Solar Cell Cooling with Phase Change Material (PCM) for Enhanced Efficiency: A Review

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Abstract. This literature aimed to explain recent studies related to the passive cooling of solar cells using Phase Change Material (PCM). Cooling is done to reduce operating temperature and to prevent a decrease in efficiency in an unfavorable environment because the efficiency of the solar cell system decreases when the operating temperature rises and can damage the PV module. The successful use of phase change materials (PCM) from latent heat storage systems is highly dependent on the thermal reliability and stability of the phase change materials used. In conclusion, the overall energy utilization ratio of cooled PV using a PCM system can be increased through a thermal regulation strategy, further research of this system is still needed to achieve maximum results in PV efficiency.

Keywords: Solar cell, PCM, Efficiency, Passive Cooling.

1. Introduction
Renewable energy in the future is a big hope in human life. But for now, most of the energy used still comes from fossil fuels such as petroleum, coal, and natural gas. Current non-renewable energy sources are decreasing and the increasing demand for the current energy in the context of environmental problems has prompted intensive research on new things, one of which is more efficient and environmentally friendly power plants with advanced technology [1]. Therefore, the use of renewable energy sources as a substitute for non-renewable energy sources needs to be increased.

Countries are now starting to develop renewable energy because at the time of population growth and development initiatives, the world's available resources are almost gone. Using resources to restore energy to build a conducive environment for human survival for a long time [2]. One source of renewable energy is the sun, solar energy is valuable energy that has been used or not yet utilized. Solar energy has many benefits, such as being environmentally friendly, abundant, renewable, and extensive sources in its application [3,4].

Solar energy itself requires a solar cell system (PV) that can convert heat energy into electricity. PV can currently only have a maximum efficiency of 15-20%, which can be converted into electrical energy [5-7]. PV receives solar radiation to be converted into electricity. However, the effect of solar radiation also increases the surface temperature of the PV, which causes a decrease in PV efficiency and can reduce the service life of the PV modules. The reduction in PV efficiency for every one degree is around 0.5% [8-11]. The productive period of PV can be extended by applying specific cooling techniques to PV from around 25-30 years to 48 years [12]. Modifications need to be made for PV to maintain the most efficient temperature level.
Researchers have conducted studies on the reduction of high temperatures in PV [10,13]. One of them is a PV cooler with Phase Change Materials (PCM) [14-17]. PCM is recognized as one of the most promising materials for storing solar thermal energy in the form of latent heat. The use of PCM for solar energy storage compensates for the intermittent characteristics of this energy source [7,18,19].

2. Effect of Temperature on Solar Cell Efficiency
Factors affecting PV temperature include cell thickness, installation design, fabrication material, and climatic conditions [20,21]. PV receives radiation directly from the sun to be able to produce electricity, but solar radiation received by the PV module and converted to electricity is only 15-20%, while 80-85% implementation becomes heat. It is important to control the solar radiation received by PV [22,23]. This absorbed heat increases the operating temperature of the PV, and as a result, the conversion efficiency and lifetime of the solar cell are reduced [24-26]. PV cooling techniques are available in different modes namely active and passive cooling. Passive cooling means the cooling media is driven by nature [13], whereas active cooling requires extra energy input to drive the cooler [27].

3. PCM Heat Storage
PCM has the capacity to store and release latent heat and can maintain stable temperature during the process of absorption or heat dissipation [12,28,29]. The process of phase change can change the state of liquids and gases by condensation and evaporation, while changes in the solid and liquid state are called melting or freezing. When the temperature around PCM rises to its melting point, chemical bonds start an endothermic process that allows PCM to absorb energy, and the melting material changes its condition from solid to liquid. Besides, when the temperature decreases to reach the freezing point of PCM, the bonds will regenerate, and the heat will be released exoterically and PCM will return to the solid-state. PCM is thus described as a thermal reservoir [30,31]. The process that occurs during PCM work will result in a decrease in volume due to phase changes, a reduction in the volume of 10% from the initial volume [19].

