



Review

Nanocontainers for Energy Storage and Conversion Applications: A Mini-Review

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Abstract: Countries that do not have oil and natural gas but are forced to reduce pollution due to combustion have stimulated and developed new technologies for absorption, storage, and energy creation based on nanotechnology. These new technologies are up-and-coming because they will solve the problem without additional environmental burden. The first technology is based on phase change materials (PCMs) that store the thermal energy produced by the sun and release it when requested. In the context of this article, there is a discussion about some devices that arise from this technology. The second technology is based on light nano-traps that convert solar energy into heat, which is then stored by heating water or other methods. The third practice is to absorb solar energy from nanoparticles, producing electricity. These technologies' principles will be discussed and analyzed to understand their perspectives.

Keywords: nanotechnology; nanocontainers; phase change materials; paraffin; thermal energy storage; household equipment; light microtraps; nanoparticle energy conversion; light absorption; electricity generation



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1. Introduction

The rehabilitation of oil and natural gas in countries that do not have such energy resources and the reduction in pollution due to combustion has led to the research and development of new technologies for the absorption and storage of solar energy [1]. We know that energy is not created or destroyed but preserved [2]. This principle is the basis of the technology of storing and exploiting solar energy from a period of low demand to a period of high demand. Renewable energy sources and storage technologies offer solutions to replace some fuels and make them life-saving solutions for the future. Energy sources, such as wind, solar, etc., will only apply if ways of storing the produced energy are found simultaneously. The generated energy can be stored with phase change materials (PCMs) [3–5]. The application of PCMs is essential where electricity is expensive or in areas where the electricity supply could be more practical.

PCMs change phases at a specific temperature achieved through internal energy transfer as a heat transfer that we call “latent heat”. Liquid-dissolved PCMs create another category of materials we call phase change slurries (PCSs), enclosed in heat transfer circuits [6]. PCS can contain up to 40% PCMs with a melting temperature of 60 °C and have a lower physical coefficient of thermal permeability compared to water. One application is water heaters, which in recent times are now on the market under operating conditions. Recent review publications present such applications [7,8]. This publication examines phase change memory (PCM) materials encapsulated into containers to improve the performance of devices. Encapsulating PCMs in nanocontainers is a one-way solution for many applications. PCMs on a paraffin basis dissolve on objects that are applied, e.g., electronic devices, thereby corroding these devices. Their isolation in a container is indicated to isolate paraffin from the environment and use its function as an energy storage/cooling material. Another application concerns the slurries where the systems need to be protected from the solution

environment to act for a long time as a kind of heat capacity enhancement of this solution. These shells guarantee the long-term operation of the PCM materials. Another severe problem solved by encapsulating the PCMs into containers is the reduction in temperature gradients during heat transfer inside or outside the material during heat transfer in and out of the material. In the last few years, many works have concerned the development of silica shells [1], styrene-methyl methacrylate copolymer [2,3], urea-formaldehyde (UF) [4,5], polystyrene (PS) [6], melamine formaldehyde (MF) [7], polymethyl methacrylate (PMMA) [8–11], polycarbonate (PC) [3,12], and polyurethane (PU) [13–15]. We refer to the corresponding literature to produce these capsules. This tremendous amount of work is the subject of this review, and suggestions will be made on how these technologies can be applied to practical applications. The reader will see more applications in this review where the development of PCM@shells is necessary for many applications.

In addition, double-wall nanocontainers incorporating solar energy absorption coatings are reported to enhance spinel coatings' absorption efficiency with light microtraps [9]. In the end, there is a literature review on producing electricity using nanocontainer nanotechnology from the sun. Figure 1 shows the applications that employ this publication.

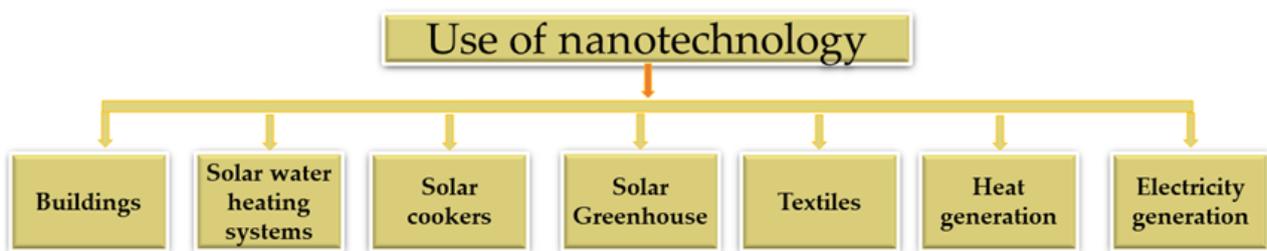


Figure 1. Applications discussed in this publication.

2. Thermal Energy Storage (TES)

Thermal energy storage is achieved through internal energy change, such as thermal (sensible heat and latent heat) and thermo-chemical [10]. Figure 2 summarizes these methods, but in the rest of the text, there will be a detailed description of the possibilities of storing thermal energy through latent heat.

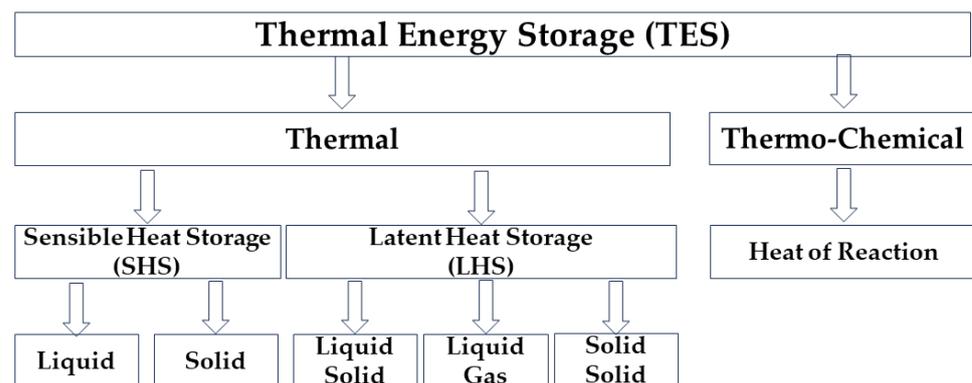


Figure 2. Forms of energy storage [11].

2.1. Sensible Heat Storage (SHS)

Sensible heat storage (SHS) materials do not change during heat storage [12]. These materials can be liquids or solids. Energy storage, Q , is carried out by changing the temperature of the material via a charging and discharging process as well as depends on the thermal specific heat capacity, C_p , and the mass, m , of the material:

$$Q = m C_p (T_f - T_i) \quad (1)$$

The parameters T_i and T_f are the initial and final temperatures, respectively.

SHS systems must have a high specific heat capacity but at the same time be stable at the time of their application, be compatible with the environment of use, have a high density, be cheap, and have almost zero CO₂ residues. A space problem often requires as high energy density as possible. Still, the manufacturer must ensure good thermal insulation of the SHS storage area, especially when the periods of charge and discharge are long, to limit heat losses. Table 1 gives examples of SHS materials [13]. One can perceive from this table that water has an excellent specific heat capacity up to 100 °C. Above 100 °C, one has to use liquids that can withstand these temperatures [13].

Table 1. Examples of sensible heat storage (SHS).

Material	Temperature °C	Density (kg/m ³)	Specific Heat Capacity (kJ/kg)
Stone	20	2560	879
Water	0–100	1000	4190
Engine oil	Till 160	888	1880
Propanol	Till 97	800	2500
Octane	Till 126	704	2400

2.2. Latent Heat Storage (LHS)

When the phase change achieves energy absorption and release, you are subjected to (Solid ↔ Solid, Solid ↔ Liquid, and Liquid ↔ Gas) material; we are talking about latent heat storage based on phase change from one physical state to another [14,15]. When a Solid ↔ Solid transition is achieved, the material is converted from one crystalline form to another, where the volume changes are relatively small compared to the volume changes one observes in Solid ↔ Liquid and Liquid ↔ Gas transitions. Pentaglycerine is a Solid ↔ Solid PCM with promising properties such as heat of fusion (16 kJ/kg) and phase transition point (81 °C) [1,16]. Solid ↔ Gas transitions may have higher latency heat values. However, it is not easy for the gas created during Solid ↔ Gas transformation to coexist, which makes these PCMs unsuitable for many applications. On the contrary, Solid ↔ Liquid PCMs are economically attractive. They are used in latent heat storage systems that aim to reduce the fluctuation of the interior temperature due to fluctuating solar radiation [17].

