Energy **145**, 963–980 (2020)
67. A.H.A. Al-Waeli, K. Sopian, H.A. Kazem, M.T. Chaichan, Evaluation of the electrical performance of a photovoltaic thermal system using nano-enhanced paraffin and nanofluids, Case Stud. Therm. Eng. **21**, 100678 (2020)
68. N.A. Habib, A.J. Ali, M.T. Chaichan, M. Kareem, Carbon nanotubes/paraffin wax nanocomposite for improving the performance of a solar air heating system, Therm. Sci. Eng. Prog. **23**, 100877 (2021)
69. M.T. Chaichan, H.A. Kazem, A.H.A. Al-Waeli, K. Sopian, Controlling the melting and solidification points temperature of PCMs on the performance and economic return of the water-cooled photovoltaic thermal system, Sol. Energy **224**, 1344–1357 (2021)
70. A.H.A. Al-Waeli, K. Sopian, M.T. Chaichan, H.A. Kazem, A. Ibrahim, S. Mat, M.H. Ruslan, Evaluation of the nanofluid and nano-PCM based photovoltaic thermal (PVT) system: an experimental study, Energy Convers. Manag. **151**, 693–708 (2017)
71. X. Zhu, X. Li, J. Shen, B. Wang, Z. Mao, H. Xu, X. Feng, X. Sui, Stable microencapsulated phase change materials with ultrahigh payload for efficient cooling of mobile electronic devices, Energy Convers. Manag. **223**, 113478 (2020)
72. F. Rostamian, N. Etesami, M. Haghgoo, Management of electronic board temperature using heat sink containing pure and microencapsulated phase change materials, Int. Commun. Heat Mass Transf. **126**, 105407 (2021)
73. M. Baba, K. Nemoto, D. Otaki, T. Sasaki, M. Takeda, N. Yamada, Temperature leveling of electronic chips by solid-solid phase change materials compared to solid-liquid phase change materials, Int. J. Heat Mass Transf. **179**, 121731 (2021)
74. H. Bashirpour-Bonab, Thermal behavior of lithium batteries used in electric vehicles using phase change materials, Int. J. Energy Res. **44**, 12583–12591 (2020)
75. A. Reza Vakhshouri, Paraffin as Phase Change Material, in *Paraffin – an Overview*, edited by F.S. Soliman (IntechOpen, 2019)
76. B.P. Jelle, S.E. Kalnæs, Phase change materials for application in energy-efficient buildings, in *Cost-Effective Energy Efficient Building Retrofitting: Materials, Technologies, Optimization and Case Studies* (Elsevier Ltd, 2017), pp. 57–118
77. Q. Al-Yasiri, M. Szabó, Influential aspects on melting and solidification of PCM energy storage containers in building envelope applications, Int. J. Green Energy **18**, 966–986 (2021)
78. Y. Qu, J. Chen, L. Liu, T. Xu, H. Wu, X. Zhou, Study on properties of phase change foam concrete block mixed with paraffin/fumed silica composite phase change material, Renew. Energy **150**, 1127–1135 (2020)
79. L. Liu, J. Chen, Y. Qu, T. Xu, H. Wu, G. Huang, X. Zhou, L. Yang, A foamed cement blocks with paraffin/expanded graphite composite phase change solar thermal absorption material, Sol. Energy Mater. Sol. Cells **200**, 110038 (2019)
80. A. Thongtha, A. Khongthon, T. Boonsri, C. Hoy-Yen, Thermal effectiveness enhancement of autoclaved aerated concrete wall with PCM-contained conical holes to reduce the cooling load, Materials (Basel) **12**, 2170 (2019)