![Figure 1. Latent energy storage by PCM with temperature changes [27,28].](image)

3.1. Type of PCM Materials
PCM is divided into three groups based on their phase state-changing solid-solid PCM, liquid-liquid PCM, and liquid gas PCM [33]. While based on the state of its chemical structure, PCM consists of organic PCM, inorganic PCM, and eutectic [34], as shown in figure 2.
3.1.1. **Organic PCM**

The properties of organic PCM is beneficial for applications and research, such as large, inexpensive, efficient, non-contradictory, and corrosion-resistant latent heat [35,36]. However, organic PCM also has the disadvantage of low thermal conductivity and leak problems during smelting conditions [35,37]. Organic PCM can be distinguished as paraffin and non-paraffin. Paraffin consists of a mixture of mostly straight-chain n-alkane CH$_3$- (CH$_2$) -CH$_3$. Crystallization from the chain (CH$_3$) - releases a latent amount of heat [27]. The melting point increases with increasing chain length. Paraffin, as an element for storing heat, melts quite a lot in its temperature range.

| The number of atoms | Melting point | Latent heat release (kJ / kg) |
|---------------------|---------------|------------------------------|
| 14                  | 5.5           | 228                          |
| 15                  | 10            | 205                          |
| 16                  | 16.7          | 237.1                        |
| 17                  | 21.7          | 213                          |
| 18                  | 28            | 244                          |
| 19                  | 32            | 222                          |
| 20                  | 36.7          | 246                          |
| 21                  | 40.2          | 200                          |
| 22                  | 44            | 249                          |
| 23                  | 47.5          | 232                          |
| 24                  | 50.6          | 255                          |
| 25                  | 49.4          | 238                          |
| 26                  | 56.3          | 256                          |
| 27                  | 58.8          | 236                          |

Whereas PCM from non-paraffin materials is PCM which is generally found with many variations of properties. Each material has special properties, unlike paraffin which has the same properties, including types of esters, fatty acids, alcohols and glycol types.
Table 2. Melting point and heat of latent fusion: (a) non-paraffin, (b) fatty acids [38].

| Material             | Melting point | Latent heat release (kJ / kg) |
|----------------------|---------------|-----------------------------|
| Formic Acid          | 7.8           | 247                         |
| Caprylic acid        | 16.3          | 149                         |
| Glycerin             | 17.9          | 198.7                       |
| Lactic acid          | 26            | 184                         |
| Methyl Palmitate     | 29            | 205                         |
| Phenol               | 1             | 120                         |
| Beeswax              | 61.8          | 177                         |
| Glycol acid          | 63            | 109                         |
| Azobenzene           | 67.1          | 121                         |
| Acrylic acid         | 68.0          | 115                         |
| Glutaric acid        | 97.5          | 156                         |
| Catechol             | 104.3         | 207                         |
| Quenon               | 115           | 171                         |
| Benzoic acid         | 124           | 167                         |
| Benzamide            | 127.2         | 169.4                       |
| Oksalat              | 54.3          | 178                         |
| Alpha Naphthol       | 96            | 163                         |

(a)

| Material             | Melting point | Latent heat release (kJ / kg) |
|----------------------|---------------|-----------------------------|
| Acetic acid          | 16.7          | 184                         |
| Polyethylene glycol  | 20 - 25       | 146                         |
| Rust Acid            | 36            | 152                         |
| Elaidic acid         | 47            | 218                         |
| Lauric acid          | 49            | 178                         |
| Petadecanoic acid    | 52.5          | 178                         |
| Tristearin           | 56            | 191                         |
| Myristic acid        | 58            | 199                         |
| Aromatic acid        | 55            | 163                         |
| Stearic acid         | 69.4          | 199                         |
| Acetamide            | 81            | 241                         |
| Methyl fumarate      | 102           | 242                         |

(b)

3.1.2. Inorganic PCM

Inorganic PCM has the advantage of a wide temperature change temperature range, high thermal conductivity, and high latent heat, but also has several defects such as corrosive, sub-cooling, and phase separation during the phase change process [39]. Inorganic PCM is classified into two types, namely hydrate and metal salts [40,41]. To cool the PV module using PCM, you must pay attention to the melting point of the PCM, adapted and designed with the operation of the PV module. PCM with a melting point that is too low is not recommended, because an important problem associated with PCM that limits efficient heat dissipation is low thermal conductivity [23,42].