Summing up, heat storage in these materials is based on capturing or releasing heat through a PCM phase change. Energy storage, Q , is given by the following formula:

$$Q = m [C_s (T_m - T) + a_m \Delta h_m + C_p (T_f - T_m)] \quad (2)$$

where m is the mass of the melted PCM, Δh_m , C_{sp} , and C_{lp} are the specific heat of the solid and liquid PCM at temperatures $T_m - T_l$ and $T_h - T_m$, respectively; this equation expresses the greater Δh , the extended cooling effect.

The imprint from this equation is that LHS achieves maximum energy density per unit of mass and volume. LHS systems suitable for space cooling have T_m between 10 and 30 °C, and space heating systems have T_m between 30 and 100 °C.

2.3. Paraffin

Paraffin consists of a chain $\text{CH}_3\text{-(CH}_2\text{)-CH}_3$ that the segment (CH_2) crystallizes, releasing a sizeable latent heat. The melting point and latent heat fusion depend on the chain length (Figure 3). With the increase in the melting temperature, as the carbon number increases (Figure 3), heat storage capacity also increases. Various works in the literature have demonstrated that paraffin has good thermal stability and stable properties after 1000–2000 cycles [18]. Furthermore, paraffin possesses high latent heat, thermal stability, chemical stability, and sufficient mechanical strength while also being non-toxic, non-corrosive, and non-supercooling. On the other hand, leakage can create problems [19,20]. Thus, the manufacture of composite PCM after encapsulating it in a highly conductive

material can reduce the pain and, at the same time, affect the ability to store heat [21]. The ol-gel method is one widely used manufacturing method adopted by various researchers for preparing paraffin PCM composites [22,23]. The properties of paraffin, such as heat storage and thermal conductivity, can be improved by encapsulating additional materials that change their thermal, physical, and mechanical properties [24], like graphite [25], SiO₂ [26], metal foam [27,28], low-density polyethylene [29], perlite [30], expanded vermiculite [31], etc. Shape stability, thermal conductivity, durability, thermal efficiency, flammability reduction, and mechanical properties have been extensively investigated, and the results have been summarized in a review article [27].

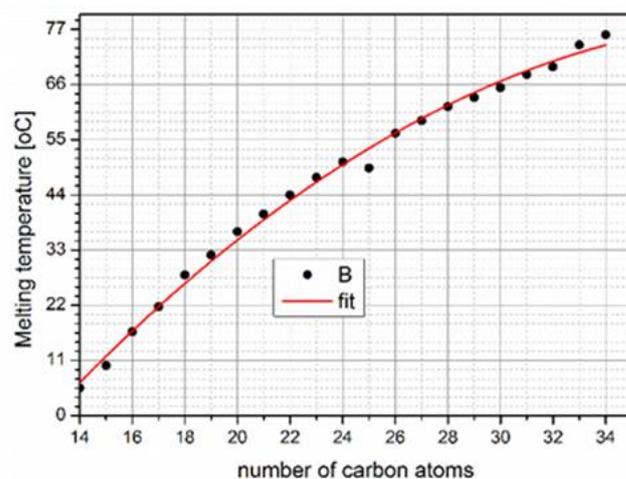


Figure 3. Paraffin melting temperature as a function of the number of carbon atoms [13].

Table 2 summarizes the thermal properties of paraffin appropriate for building applications.

Table 2. Thermal properties of paraffin.

PCM	Melting Temp. (°C)	The Heat of Fusion (kJ/kg)	Thermal Conductivity (w/mk)	Density (kg/m ³)	Ref.
Paraffin C13–C24	22–24	189	0.21 (liquid)	760 (liquid) 900 (solid)	[32]
Paraffin RT-27	28	179	0.2	800	[33]
Paraffin RT-18	15–19	134	0.2	756	[33]
Paraffin C18	28	244	0.148 (liquid)		[34]

Lately, there has been an increasing number of publications concerning paraffin in containers. These publications are concerned with awareness of problems related to conductivity and leakage, stability of the shells in solutions at higher temperatures, and the other disadvantages of encapsulation. These problems can be solved by combining them with metallic or non-metallic particles, fibrous materials, expanded or porous materials, and additives that slow flame spread. Figure 4 shows paraffin as an energy storage material that can be mixed with other materials to create a composite material with new customized properties to solve the problem. A recent publication brings together all the findings of work related to the solution of this problem [27]. Melamine formaldehyde with an average diameter of about 1 µm encapsulated n-octadecane and nucleating agents by in situ polymerization. The work aimed to find the effects of sodium chloride, 1-octadecyl, and paraffin on the crystallization properties of the PCM as well as on the morphology and dispersion of microcapsules using SEM, DSC, and XRD. Supercooling was avoided with 6 wt% sodium chloride in the emulsion. The surface of the capsules was rough. The addition of 9% w/w of 1-octadecanoic to the PCM was found to prevent supercooling, but the capsules showed agglomerates. A third attempt incorporated 20% w/w of paraffin into the PCM material, which seemed free of supercooling and did not affect the morphology and dispersion of the microcapsules [35]. Paraffin in the silica container appeared to solidify

at 58.27 °C with a latent heat of 107.05 kJ/kg and melt at 58.37 °C with a latent heat of 165.68 kJ/kg. These measurements showed that the containers were filled up to 87.5%. It seems the encapsulation of paraffin in silicon oxide and paraffin improves the thermal stability of paraffin due to the cooperation of paraffin with the silicon oxide shell. This experiment proves that the encapsulation of paraffin with silicon oxide shells has beneficial effects [36]. Paraffin type RT80 is stored in a styrene butyl acrylate copolymer shell using the microemulsion polymerization process. The amount of encapsulation achieved was 8 to 20%. The heats of melting and crystallization were about 5–25 J/g depending on the mass of paraffin incorporated into the nanocontainers. However, it was observed that the melting temperature of the paraffin in the nanocontainer was 1–7 °C lower than that corresponding to free paraffin, i.e., raw, RT80. This finding is noted here because there may be something similar in other encapsulations of various other PCMs incorporated into the nanocontainers [37,38]. However, it was observed that the encapsulated paraffin shows thermal stability up to the 200 heat-cooling cycles it has undergone inside the silica shell [39].

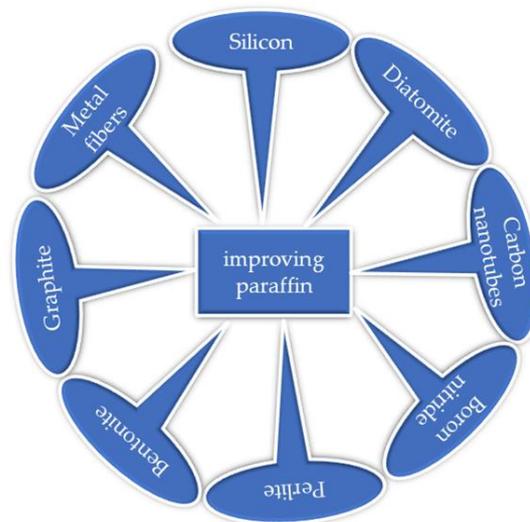


Figure 4. Added materials to improve paraffin properties (data from [27]).