81. S.-Q. Tian, S.-F. Yu, X. Wang, L.-W. Fan, Z.-T. Yu, X. Xu, J. Ge, Experimental determination and fractal modeling of the effective thermal conductivity of autoclave aerated concrete (AAC) impregnated with paraffin for improved thermal storage performance, Appl. Therm. Eng. **163**, 114387 (2019)
82. A. Frazzica, V. Brancato, V. Palomba, D. La Rosa, F. Grungo, L. Calabrese, E. Proverbio, Thermal performance of hybrid cement mortar-PCMs for warm climates application, Sol. Energy Mater. Sol. Cells **193**, 270–280 (2019)
83. X. Sun, J. Jovanovic, Y. Zhang, S. Fan, Y. Chu, Y. Mo, S. Liao, Use of encapsulated phase change materials in lightweight building walls for annual thermal regulation, Energy **180**, 858–872 (2019)
84. M.I. Hasan, H.O. Basher, A.O. Shdhan, Experimental investigation of phase change materials for insulation of residential buildings, Sustain. Cities Soc. **36**, 42–58 (2018)
85. X. Sun, M.A. Medina, K.O. Lee, X. Jin, Laboratory assessment of residential building walls containing pipe-encapsulated phase change materials for thermal management, Energy **163**, 383–391 (2018)
86. L. Navarro, A. de Gracia, A. Castell, L.F. Cabeza, Experimental study of an active slab with PCM coupled to a solar air collector for heating purposes, Energy Build. **128**, 12–21 (2016)
87. S. Wi, S.J. Chang, S. Kim, Improvement of thermal inertia effect in buildings using shape stabilized PCM wallboard based on the enthalpy-temperature function, Sustain. Cities Soc. **56**, 102067 (2020)
88. A. Sharma, V.V. Tyagi, C.R. Chen, D. Buddhi, Review on thermal energy storage with phase change materials and applications, Renew. Sustain. energy Rev. **13**, 318–345 (2009)
89. V.V. Tyagi, D. Buddhi, PCM thermal storage in buildings: a state of art, Renew. Sustain. Energy Rev. **11**, 1146–1166 (2007)
90. A.R.V.E.-F.S. Soliman, Paraffin as Phase Change Material, in *IntechOpen* (2020), p. Ch. 5
91. F.H. Rhodes, C.W. Mason, W.R. Sutton, Crystallization of Paraffin Wax1, Ind. Eng. Chem. **19**, 935–938 (1927)
92. S.W. Ferris, H.C. Cowles, Crystal behavior of paraffin wax, Ind. Eng. Chem. **37**, 1054–1062 (1945)
93. Q. Wang, W. Wei, D. Li, H. Qi, F. Wang, M. Arıcı, Experimental investigation of thermal radiative properties of Al2O3-paraffin nanofluid, Sol. Energy **177**, 420–426 (2019)
94. M. Amin, F. Afriyanti, N. Putra, Thermal properties of paraffin based nano-phase change material as thermal energy storage, IOP Conf. Ser. Earth Environ. Sci. **105** (2018)

95. A. Shahsavar, S. Khanmohammadi, D. Toghraie, H. Salihepour, Experimental investigation and develop ANNs by introducing the suitable architectures and training algorithms supported by sensitivity analysis: measure thermal conductivity and viscosity for liquid paraffin based nanofluid containing Al2O3 nanoparticles, J. Mol. Liq. **276**, 850–860 (2019)
96. A. Nematpour Keshteli, M. Sheikholeslami, Nanoparticle enhanced PCM applications for intensification of thermal performance in building: a review, J. Mol. Liq. **274**, 516–533 (2019)