Table 3. Melting point and heat of latent fusion: (a) hydrate salts, (b) metals [38].

| The number of atoms | Melting point | Latent heat release (kJ / kg) |
|---------------------|---------------|-----------------------------|
| K2HPO4.6H2O         | 14            | 109                         |
| FeBr3.6H2O          | 21            | 105                         |
| Mn (NO3)            | 25.5          | 148                         |
| FeBr3.6H2O          | 27            | 105                         |
| CaCl2.12H2O         | 29.8          | 174                         |
| LiNO3.2H2O          | 30            | 296                         |
| LiNO3.3H2O          | 30            | 267                         |
| Na2O3.10H2O         | 32            | 241                         |
| Na2SO410H2O         | 32.4          | 173                         |
| KFe (SO4) 2.12H2O   | 33            | 138                         |

(a)

| The number of atoms | Melting point | Latent heat release (kJ / kg) |
|---------------------|---------------|-----------------------------|
| Gallium-gallium     | 29.8          | -                           |
| Antimony eutectic   | 29.8          | -                           |
| Gallium             | 30            | 80.3                        |
| Eutectic Cerrolow   | 58            | 90.9                        |
| Eutectic Bi-Cd-In   | 61            | 25                          |
| Eutectic Cerrobend | 70            | 32.6                        |
| Eutectic Bi-Pb-In   | 70            | 29                          |
| Eutectic Bi-In      | 72            | 25                          |
| Bi-Pb-Sn eutectic   | 96            | -                           |
| Eutectic Bi-Pb      | 125           | -                           |
3.2. Selection of PCM material
The selection of the ideal PCM must have great latent heat, high thermal conductivity, melting temperature in the practical range of operation, smelting, which is compatible with minimum sub-cooling, non-toxic, non-corrosive, chemically stable, and low cost [27,43]. Cooling the PV module using PCM, the melting point of the PCM must be adjusted according to the operation designed from the PV module. PCM with a melting point that is too low is not recommended [42]. Low thermal conductivity is an important problem associated with PCM which limits efficient heat dissipation [23]. PCM with different classes and categories have various melting temperatures, each of which has a special latent heat capacity for melting as shown in Figure 3. Comparison of various PV panel cooling techniques for compatibility is summarized in table 3.

Table 4. The advantages and disadvantages of PCM material types.

| Classification   | Advantages                                      | Disadvantages                                      |
|------------------|-------------------------------------------------|----------------------------------------------------|
| Organic PCM      | Availability in a large temperature range       | Low thermal conductivity (around 0.2 W / m K)      |
|                  | High fusion heat                                 | Changes in relative large volumes                  |
|                  | There is no cooling                              | Flammability                                       |
|                  | Chemically stable and recyclable                 |                                                    |
|                  | Good compatibility with other materials          |                                                    |
| Inorganic PCM    | High fusion heat                                 | Cooling                                            |
|                  | High thermal conductivity (around 0.5 W / mK)    | Corrosion                                          |
|                  | Low volume change                                |                                                    |
|                  | Availability in low cost                        |                                                    |
| Eutectic         | Sharp melting temperature                       | Lack of current test data from the thermo-physical |
|                  | High volumetric thermal storage density          | nature                                             |
Figure 3. Melting temperature and enthalpy phase change for existing PCM [44].

4. Application of Phase Change Material for Solar cells

The PV module used was a mini HTSS-5 solar panel with a size of 209 × 245 × 17 mm [17]. The concentrator disc diameter was about 1.2 m. CPV-T collector, there were two layers of encapsulated PCM sphere which were filled with paraffin wax, and utilizing paraffin because the temperature phase changed about 50 °C when it melted, was relatively inexpensive and easily accessible. The density of solid and liquid phases of PCM was around 0.9 × 10³ and 0.7 × 10³ kg / m³. Horizontal radiation varied in the range [300 W / m², 800 W / m²]. In this range of changes from solar radiation, the increase in the average output power of the CPV PCV cooling system relative to the CPV system cooling water was often more than 50 W / m².

A simplified 1-D model developed to simulate the performance of the PV-PCM system in two Turkish cities, as representatives of the Mediterranean region [27]. The results showed that the PV temperature could be reduced from 0.31-10.26 °C, so that the annual average efficiency increase was almost 1.59% (note: provided the original PV efficiency was 15%, the efficiency increase was (1 + 1.59%) × 15%)

Figure 4. Physical model of PV-PCM system [27].
Using three Silicon Nitride Monocrystalline PV modules with a size of 839x537x50 mm, and a maximum output power of 50 W [45]. PV one was PV without PCM, while the second PV used paraffin wax while the third PV used PCM bee wax. The study was conducted from 07:00 to 18:00. The maximum intensity of solar radiation was reached at 12.00 (noon) at 1024 W/ m2. The temperature of the PV module increased to 28 °C, while the PV panel with PCM was only 11 °C. The electricity saving panel for PV without PCM was between 6.1% - 6.5%. As for PV panels with PCM, the efficiency of 7.0% - 7.8% can be seen in Figure 5.