2.4. Non-Paraffins

Non-paraffin is a phase change material that provides energy storage [40]. It can be esters, fatty acids, alcohols, and glycols. Some of the characteristics of these organic materials are as follows: (i) high heat of melting, (ii) some are flammable, (iii) low thermal conductivity, (iv) low flash points, (v) different levels of toxicity, and (vi) instability at high temperatures. Saturated fatty acids have the formula $\text{CH}_3(\text{CH}_2)_{2n}\text{COOH}$ [41]. Fatty acids have a reproducible melting and freezing point, showing minimal phase transition volume changes [42]. Their disadvantages are low thermal conductivity and cost, which is higher than paraffin [41]. Fatty acid esters are produced from acids where one alkyl group replaces a hydroxyl group. The transition temperature is narrow, and their mixtures form eutectics with negligible subcooling. These are available in the cosmetics and clothing industries and are widely available [43]. Sugar alcohol has the usual expression $\text{HOCH}_2(\text{CHOH})_n\text{CH}_2\text{OH}$. They have latent fusion heat of about 300 kJ/kg and 375 MJ/m³. These have a high melting temperature of over 90 °C and can be flammable, which makes them difficult to use in buildings [44]. Polyethylene glycols (PEGs) have the chemical formula $\text{H.O.-(CH}_2\text{-O-CH}_2\text{)-}_n\text{-CH}_2\text{-O.H}$. They exhibit chemical and thermal stability and are non-flammable, non-toxic, non-corrosive, and cheap. Their thermal conductivity is low. These PCMs' melting point and latent fusion heat increase as their molecular weight increases [45]. Aromatic hydrocarbons, monohydroxy alcohols, ketones, ethers, halogen derivatives, and oleochemical carbonates are promising compounds because of their use as PCMs. The

thermal storage density is 100–200 kJ/kg [46]. Table 3 gives some thermal properties of fatty acids suitable for building walls.

Table 3. Thermal properties of fatty acids.

PCM	Melting Temp. (°C)	The Heat of Fusion (kJ/kg)	Thermal Conductivity (w/mk)	Density (kg/m ³)	Ref.
Capric acid	30.2	142.7	0.2 (liquid) 0.12 (solid)	815 (liquid) 752 (solid)	[47]
CA and 1-dodecanol (CADE)	26.5	126.9	0.2 (liquid) 0.12 (solid)	817 (liquid) 754 (solid)	[47]
Capric acid and palmitic acid	26.2	177	2.2	784	[48]
Capric acid	30	142.7		815 (liquid) 752 (solid)	[48]
CA and 1-dodecanol (CADE)	27	126.9		817 (liquid) 754 (solid)	[49]

2.5. Inorganic Phase Change Materials

Inorganic materials are subordinated to salt hydrates and minerals [40,44,50–57]. These phase-change materials do not thaw significantly, and the melting heat does not change with repeated transitions. Salt hydrates contain a crystalline solid of the general formula $AB \cdot nH_2O$. The solid–liquid transformation of salt hydrates is saltwater dehydration, although this process resembles thermodynamic melting or cooling. Because they have a high density, the latent heat of fusion per volume is greater than that of organic materials [12]. The thermal conductivity is low to moderate but flammable and cheaper than paraffin. However, they are thermally unreliable for long periods of operation because the phase separation occurs under cooling and heating cycles [58]. One way to avoid this problem is to add fattening agents. The melting process leading to salt and water causes salt precipitation due to the difference in density between salt and water and changing the stoichiometry after several cycles. Other materials, such as clay, must be added to extend their lifespan and eventually reach 1000 cycles without altering their properties [59]. $Mg(NO_3)_2 \cdot 6H_2O$ were incorporated in nano-poly(ethyl-2-cyanoacrylate) capsules with 100 to 200 nm size. The DSC method showed the stability of the salt hydrates, which remained unchanged after 100 thermal cycles, with a latent heat of 83.2 J/g. This method of encapsulation and volume improvements of $Mg(NO_3)_2 \cdot 6H_2O$ in nanocontainers guides its structural integrity and chemical stability. This method opens a future energy storage applications due to its heat capacity and cost-effectiveness compared with the paraffin commonly used [60]. The encapsulated PCM shows reduced supercooling up to 100 melting–freezing cycles and only a 3% reduction in latent heat after these cycles [60].

Using the sol-gel process, the sodium thiosulfate pentahydrate (SoTP) was encapsulated in silica containers. According to SEM measurements, the MicroPCM has a spherical shape of approximately 200 nm. Supercooling has significantly been reduced. The thermal conductivity of SoTP in silica varied between 0.6035 and 0.7718 W/(m·k) [61]. $Na_2SO_4 \cdot 10H_2O$ suffers from phase separation and supercooling in heat storage applications. These effects can be diminished when implanted in silicon nanocontainers. Its inclusion of $Na_2SO_4 \cdot 10H_2O @ SiO_2$ from the SiO_2 matrix suspends its supercooling due to its limitation to the nanocontainer. This method is necessary for applying this substance in the future for thermal energy storage applications [62]. These studies show that nanocontainer entrapment neutralizes the supercooling and separation of the salt hydrates and opens new applications for them as heat storage materials.

Microcapsules with modified methyl polymethacrylate (PMMA) were loaded with disodium hydrogen phosphate heptahydrate ($Na_2HPO_4 \cdot 7H_2O$), and their thermal properties were tested. The analysis showed an improved degree of supercooling, making this a valuable combination for thermal energy storage materials [63].

A eutectic mixture is one compound consisting of two or more components, such as mixtures of organic–organic, organic–inorganic, and inorganic–inorganic compounds. The

eutectic compound changes phases without phase separation and has a single cooling–melting point [42]. Note that their melting temperature is lower than their compounds [12].

Very recently, the thermal stability of a binary mixture of the lithium chloride salt of lithium hydroxide (LiCl–LiOH) as a medium for storing thermal energy has been studied. The study showed that the binary at a concentration of 32 mol% LiCl–68 mol% LiOH exhibits a melting temperature between 269 °C and 292 °C with a fusion heat amounting to 379 J/g. Thermal repeatability was examined up to 30 cooling and heating cycles and showed little change in melting temperature and fusion heat. The thermal decomposition analysis indicated a slight weight loss of up to 500 °C and demonstrated excellent thermal stability. This system of LiCl–LiOH salts can be used as a thermal energy storage material in applications reaching 500 °C [64].

The binary salt system CaCl₂ (58 wt.%)–LiCl (42 wt.%) is a suitable PCM for high-temperature applications. To investigate how it operates at high temperatures, a study was conducted where the starting melting temperature of 488 °C and stabilization temperature of 480 °C were found. The fusion heat was 206 J/g, while the crystallization heat was 206 J/g. The study showed that fusion enthalpy changes significantly after 30 cycles of cooling and heating, and these materials exhibit thermal instability with a change in mass. These properties make it unwieldy for applications requiring the thermal stability of PCMs [65]. Table 4 gives some thermal properties of hydrated salts suitable for building walls.

Table 4. Thermal properties of hydrated salts suitable for building walls.

PCM	Melting Temp. (°C)	The Heat of Fusion (kJ/kg)	Thermal Conductivity (w/mk)	Density (kg/m ³)	Ref.
Hydrated salt	29	175	1.0	1490	[66]
CaCl ₂ ·6H ₂ O	29	187.49	0.54 (liquid) 1.09 (solid)	560 (liquid) 1800 (solid)	[66]
Mn(NO ₃) ₂ ·6H ₂ O + MnCl ₂ ·4H ₂ O	27	125.9	0.6	1700	[66]
SP25A8 hydrate salt	26	180	0.6	1380	[33]
sodium sulfate decahydrate	32.5	180	0.6	1600	[67]

In summary, the above tables are a small sample of PCMs discovered in the literature and are helpful for buildings. One can find more compositions of PCMs in literature. Figure 5 shows that different regions use different PCMs dictated by climate conditions. This is due to the other thermal properties of the structures used for buildings in different climate areas [68,69].