97. M.T. Chaichan, R.M. Hussein, A.M. Jawad, Thermal conductivity enhancement of iraqi origin paraffin wax by nano-alumina, Al-Khwarizmi Eng. J. **13**, 83–90 (2017)
98. Y. Zhu, Y. Qin, C. Wei, S. Liang, X. Luo, J. Wang, L. Zhang, Nanoencapsulated phase change materials with polymer-SiO_2 hybrid shell materials: compositions, morphologies, and properties, Energy Convers. Manag. **164**, 83–92 (2018)
99. K.Y. Leong, M.R. Abdul Rahman, B.A. Gurunathan, Nano-enhanced phase change materials: a review of thermo-physical properties, applications and challenges, J. Energy Storage **21**, 18–31 (2019)
100. Q. Al-Yasiri, M. Szabó, M. Arıcı, Single and hybrid nanofluids to enhance performance of flat plate solar collectors: application and obstacles, Period. Polytech. Mech. Eng. **65**, 86–102 (2021)
101. L.S. Sundar, K.V. Sharma, M.K. Singh, A.C.M. Sousa, Hybrid nanofluids preparation, thermal properties, heat transfer and friction factor – a review, Renew. Sustain. Energy Rev. **68**, 185–198 (2017)
102. V. Saydam, X. Duan, Dispersing different nanoparticles in paraffin wax as enhanced phase change materials, J. Therm. Anal. Calorim. **135**, 1135–1144 (2019)
103. J. Jeon, J.H. Park, S. Wi, K.-H. Kim, S. Kim, Thermal performance enhancement of a phase change material with expanded graphite via ultrasonication, J. Ind. Eng. Chem. **79**, 437–442 (2019)
104. M. Kenisarin, K. Mahkamov, F. Kahwash, I. Makhkamova, Enhancing thermal conductivity of paraffin wax 53-57 °C using expanded graphite, Sol. Energy Mater. Sol. Cells **200**, 110026 (2019)
105. M. Karthik, A. Faik, B. D'Aguanno, Graphite foam as interpenetrating matrices for phase change paraffin wax: A candidate composite for low temperature thermal energy storage, Sol. Energy Mater. Sol. Cells **172**, 324–334 (2017)
106. Z.A. Qureshi, H.M. Ali, S. Khushnood, Recent advances on thermal conductivity enhancement of phase change materials for energy storage system: a review, Int. J. Heat Mass Transf. **127**, 838–856 (2018)
107. H.M. Ali, Experimental investigation on paraffin wax integrated with copper foam based heat sinks for electronic components thermal cooling, Int. Commun. Heat Mass Transf. **98**, 155–162 (2018)
108. X. Xiao, P. Zhang, M. Li, Preparation and thermal characterization of paraffin/metal foam composite phase change material, Appl. Energy **112**, 1357–1366 (2013)
109. M.E. Zayed, J. Zhao, W. Li, A.H. Elsheikh, A.M. Elbanna, L. Jing, A.E. Geweda, Recent progress in phase change materials storage containers: Geometries, design considerations and heat transfer improvement methods, J. Energy Storage **30**, 101341 (2020)
110. S.A. Shehzad, B. Alshuraiaan, M.S. Kamel, M. Izadi, T. Ambreen, Influence of fin orientation on the natural convection of aqueous-based nano-encapsulated PCMs in a heat exchanger equipped with wing-like fins, Chem. Eng. Process. – Process Intensif. 108287 (2020)
111. R. Elarem, T. Alqahtani, S. Mellouli, F. Askri, A. Edacherian, T. Vineet, I.A. Badruddin, J. Abdelmajid, A comprehensive review of heat transfer intensification methods for latent heat storage units, Energy Storage e127 (n.d.)