Figure 5. The relationship of electrical efficiency with the surface temperature of the PV panels [45].

This system used 4 Monocrystalline silicon PV modules with a power of 80W and a size of 1200 × 508 × 35 mm [25]. Stainless steel (thermal conductivity 16 W / m K), dimensions 1000 × 471 × 65 mm. The PCM used was eutectic with capric acid (75%) and palmitic (25%). The first PV with PCM cooling, the second PV with integrated pipelines (PV / T system), the third PV with additional cooling (PV with containers) and the fourth PV without cooling. The peak of solar radiation recorded was 1177 W / m2. PCM has been shown to increase the extraction of heat energy from PV up to seven times compared to systems without PCM.

Figure 6. A scheme portraying the design of (a) System 1 (PV / T / PCM) (b) System 2 (PV / T) (c) System 3 (PV with container) and (d) System 4 (PV) in the experiment [25]
PCM effects on PV modules by increasing the efficiency of PV modules and utilizing lost temperatures [23]. The PV module used was polycrystalline silicon with dimensions of 100 × 100 × 5 mm. This study discussed five types of PCM with melting temperatures varying from 25 ± 4°C. The reduction was maintained for 5 hours at 1000 W / m². Showing the temperature at the front surface of the PV for all PCM in system A compared to the reference at insulation of 1000 W / m², and a temperature of around 20 ± 1°C. After 4 hours, the temperature deviations for RT20, CL, SP22, CaCl₂ and CP were respectively 3.5°C, 4°C, 7.5°C, 11°C, and 12°C. The temperature deviation duration was 5.5 hours, 6 hours, 9 hours, 9.5 hours and 11 hours for each RT20, CL, SP22, CP, and CaCl₂, respectively. As shown in Figure 6, five PCM evaluated in three conditions indicated that the performance of PCM thermal regulation depended on the PCM thermal conductivity and thermal mass of PCM and on all PCM systems / PV. Comparing the PCM, highest temperature reduction reached by the CaCl₂ salt hydrate.

![Figure 7](image_url)  
**Figure 7.** Temperature changes on the front surface of PV in system A at 1000 W / m² insulation and surroundings temperature of 20 ± 1°C [23].

Six PV solar cells (2 mm apart from each other) with a size of 125 × 125 mm attached to the aluminium front plate [46]. The external dimensions of the PCM container were 1060 × 334.47 × 55 mm, the maximum irradiation was 670W/m². In figure 7, it can be seen that the average temperature of PV cells was around 20 °C lower than PV cells without PCM. Integrating PCM into the solar cell system concentrated on cooling the solar cells, which reduced the average temperature of the solar cell up to 20-25 °C and therefore increased electrical efficiency by 10-12%.
Figure 8. Temperature variations on (a) PV cells for systems with or without PCM, (b) position close to PV cells, (c) position at the top of the PCM container and (d) position at the bottom of the PCM container [46].

5. Conclusion
An overview of cooling techniques for solar cell power systems using phase change materials has been carried out to improve the efficiency of solar cell panels and power generation systems from renewable power. PCM is a potential candidate for good PV cooling but each has weaknesses and strengths, with common problems of liquid leakage and low thermal conductivity. PCM is not an economical and most preferred cooling solution. The choice of suitable type of phase change material can be one of the most significant obstacles. Therefore, further research needs to be done on cooling PV with PCM to achieve maximum efficiency and can also be obtained at a more economical price.

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References

[1] G. K. Singh, “Solar power generation by PV (photovoltaic) technology: A review,” Energy, vol. 53, pp. 1–13, 2013, doi: 10.1016/j.energy.2013.02.057.

[2] M. Rumbayan, A. Abudureyimu, and K. Nagasaka, “Mapping of solar energy potential in Indonesia using artificial neural network and geographical information system,” Renew. Sustain. Energy Rev., vol. 16, no. 3, pp. 1437–1449, 2012, doi: 10.1016/j.rser.2011.11.024.