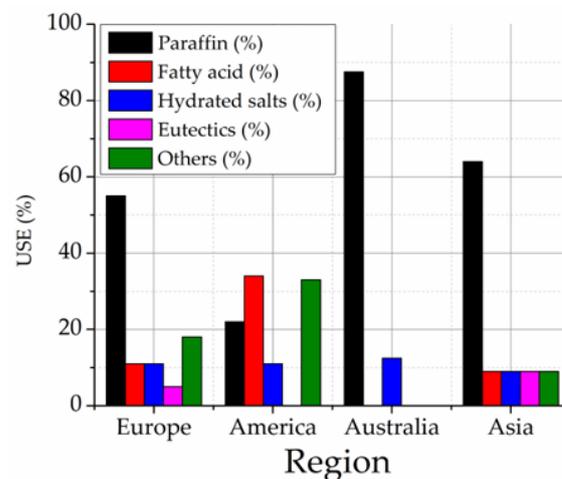


Figure 5. Different PCMs are used in other areas of the world with varying climate conditions (data taken from [52]).

2.6. Phase Change Materials (PCMs)

Heat storage in materials based on phase change is called latent heat storage and occurs when a material is converted from solid to liquid or liquid to solid [4]. The temperature in these materials rises as they absorb heat. PCMs absorb and give off heat almost constantly (Figure 6). As a result, they store 5–14 times more heat per unit volume than logical storage materials such as water, masonry, or rock. These materials must exhibit specific desirable thermodynamic, kinetic, and chemical properties. In addition, there are economic criteria for their use. One important consideration is the easy availability of these materials. Table 5 gives the basic properties of the PCM.

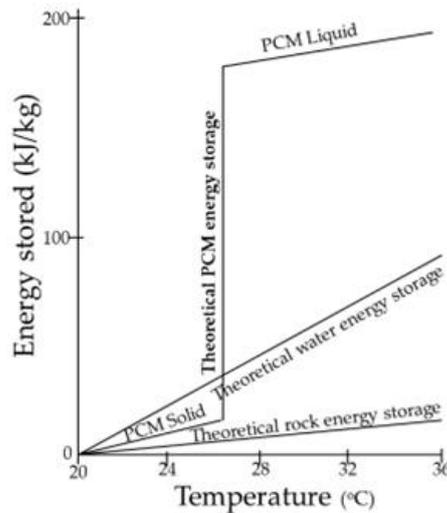


Figure 6. PCM energy storage.

Table 5. Properties of PCM.

Thermal Properties	The Suitable Phase Transition Temperature	High Latent Heat of the Transition	Good Heat Transition
Physical properties	The suitable phase transition temperature	High latent heat of the transition	Good heat transmission
Chemical properties	Long-term chemical stability	Compatibility with materials of manufacture	Non-toxic and non flammable
Kinetic properties	No subcooling	Sufficient crystallization rate	
Economic criteria	Abundance	Availability	Low cost

Figure 7 shows the fusion heat versus the melting temperature of the various PCMs. This figure shows the multiple PCMs’ defined temperature and enthalpy ranges that determine their applications. Paraffin, fatty acids, and hydrates are suitable for producing low-temperature heat (up to 100 °C) for use in the building and solar thermal industries, thermal storage in structural elements, and ventilation and air conditioning thermos units. With comprehensive service in the range of medium temperatures from 100 to 250 °C, this area can intersect the needs of the manufacturing sector and the whole range of heating and cooling needs of large industries. Many industries in this area also generate small-scale electricity, including in tourist resorts’ cooling and heating facilities and devices operating in this area, such as solar cookers, from where these PCMs are necessary. The encapsulation of PCMs in containers of various sizes, from a few microns to a few centimeters, is required in many applications where they meet the devices. It can lead to corrosion or dispersion that follows their dissolution and deactivation [7].

Many PCMs have the “supercooling” effect, resulting in the crystallization rate being very low in temperature compared to the melting point. Supercooling is a state where the

liquid solidifies below the melting point, and the lag in the melting process only depends on the discharge speed from this material starting from the melting temperature. Suppose such a material is incorporated into cooling–heating devices, controlled at a specific temperature; such a situation will make it difficult to control the device. In that case, temperature control is difficult if the heat is extracted instead of a constant temperature within a continuous-temperature region corresponding to the material’s heat extraction, which is often not reproducible. Supercooling will directly affect the temperature margins in the rest of the thermal system and is a significant problem in the design and implementation of a device.

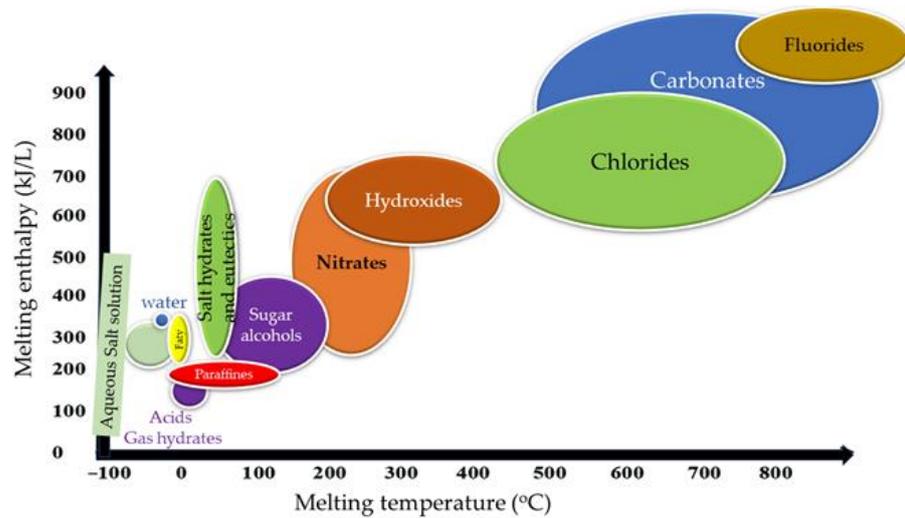


Figure 7. Melting enthalpy vs. melting temperature for most common PCMs.

2.7. Classification

Table 6 suggests that the PCMs are classified as organic, inorganic, and eutectic. Table 6 shows these categories of materials. Organic PCMs are divided into paraffin and non-paraffin PCMs. Inorganic PCMs include hydrates, metals, and alloys. These have high latent heat and thermal conductivity and are non-toxic and non-flammable, contrasting with the organic PCMs.

Table 6. Classification of PCMs.

PCM		
↓ Organic ↓	↓ Inorganic ↓	↓ Eutectic ↓
Paraffin Non-Paraffin	Salt-Hydrates Metal	Organic-Organic Organic-Inorganic Inorganic-Inorganic

2.8. Techniques for Measuring the Latency of Melting Heat and Melting Temperature

The methods used to estimate the latent heat of melting and melting temperature of PCMs are as follows:

1. Differential thermal analysis (DTA);
2. Differential scanning calorimeter (DSC).

The sample and materials are heated constantly while DSC or DTA curves and ΔT are recorded between the sample and the reference material. The reference material recommended is alumina. The latent heat of melting is calculated using the area below the top of the melting curve and calculated from the tangent at the curve’s base. Recent literature describes in detail how these measurements are made, as well as the analyses of these measurements [70].

3. Solar Water Heating Systems

A solar water heater is a case where PCMs can be applied since they are relatively cheap materials and do not raise costs but only increase the efficiency of the water heater and insulation compared to polyurethane. During the hours of sunshine, the water heats until the heat is transferred to the PCM when the temperature reaches the material's melting point. The PCM gathers energy in the form of latent heat and melts. During long hours of sunshine, hot water is withdrawn and replaced by cold water, which gains power from PCM.

The PCM's energy in its phases changes from liquid to solid. Therefore, constructing a water heater unit with PCM will be integrated into its thermal insulation system. The hot water can be transferred from the water heaters to a heat storage system located in the basement of a house that will return to where it is needed in sunless hours.