112. P.K.S. Rathore, S.K. Shukla, N.K. Gupta, Synthesis and characterization of the paraffin/expanded perlite loaded with graphene nanoparticles as a thermal energy storage material in buildings, J. Sol. Energy Eng. **142** (2020)
113. M. Zhang, C. Wang, A. Luo, Z. Liu, X. Zhang, Molecular dynamics simulation on thermophysics of paraffin/EVA/graphene nanocomposites as phase change materials, Appl. Therm. Eng. **166**, 114639 (2020)
114. N. Sahan, M. Fois, H. Paksoy, The effects of various carbon derivative additives on the thermal properties of paraffin as a phase change material, Int. J. Energy Res. **40**, 198–206 (2016)
115. Y. Zhou, C. Li, H. Wu, S. Guo, Construction of hybrid graphene oxide/graphene nanoplates shell in paraffin microencapsulated phase change materials to improve thermal conductivity for thermal energy storage, Colloids Surf. A 124780 (2020)
116. A.H. Ali, S.I. Ibrahim, Q.A. Jawad, R.S. Jawad, M.T. Chaichan, Effect of nanomaterial addition on the thermophysical properties of Iraqi paraffin wax, Case Stud. Therm. Eng. **15**, 100537 (2019)
117. M. Li, Q. Guo, S. Nutt, Carbon nanotube/paraffin/montmorillonite composite phase change material for thermal energy storage, Sol. Energy **146**, 1–7 (2017)
118. J. Wang, H. Xie, Y. Li, Thermal properties of phase change composites containing ferric oxide nanoparticles, J. Nanosci. Nanotechnol. **15**, 3276–3279 (2015)
119. G. Raza, Y. Shi, Y. Deng, Expanded graphite as thermal conductivity enhancer for paraffin wax being used in thermal energy storage systems, in *2016 13th International Bhurban Conference on Applied Sciences and Technology (IBCAST)* (IEEE, 2016), pp. 1–12
120. B. Zhang, Y. Tian, X. Jin, T.Y. Lo, H. Cui, Thermal and mechanical properties of expanded graphite/paraffin gypsum-based composite material reinforced by carbon fiber, Materials (Basel) **11** (2018)
121. C. Ma, Y. Zhang, X. Chen, X. Song, K. Tang, Experimental study of an enhanced phase change material of paraffin/expanded graphite/nano-metal particles for a personal cooling system, Materials (Basel) **13**, 980 (2020)
122. C. Wang, T. Lin, N. Li, H. Zheng, Heat transfer enhancement of phase change composite material: copper foam/paraffin, Renew. Energy **96**, 960–965 (2016)
123. Y. Li, J. Li, Y. Deng, W. Guan, X. Wang, T. Qian, Preparation of paraffin/porous TiO_2 foams with enhanced thermal conductivity as PCM, by covering the TiO2 surface with a carbon layer, Appl. Energy **171**, 37–45 (2016)
124. B. Shang, J. Hu, R. Hu, J. Cheng, X. Luo, Modularized thermal storage unit of metal foam/paraffin composite, Int. J. Heat Mass Transf. **125**, 596–603 (2018)
125. M. Maleki, P.T. Ahmadi, H. Mohammadi, H. Karimian, R. Ahmadi, H.B.M. Emrooz, Photo-thermal conversion structure by infiltration of paraffin in three dimensionally

interconnected porous polystyrene-carbon nanotubes (PS-CNT) polyHIPE foam, Sol. Energy Mater. Sol. Cells **191**, 266–274 (2019)
126. A.M. Abdulateef, J. Abdulateef, S. Mat, K. Sopian, B. Elhub, M.A. Mussa, Experimental and numerical study of solidifying phase-change material in a triplex-tube heat exchanger with longitudinal/triangular fins, Int. Commun. Heat Mass Transf. **90**, 73–84 (2018)
127. A. Arshad, H.M. Ali, M. Ali, S. Manzoor, Thermal performance of phase change material (PCM) based pin-finned heat sinks for electronics devices: effect of pin thickness and PCM volume fraction, Appl. Therm. Eng. **112**, 143–155 (2017)
128. S. Mousavi, M. Siavashi, M.M. Heyhat, Numerical melting performance analysis of a cylindrical thermal energy storage unit using nano-enhanced PCM and multiple horizontal fins, Numer. Heat Transf. Part A Appl. **75**, 560–577 (2019)
129. Z. Khan, Z.A. Khan, Role of extended fins and graphene nano-platelets in coupled thermal enhancement of latent heat storage system, Energy Convers. Manag. **224**, 113349 (2020)

Cite this article as: Qudama Al-Yasiri, Márta Szabó, Paraffin As a Phase Change Material to Improve Building Performance: An Overview of Applications and Thermal Conductivity Enhancement Techniques, Renew. Energy Environ. Sustain. **6**, 38 (2021)