[3] Ubaidillah, K. Hudha, and H. Jamaluddin, “Simulation and experimental evaluation on a skyhook policy-based fuzzy logic control for semi-active suspension system,” Int. J. Struct. Eng., vol. 2, no. 3, pp. 243–272, 2011, doi: 10.1504/IJSTRUCTE.2011.040783.

[4] A. L. Bukar and C. W. Tan, “A review on stand-alone photovoltaic-wind energy system with fuel cell: System optimization and energy management strategy,” J. Clean. Prod., vol. 221, pp. 73–88, 2019, doi: 10.1016/j.jclepro.2019.02.228.

[5] J. Zhao, Z. Li, and T. Ma, “Performance analysis of a photovoltaic panel integrated with phase change material,” Energy Procedia, vol. 158, pp. 1093–1098, 2019, doi: 10.1016/j.egypro.2019.01.264.

[6] Z. Rostami, M. Rahimi, and N. Azimi, “Using high-frequency ultrasound waves and nanofluid for increasing the efficiency and cooling performance of a PV module,” Energy Convers. Manag., vol. 160, no. November 2017, pp. 141–149, 2018, doi: 10.1016/j.enconman.2018.01.028.

[7] B. Norton et al., “Enhancing the performance of building integrated photovoltaics,” Sol. Energy, vol. 85, no. 8, pp. 1629–1664, 2011, doi: 10.1016/j.solener.2009.10.004.

[8] F. Karimi, H. Xu, Z. Wang, J. Chen, and M. Yang, “Experimental study of a concentrated PV/T system using linear Fresnel lens,” Energy, vol. 123, pp. 402–412, 2017, doi: 10.1016/j.energy.2017.02.028.

[9] S. Soltani, A. Kasaean, H. Sarraha, and D. Wen, “An experimental investigation of a hybrid photovoltaic/thermoelectric system with nanofluid application,” Sol. Energy, vol. 155, pp. 1033–1043, 2017, doi: 10.1016/j.solener.2017.06.069.

[10] S. S. Chandel and T. Agarwal, “Review of cooling techniques using phase change materials for enhancing efficiency of photovoltaic power systems,” Renew. Sustain. Energy Rev., vol. 73, no. February, pp. 1342–1351, 2017, doi: 10.1016/j.rser.2017.02.001.

[11] E. Skoplaki and J. A. Palyvos, “On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations,” Sol. Energy, vol. 83, no. 5, pp. 614–624, 2009, doi: 10.1016/j.solener.2008.10.008.

[12] P. Royo, V. J. Ferreira, A. M. López-Sabrín, and G. Ferreira, “Hybrid diagnosis to characterise the energy and environmental enhancement of photovoltaic modules using smart materials,” Energy, vol. 101, no. 2016, pp. 174–189, 2016, doi: 10.1016/j.energy.2016.01.101.

[13] S. Nižetić, A. M. Papadopoulos, and E. Giama, “Comprehensive analysis and general economic-environmental evaluation of cooling techniques for photovoltaic panels, Part I: Passive cooling techniques,” Energy Convers. Manag., vol. 149, pp. 334–354, 2017, doi: 10.1016/j.enconman.2017.07.022.

[14] H. Xu, C. Zhang, N. Wang, Z. Qu, and S. Zhang, “Experimental study on the performance of a solar photovoltaic/thermal system combined with phase change material,” Sol. Energy, vol. 198, no. January, pp. 202–211, 2020, doi: 10.1016/j.solener.2020.01.064.

[15] L. Šiahkamari, M. Rahimi, N. Azimi, and M. Banibayat, “Experimental investigation on using a novel phase change material (PCM) in micro structure photovoltaic cooling system,” Int. Commun. Heat Mass Transf., vol. 100, pp. 60–66, 2019, doi: 10.1016/j.icheatmasstransfer.2018.12.020.

[16] M. Emam and M. Ahmed, “Cooling concentrator photovoltaic systems using various configurations of phase-change material heat sinks,” Energy Convers. Manag., vol. 158, no. December 2017, pp. 298–314, 2018, doi: 10.1016/j.enconman.2017.12.077.

[17] Y. Su, Y. Zhang, and L. Shu, “Experimental study of using phase change material cooling in a
solar tracking concentrated photovoltaic-thermal system,” *Sol. Energy*, vol. 159, no. August 2017, pp. 777–785, 2018, doi: 10.1016/j.solener.2017.11.045.