An isolated sizeable cylindrical storage tank was used to experimentally investigate the material storage performance of paraffin wax in small spherical aluminum containers. The aluminum containers are commercially available. It was found that a PCM-loaded storage device has an advantage of 13 to 10 °C in hot water storage compared to a layout without PCMs. During a 24 h trial, the stored water temperature remained 30 °C higher than the ambient temperature. One can use such devices for one's everyday routine [71].

In an exciting work, the absorbent plate of a solar water heater was painted with paraffin wax PCM and compared with a corresponding plate without paraffin paint. The solar water heater with a storage absorption plate painted with paraffin performs better than the solar collector without paraffin wax. The experimental performance was 70.98% for the paraffin layout, and for the numerical simulation, it was 67.73%. These experiments showed that the absorption with paraffin increased significantly in the water heater system due to the collector's increased ability to absorb the sun's rays [72].

Emphasis has been placed in the literature on improving the efficiency of commercial solar water systems by using PCM throughout the heating season [73]. PCM particles from 1 to 3 mm have been used in thermal energy storage, and analysis showed that the application was beneficial inside a water tank with a significant drop-in heat transfer rate [74,75]. Such a system is believed to be more flexible and responsive for energy storage at a reduced volume [74]. It was found that the temperature difference required to transfer the heat coefficient by natural convection is reduced by quite a large percentage [73].

Solar water heating in a solar collector system can significantly improve efficiency if the water tank is structured with phase change materials. One experiment used 2.5 kg of paraffin wax cut into a cylindrical aluminum casing with a total % PCM volume of 3%. The outer diameters of the cylindrical geometry were at a height of 0.3 m, and the inner diameter was 0.127 m. The temperature distribution along the size of the storage tank the energy and energy efficiency of the charge and the collector's efficiency were finally calculated and compared with CFD software. The system's energy efficiency improved by up to 36.48% due to improved heat transfer between PCM and water [76].

The lack of stability of PCM storage materials inside the systems mentioned above creates a problem and limits the development of PCM applications. This instability has aroused scientists' interest in incorporating them into containers to isolate them from their environment to determine their alterations [77]. The freezing and melting of PCM, 50–80% entrapped in polyester spherical containers studied in the literature, found their lifespan [78,79]. BASF developed microencapsulated PCMs for commercial use in solar water heaters [80].

Figure 8 shows a typical heat transfer unit consisting of a large, medium container, into which spheres of a few centimeters containing paraffin are incorporated and organized in a class. Among these spheres is a slurry consisting of nanospheres, which may be a kind of paraffin, encapsulated silica spheres, which flow undisturbed into the large spheres and exit the end of this arrangement. The thermal properties of such an installation depend on the type of pools and fluid we use, the size of the facility, i.e., cross-sectional area and length, the slurry flow rate, and the temperature of the slurry inlet [81]. The device stores

thermal energy during the day with sunshine and returns to the heating and cooling system of buildings on demand, where a second circuit is activated when the ambient temperature drops to the point that requires the commissioning of this device [7,71]. Depending on the thermal energy storage system, one can use these facilities for heating swimming pools, buildings, and other household appliances, depending on the system's architectural design.

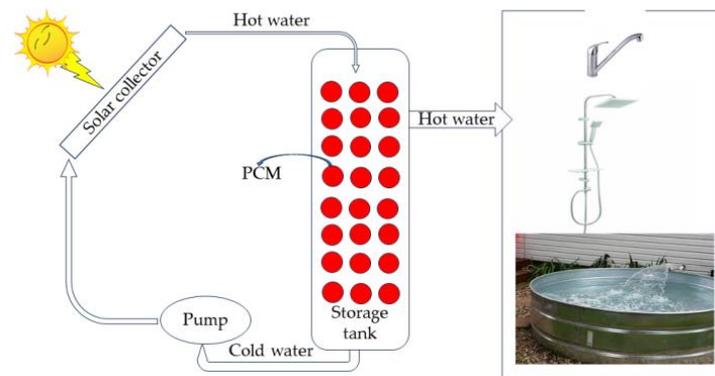


Figure 8. Solar collectors can heat the water of a water heater and a hot water storage system in the basement of a house, which we can use during periods when sunshine is low [12,82–84].

4. Solar Cookers

Solar cookers are one of the significant applications of PCMs that can be used for cooking when there is no sun (Figure 9). The kitchen will use PCM with latent heat and storage materials in a solar cooker-type frame to cook food late at night. Solar cookers are limited to lots of sunshine and equipped with heat storage systems above 100 °C. PCMs can be magnesium nitrate hexahydrate ($\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$) as a PCM for heat storage [85].

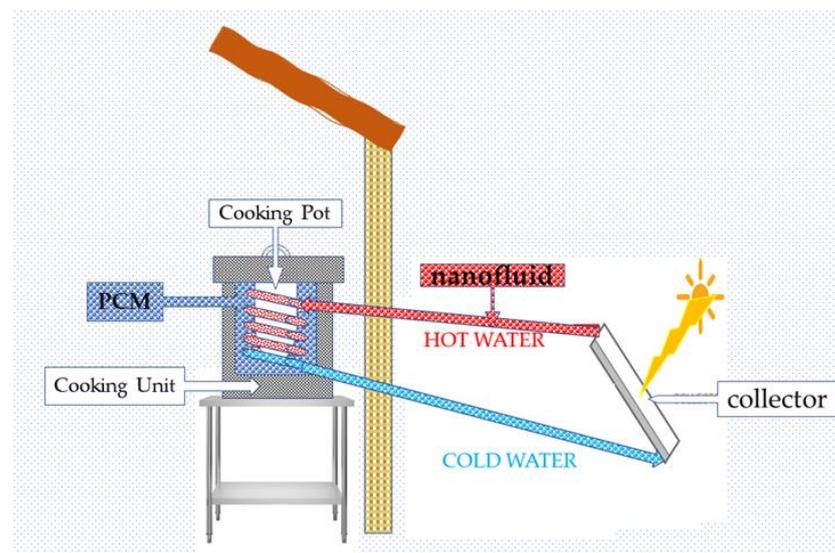


Figure 9. Solar cookers.

PCM is charged faster when the charging temperature increases. Decent as it was found, the heat discharge time increases with the degree of overheating of the PCM. The kitchen's performance was four times that of other steam sun appliances for indoor cooking. It was observed that when the PCM was magnesium chloride hexahydrate with a melting temperature of 110.7 °C, the device achieved temperatures higher than 100 °C. A solar cooker was developed to collect energy, store it during the day, and use it for cooking food at night using acetamide latent heat storage materials. This cooker was compared to a typical solar cooker, proving that cooking food is possible in the evenings [86]. Solar

concentration-type cookers are believed to have a significant rate of return. Theoretical studies were carried out on this where heat losses from the empty food containers were considered. High temperatures will be achieved when these containers are constructed adequately with the appropriate devices, including PCM. These structures are sensitive to wind speed, where in the end, it will take longer average cooking time with increasing wind speed [87]. High temperatures of up to 200 °C were obtained in a solar system using vacuum collectors with built-in long heat pipes for frying and baking in a short time using water as a working liquid. The performance of such a system is excellent, and instabilities in the thermal conductivity of lines under different load conditions are not observed [88]. Liquid suspensions (slurries) containing particles 1 to 100 nm in size are called nanofluids and have received considerable attention for amplifying these liquids in enhanced heat transfer applications. A slurry containing indium nanoparticles and indium polyalphaolefin (PAO)-coated nanoparticles exhibiting a melting temperature of 157 °C exhibits increased thermal conductivity and specific heat of conventional fluids [89]. A single-phase liquid with a particular heat transfer capacity is improved by twice as much if phase change nanoparticles are added, which can discard heat energy during solid–liquid phase changes. These experiments were carried out using two types of slurry, naked indium, and silicon-coated indium, for high-temperature applications of 150 to 180 °C. This system can operate at a high temperature of 150 to 180 °C. Experiments showed that the heat transfer coefficient reached 47,000 W/m² K at a flow rate of 3.5 mL/s (velocity 0.28 m/s). Thermal cycle tests were performed 5000 times, proving the stability of the slurry [89,90].