[18] H. Asgharian and E. Baniasadi, “A review on modeling and simulation of solar energy storage systems based on phase change materials,” *J. Energy Storage*, vol. 21, no. December 2018, pp. 186–201, 2019, doi: 10.1016/j.est.2018.11.025.

[19] K. Faraj, M. Khaled, J. Faraj, F. Hachem, and C. Castelain, “Phase change material thermal energy storage systems for cooling applications in buildings: A review,” *Renew. Sustain. Energy Rev.*, vol. 119, no. May, p. 109579, 2020, doi: 10.1016/j.rser.2019.109579.

[20] H. J. Choi, S. A. Mazlan, and F. Imaduddin, “Fabrication and viscoelastic characteristics of waste tire rubber based magnetorheological elastomer,” *Smart Mater. Struct.*, vol. 25, no. 11, pp. 1–14, doi: 10.1088/0964-1726/25/11/115026.

[21] F. Imaduddin, M. Nizam, and S. A. Mazlan, “Response of A Magnetorheological Brake under Inertial Loads,” vol. 7, no. 2, pp. 308–322, 2015.

[22] F. Bendelala, A. Cheknane, and H. Hilal, “Enhanced low-gap thermophotovoltaic cell efficiency for a wide temperature range based on a selective meta-material emitter,” *Sol. Energy*, vol. 174, no. June, pp. 1053–1057, 2018, doi: 10.1016/j.solener.2018.10.006.

[23] A. Hasan, S. J. McCormack, M. J. Huang, and B. Norton, “Evaluation of phase change materials for thermal regulation enhancement of building integrated photovoltaics,” *Sol. Energy*, vol. 84, no. 9, pp. 1601–1612, 2010, doi: 10.1016/j.solener.2010.06.010.

[24] Y. Yuan, L. Ouyang, L. Sun, X. Cao, B. Xiang, and X. Zhang, “Effect of connection mode and mass flux on the energy output of a PVT hot water system,” *Sol. Energy*, vol. 158, no. September, pp. 285–294, 2017, doi: 10.1016/j.solener.2017.09.049.

[25] M. C. Browne, B. Norton, and S. J. McCormack, “Heat retention of a photovoltaic/thermal collector with PCM,” *Sol. Energy*, vol. 133, pp. 533–548, 2016, doi: 10.1016/j.solener.2016.04.024.

[26] M. A. Bashir, H. M. Ali, S. Khalil, M. Ali, and A. M. Siddiqui, “Comparison of performance measurements of photovoltaic modules during winter months in Taxila, Pakistan,” *Int. J. Photoenergy*, vol. 2014, 2014, doi: 10.1155/2014/898414.

[27] M. Arıcı, F. Bilgin, S. Nižetić, and A. M. Papadopoulos, “Phase change material based cooling of photovoltaic panel: A simplified numerical model for the optimization of the phase change material layer and general economic evaluation,” *J. Clean. Prod.*, vol. 189, pp. 738–745, 2018, doi: 10.1016/j.jclepro.2018.04.057.

[28] L. Navarro et al., “Thermal energy storage in building integrated thermal systems: A review. Part 2. Integration as passive system,” *Renew. Energy*, vol. 85, pp. 1334–1356, 2016, doi: 10.1016/j.renene.2015.06.064.

[29] L. Navarro et al., “Thermal energy storage in building integrated thermal systems: A review. Part 1. active storage systems,” *Renew. Energy*, vol. 88, pp. 526–547, 2016, doi: 10.1016/j.renene.2015.11.040.

[30] M. K. Shabdin et al., “Material Characterizations of Gr-Based Magnetorheological Elastomer for Possible Sensor Applications: Rheological and Resistivity Properties,” pp. 1–15, doi: 10.3390/ma12030391.

[31] Q. Wang, R. Wu, Y. Wu, and C. Y. Zhao, “Parametric analysis of using PCM walls for heating loads reduction,” *Energy Build.*, vol. 172, pp. 328–336, 2018, doi: 10.1016/j.enbuild.2018.05.012.

[32] R. Wen, W. Zhang, Z. Lv, Z. Huang, and W. Gao, “A novel composite Phase change material of Stearic Acid/Carbonized sunflower straw for thermal energy storage,” *Mater. Lett.*, vol. 215, pp. 42–45, 2018, doi: 10.1016/j.matlet.2017.12.008.