Solar cookers are feasible in countries of plentiful sunshine under three conditions: the solar concentrate, which must be a pipe or parabolic arrangement, and the appropriate backing stove with good insulation, as shown in Figure 9. Appropriate nanofluids and PCMs must also be investigated for reducing cooking time and optimizing the temperature the device can achieve.

5. Solar Green House

In greenhouses and closed-end fish farms, PCM will store solar energy for the heating and drying process and plant, spirulina, and shrimp production. PCM-type CaCl₂·6H₂O in the aerosol cans will store energy inside and outside the facility. In addition, buildings will use these facilities for air conditioning (Figure 10) [40,46,58,84,91–95].

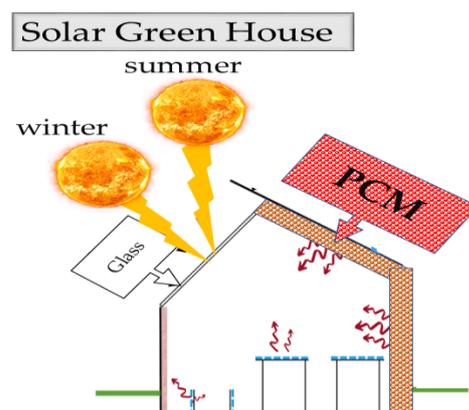


Figure 10. Solar greenhouse.

Greenhouses can be stabilized indoors in a Mediterranean climate with renewable energy sources for heating in cold seasons using phase change materials (PCMs). This was demonstrated in a warm, mild east–west orientation containing CaCl₂·6H₂O as PCM. The result showed that with an equivalent of 32.4 kg of PCM per square meter of the greenhouse surface, the greenhouse temperature was between 6 and 12 °C and had few fluctuations during winter. The relative humidity averaged 10–15% at night [96].

6. Buildings

PCMs have been developed for thermal storage in buildings. PCM is integrated into walls, plasterboard, shutters, insulation, and underfloor heating systems as part of the building for heating and cooling applications [46,95,97,98]. The purpose is to shift the peak load and harness solar energy. The implementation of PCMs in the building can have two different objectives. They first used natural heat as solar energy for heating or cooling. Second, they used artificial heat or complex sources. In any case, storage of heat or cold is necessary to match availability and demand over time. PCMs will be used in wall construction, building elements other than the walls, storage plants, plasterboard, bricks, and paints (Figure 11).

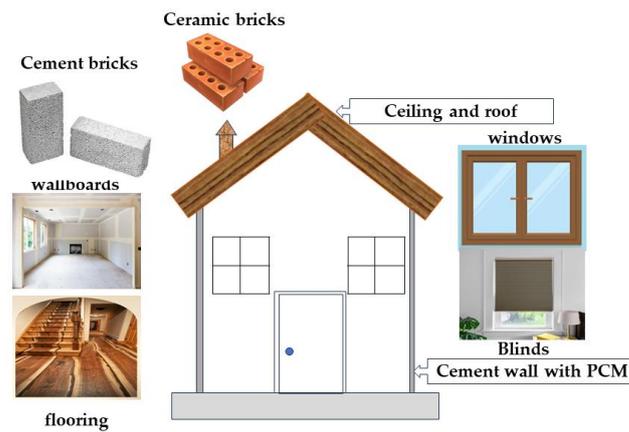


Figure 11. PCMs in buildings.

In recent years, buildings have developed efficient materials and technologies to meet these cooling and heating needs. Building envelopes lose more energy and are integrated with heat storage materials to regulate the internal temperature and improve the energy efficiency of buildings. Figure 12 shows the external change in ambient temperature and the reduction in this oscillation within the building if surrounded by PCM walls [13].

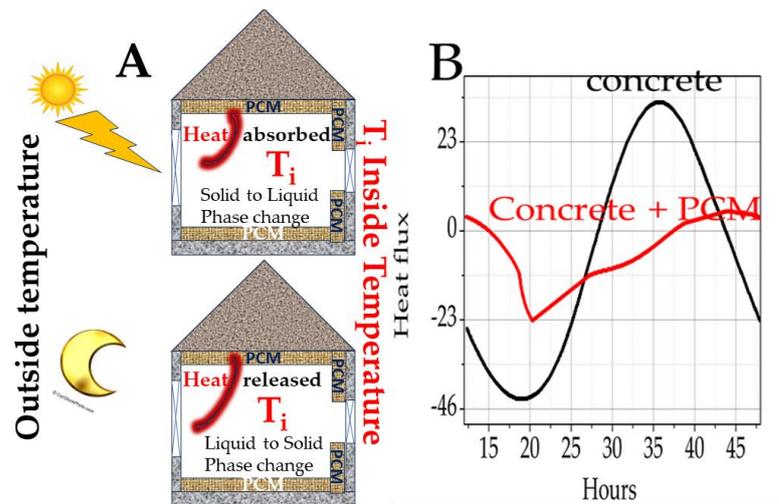


Figure 12. (A) PCM embedded in building walls. During the day, the sun's energy is absorbed and expelled indoors at night. (B) Variation of the inside temperature, T_i (red curve), and outside temperature (black curve) [13].

The choice of PCM incorporated into buildings should suit indoor and human comfort temperatures. Thermal comfort for people indoors is 23.5 °C to 25.5 °C in summer and 21 °C to 23 °C in winter. Based on these preferences, PCMs for buildings must have

operating temperatures between 18 °C and 30 °C. According to these criteria, the melting point of PCM is selected. Latent heat fusion determines the amount of material we will use in buildings. The density of PCMs also plays a vital role in the selection so as not to occupy a large volume in buildings. The reader from an industry interested in using PCMs for buildings can refer to the literature to find the appropriate material for the structure considering the region's climate [8,95]. Tables 1–3 present a few building materials.

The PCMs incorporated into containers do not adversely affect the building material's operation. The dimensions of the small encapsulated PCMs are so small that no effects on the properties of materials are observed. The enclave is a simple and economical technique of integrating materials into compatible building materials, and there are currently products from companies called Micronal1PCM. The melting point of this material is 26 to 8C, and the phase change enthalpy is 110 kJ/kg. PCMs were incorporated into concrete and reached a compressive strength of 25 MPa and a tensile strength of over 6 MPa (after 28 days) [99]. Thermal analyses of small, encapsulated paraffin were performed, and it was found that their geometric size was kept constant for up to 1000 cycles. A high storage and release capacity of energy amounting to 20–90 J/g, depending on the composition ratios, was also found [100].

Two rooms were full-size in one experiment, one with panels with PCM and the others without PCMs. The panels encapsulating capric acid were installed on the outer surface and encapsulated a 1-dodecanol (CADE) with a melting point of 26.5 °C. The experiment showed first the stability of the average temperature at 26 °C and the reduction in temperature fluctuations inside the room to 2 °C. In contrast, the external fluctuations were up to 32 °C [47].

7. Textiles

An essential application in the future can be in fabrics that contain phase change materials and immediately mitigate external temperature changes and maintain a constant body temperature [101]. Encapsulating PCM in capsules and incorporating these into textile products provides tremendous energy storage benefits and protects the body from temperature changes. These can be used to irrigate bed linen, and in various clothing technologies, constant temperatures are necessary [101]. The PCM capsules are planned to be incorporated into acrylic fiber yarns that, with some processing, will be subjected to standard textile machinery. When the outside temperature rises, the microcapsules absorb heat and store it as liquefaction of phase change materials. The opposite happens when the temperature drops; worse phase change materials solidify again, releasing temperature. These possibilities can be realized with capsules containing PCMs incorporated into garments. The microcapsules must be incorporated into the fibers of the fabrics directly to be woven into the final product. Gelatin/sodium alginate/clay capsules encapsulated n-eicosane and examined whether they can improve fabrics' thermal comfort and flame-retardant properties. Electron microscopy (SEM) confirmed that the produced n-eicosane/capsule system was spherical, averaging 1.5 µm. Thermal analysis showed that they could store 97–114 J/g and release 82–105 J/g latent thermal energy, quantities sufficient for their application in the textile industry. The experiments showed that this n-eicosane/capsule system significantly slows flame in fabrics [102]. Commercial microcapsules of type CENTER FINISH 164/01 M.T. produced by COLOR CENTER (Tarrasa, Spain) were incorporated into textile fibers. The shell of the capsules was melamine formalin, and the capsules contained a mint aroma. Their size was about 5–10 µm. This study is unique because it aimed to mitigate odor in the body, which was proven after this technology. The debate is that goals can be made with a dual mission, such as stabilizing the temperature through a PCM in the container and avoiding odors with substances incorporated into the capsules [103]. A technique was developed based on containers manufactured on the in-situ polymerization process to be used in various applications in the textile industry. The thermal performance of the resulting fabrics was tested for given cold weather conditions and a person's physical activity

using multilayer fabrics. They can operate at $-2\text{ }^{\circ}\text{C}$ for about an hour. The microcapsules were widely distributed, as demonstrated by SEM studies [104].

8. Nano- and Micro-Encapsulation of PCM

Caprylic acid is a PCM that can find use in sectors such as construction, textiles, and agriculture because it has a melting point of about $16\text{ }^{\circ}\text{C}$ and a latent heat storage capacity of 158 J/g . It is in liquid form at room temperature, and under such conditions, it is not easy to use. Encapsulating caprylic acid in capsules is the one-way solution for its use as a PCM [49]. This is why the caprylic acid (octanoic acid) was incorporated into various wall materials, such as urea-formaldehyde resin, melamine-formaldehyde resin, and urea-formaldehyde resin. The PCM compound was hardened with formaldehyde. The size of the capsules was measured by scanning electron microscopy (SEM) and found to be between 200 nm and $1.5\text{ }\mu\text{m}$. This research found that the shell prepared from the urea-formaldehyde resin was the best for the caprylic acid goal. The thermal analysis determined that PCM's melting phase change enthalpy and freezing were 93.9 J/g and 106.1 J/g , respectively [49].

The sol-gel method encapsulated paraffin in TiO_2 as thermal energy storage materials. Paraffin in the TiO_2 was encapsulated in the TiO_2 according to FT-IR, XRD, and SEM measurements. The encapsulated paraffin melts at $58.8\text{ }^{\circ}\text{C}$ and has a latent heat of 161.1 kJ/kg and solidifies at $56.5\text{ }^{\circ}\text{C}$ with a latent heat of 144.6 kJ/kg , as the microencapsulation ratio is 85.5% . These results show that micro-encapsulated paraffin and TiO_2 may have major thermal energy storage potential. The literature describes how one can manufacture TiO_2 and encapsulate paraffin [105].

Stearic acid (S.A.) was imprisoned in silicon dioxide (SiO_2) containers to create PCMs using the sol-gel method. Silica stearic acid solidifies at $52.6\text{ }^{\circ}\text{C}$ with a latent heat of 162.0 kJ/kg and melts at $53.5\text{ }^{\circ}\text{C}$ with a latent heat of 171.0 kJ/kg when the S.A. encapsulation ratio is 90.7% . The analysis showed that silica shells improve their thermal stability with stearic acid (S.A.), possibly using a thermal energy storage medium in buildings. Chemical preparations were described in the literature [106].

One paper used emulsion polymerization to characterize the nano-micro-encapsulated capric, lauric, and myristic acids with polystyrene (P.S.). The thermal analysis showed that the feathers melt and freeze at $22\text{--}48\text{ }^{\circ}\text{C}$ and $19\text{--}49\text{ }^{\circ}\text{C}$ as they store and release latent heat in the $87\text{--}98\text{ J/g}$ range and $84\text{--}96\text{ J/g}$ range. They found a minor alteration of properties after 5000 thermal cycles. The results of these ratings suggest that these materials can be used for thermal regulation, solar heat pumps, and many space heating applications in buildings [107].

Magnetic microcapsules were prepared using an n-eicosane core and $\text{Fe}_3\text{O}_4/\text{SiO}_2$ shell, a dual-functional phase change material. After a study, the magnetic microcapsules exhibited magnetic qualities and extremely low magnetic retention and compulsion. The dual property makes them useful for innovative applications in fiber fabrics and many other military uses that require double armor properties [108].

Nanoencapsulated phase change materials and their high mechanical stability are used in thermal energy storage and heat transfer systems. But they have two main drawbacks; the first is poor thermal conductivity, and the second is supercooling, leaving the latent heat almost intact. To solve these problems, silicon oxide shells were prepared in a graphene microemulsion. The measurements showed an increase in thermal conductivity of 132.9% . In pure water, thermal conductivity increased by 9.6% , and the photo-thermal conversion efficiency improved from 31% to 70% . The new technology allows for unthinkable applications in intelligent fabrics, thermal energy storage, and heat transfer fluids [108].

Microcapsules were synthesized using the microemulsion polymerization method and studied to find the best composition conditions that remained stable at high temperatures. These are n-octadecane in poly (styrene-co-divinylbenzene-co-acrylamide) shells encapsulating n-octadecane as PCM. The materials' melting and freezing onset temperatures were slightly lower than the phase transition temperatures of n-octadecane and the

enthalpy values. With this preparation technique, the capsules are stable up to 148 °C. The high-temperature stability makes them useful for temperatures above 100 °C [109].

A eutectic mixture of myristic acid – palmitic acid (MA-PA) was incorporated in polymethylmethacrylate (PMMA) containers. Their size was determined to have distributions between 0.1 and 300 µm. The melting temperature was 38 °C, while the storage capacity was 100.5 J/g. TGA measurements showed that the capsule withstood up to 250 °C. The capsules have excellent thermal and chemical resistance because they withstand 5000 cooling and heating cycles. These results are promising for many practical applications [110].

Paraffin was incorporated into SiO₂ capsules using methods known from the literature to store heat [111]. The capsules were enriched with various amounts of paraffin up to 80%, showing a latent heat of up to ~156 J/g. The size of the spheres ranged between 550 and 700 nm. The paraffin/SiO₂ system does not show agglomeration, making it promising for heat storage applications [23].

The mechanical properties of the shell prepared were studied using melamine-formaldehyde resin as the shell material and found to possess a yield point of about 1.1·10⁵ Pa, showing that the capsules exhibited plastic behavior. The capsules incorporated lauryl alcohol as phase change material with a melting point of 24 °C, and the quantity of heat included in the phase transition was 225.5 J/g. The diameter of the microcapsules varies from 5 to 10 µm, and they were spherical and smooth. The purpose of creating these capsules was to be used indoors to save energy [112].

Shells were prepared with different fractions of fatty acids to find the maximum concentration of fatty acids in PMMA that acts as a supporting material. The fatty acids were stearic acid (S.A.), palmitic acid (P.A.), myristic acid (M.A.), and lauric acid (L.A.), which are promising materials for use as PCMs. Mixtures of fatty acid/PMMA equal to 80/20 wt.% gallery do not show leakage of the fatty acids from the shell but are also thermally stable. The stable form of these pellets is required for applications on floors and plasterboard to eliminate the thermal resistance caused by the shell [113].

In one paper, the authors prepared binary thin and paraffin mixtures such as n-heptadecane (C17), n-octane-cane (C18), n-nonadecane (C19), n-eicosane (C20), and n-tetracosane (C24), which were encapsulated in Polymethyl methacrylate (PMMA). This resulted in PMMA/(C17–C24), PMMA/(C19–C18), PMMA/(C19–C24), PMMA/(C20–C24), and PMMA/(C20–C24) micro/nano-capsules, which were characterized to find their physicochemical properties. The melting temperature range was 20–36 °C, and the latent heat capacity ranged between 86 and 169 J/g. They underwent several freezing–melting cycles to measure their stability, and it was found that they withstood even 5000 cycles. They also had good thermal conductivity and revocable freezing–melting points [114].