[33] D. Zhou, C. Y. Zhao, and Y. Tian, “Review on thermal energy storage with phase change materials (PCMs) in building applications,” *Appl. Energy*, vol. 92, pp. 593–605, 2012, doi: 10.1016/j.apenergy.2011.08.025.

[34] M. Li and J. Shi, “Review on micropore grade inorganic porous medium based form stable
composite phase change materials: Preparation, performance improvement and effects on the properties of cement mortar,” *Constr. Build. Mater.*, vol. 194, pp. 287–310, 2019, doi: 10.1016/j.conbuildmat.2018.10.222.

[35] X. Tong, N. Li, M. Zeng, and Q. Wang, “Organic phase change materials confined in carbon-based materials for thermal properties enhancement: Recent advancement and challenges,” *Renew. Sustain. Energy Rev.*, vol. 108, no. December 2018, pp. 398–422, 2019, doi: 10.1016/j.rser.2019.03.031.

[36] V. V. Tyagi, S. C. Kaushik, S. K. Tyagi, and T. Akiyama, “Development of phase change materials based microencapsulated technology for buildings: A review,” *Renew. Sustain. Energy Rev.*, vol. 15, no. 2, pp. 1373–1391, 2011, doi: 10.1016/j.rser.2010.10.006.

[37] W. L. Cheng, R. M. Zhang, K. Xie, N. Liu, and J. Wang, “Heat conduction enhanced shape-stabilized paraffin/HDPE composite PCMs by graphite addition: Preparation and thermal properties,” *Sol. Energy Mater. Sol. Cells*, vol. 94, no. 10, pp. 1636–1642, 2010, doi: 10.1016/j.solmat.2010.05.020.

[38] A. Sharma, V. V. Tyagi, C. R. Chen, and D. Buddhi, “Review on thermal energy storage with phase change materials and applications,” *Renew. Sustain. Energy Rev.*, vol. 13, no. 2, pp. 318–345, 2009, doi: 10.1016/j.rser.2007.10.005.

[39] Y. Lin, G. Alva, and G. Fang, “Review on thermal performances and applications of thermal energy storage systems with inorganic phase change materials,” *Energy*, vol. 165, pp. 685–708, 2018, doi: 10.1016/j.energy.2018.09.128.

[40] M. Kenisarin and K. Mahkamov, “Salt hydrates as latent heat storage materials: Thermophysical properties and costs,” *Sol. Energy Mater. Sol. Cells*, vol. 145, pp. 255–286, 2016, doi: 10.1016/j.solmat.2010.05.029.

[41] M. K. Rathod and J. Banerjee, “Thermal stability of phase change materials used in latent heat energy storage systems: A review,” *Renew. Sustain. Energy Rev.*, vol. 18, pp. 246–258, 2013, doi: 10.1016/j.rser.2012.10.022.

[42] A. Hasan, S. J. McCormack, M. J. Huang, and B. Norton, “Characterization of phase change materials for thermal control of photovoltaics using Differential Scanning Calorimetry and Temperature History Method,” *Energy Convers. Manag.*, vol. 81, pp. 322–329, 2014, doi: 10.1016/j.enconman.2014.02.042.

[43] P. Atkin and M. M. Farid, “Improving the efficiency of photovoltaic cells using PCM infused graphite and aluminium fins,” *Sol. Energy*, vol. 114, pp. 217–228, 2015, doi: 10.1016/j.solener.2015.01.037.

[44] D. W. Hawes, D. Banu, and D. Feldman, “Latent heat storage in concrete. II,” *Sol. Energy Mater.*, vol. 21, no. 1, pp. 61–80, 1990, doi: 10.1016/0165-1633(90)90043-Z.

[45] R. Thaib, S. Rizal, M. Riza, T. M. I. Mahlia, and T. A. Rizal, “Beeswax as phase change material to improve solar panel’s performance,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 308, no. 1, pp. 5–11, 2018, doi: 10.1088/1757-899X/308/1/012024.

[46] W. Lu, Z. Liu, J. F. Flor, Y. Wu, and M. Yang, “Investigation on designed fins-enhanced phase change materials system for thermal management of a novel building integrated concentrating PV,” *Appl. Energy*, vol. 225, no. January, pp. 696–709, 2018, doi: 10.1016/j.apenergy.2018.05.030.