Various techniques characterized n-heptadecane in an n-heptadecane shell. Their diameters were found to be 14–0.40 µm. Their properties were stable after 5000 repeated thermal cycles. TGA measurements proved that they have excellent thermal conductivity and stability. The analysis results showed that they have good energy storage capabilities [115].

Sodium phosphate dodecahydrate (DSP) was encapsulated in methylene diisocyanate (MDI). The study dealt in detail with the production conditions, the capsule's morphology, and the water-soluble materials' efficiency. The increase in the quantity of MDI promoted urethane bonds, whereas they decreased with the increase in the amount of cellulose acetate butyrate (CAB). The result showed that the best MDI-to-CAB ratio was 0.4 to 1 [116].

Poly(diallyl dimethyl ammonium chloride) sodium salt (PDADMAC) and Poly(4-styrene sulfonic acid) sodium salt (PSS) were used to manufacture multilayer shells in emulsified octadecane droplets using either bovine serum albumin (BSA) or sodium dodecyl sulfate (SDS) as surfactant. The size of the sphere was 500 microns. A high degree of loading equal to 91.3% by mass was also measured, demonstrating thermal stability after multiple cycles and heat treatments [117].

The encapsulation of N-octadecan in a polyurea nanocontainer was accomplished, and analyses followed to find its properties. The best conditions are obtained due to a shell core weight ratio of 70 to 30, making these materials suitable for PCM products [118].

Alumina shell capsules were filled in with copper spheres about 3 mm in diameter from an opening in the alumina capsule, which was finally sealed after a CuAl_2O_4 compound creation process. XRD and SEM confirmed the sealing process. The result showed that copper pellets containing 5–10% aluminum created a system that can store heat and operate above 1000 °C. In the future, such methodical production methods can be used for other PCMs in different temperatures for different devices. Figure 13 shows how these advanced PCMs are produced and operated [119].

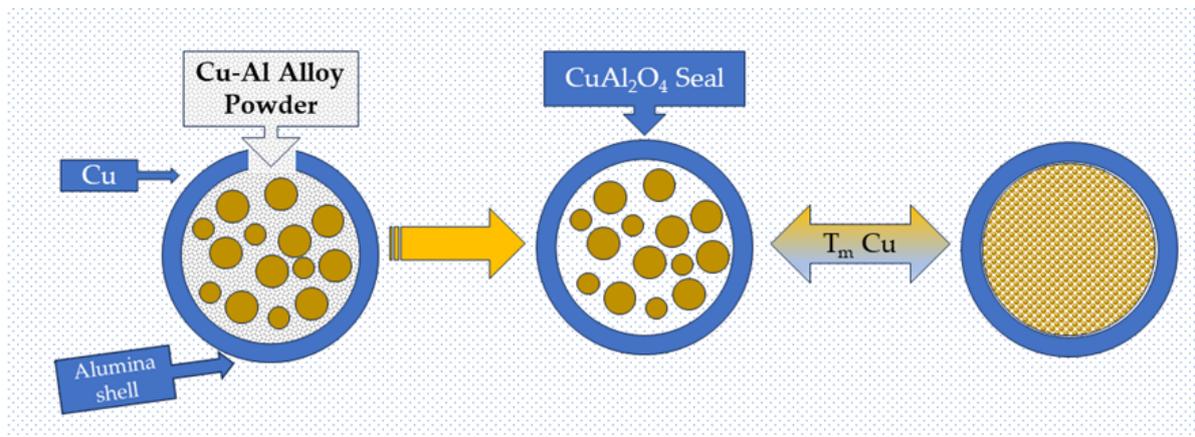


Figure 13. High-temperature Cu—(5–10%) Al PCM encapsulated into an aluminum shell.

Copper spheres were laid in a nickel-chromium bilayer with an electrical conversion method, and studies were carried out to find the latent heat density of the capsules, which was found to be 75% of the theoretical value of 71 J/g at the melting temperature of 1077 °C. They showed no capsule oxidation and remained stable after a long charge and discharge cycle. It turned out that these capsules can be used for storing energy at high temperatures [120].

9. Heat Generation

Water heaters use solar selective coatings to convert solar energy into thermal energy. These coatings must meet three criteria to be helpful: showing high absorption, α , in the spectral range from 0.4 to 2.5 μm , having a low emission, ϵ , in the infrared range from 2.5 to 50 μm , and demonstrating high selectivity, α/ϵ , at 100 °C. The ideal selective coating shows reflection with $R = 0$ in the visible region and $R = 1$ in the infrared, i.e., the black body spectra. Tabor produced the first commercially valuable absorbent coating by electro-galvanization 1995 [121]. Chrome has become the typical product in the marketplace [122]. Today's commercial absorbent layers are produced with vacuum deposition techniques with excellent results. Alanod launched on the market various commercial products such as mirotherm Control[®], mirotherm[®], eta plus[®], and mirosoil[®] with α_s and ϵ_T up to 97% and 4% ($b/w = 24.25$), with the PVD technique [123]. In recent years, scientists have manufactured solar absorbent coatings with the sol-gel process to reduce the cost of the production facilities of these returns with great success [124]. Based on CoCuMnO_x spinels with SiO_x coatings, coatings CuO@SiO_2 were prepared with values $\alpha_s = 0.85\text{--}0.91$ and ϵ_T below 0.036 ($\alpha/\epsilon = 17\text{--}18$) [125,126]. In coatings with CuCoMnO_x produced on an aluminum substrate, CuO@SiO_2 micro-containers were incorporated into these coatings of $980 \mu\text{m} \pm 30 \text{ nm}$. CuO micro-containers $715 \mu\text{m} \pm 15 \text{ nm}$ in size were first prepared. The TEM measurement demonstrates that the CuO micro-containers are internally empty [9]. CuO micro-containers are coated with SiO_2 to produce CuO@SiO_2 double-shell micro-containers [9]. The concentration of CuO@SiO_2 micro-containers in the spinel coatings

varied from 0 to 1 wt.%. The resulting α/ϵ ratio was measured in these samples [9]. Figure 14 shows the results of α/ϵ ratio as a function of concentration. The α/ϵ ratio varies linearly with the concentration from 5 to 10 for 0 to 1 CuO@SiO_2 , respectively.

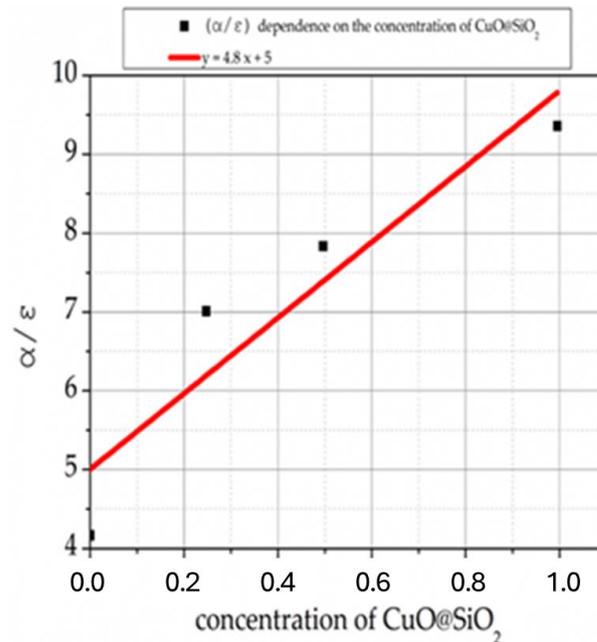


Figure 14. (α/ϵ) dependence on the concentration of CuO@SiO_2 .

The additional light absorption is generated by increasing the α/ϵ ratio by the CuO@SiO_2 micro-containers. The CuO@SiO_2 micro-containers act in the coatings as “light microtraps” [9]. Figure 15 describes the mechanism of light trapping in the CuO@SiO_2 graphically and comprehensively described in the literature [9].

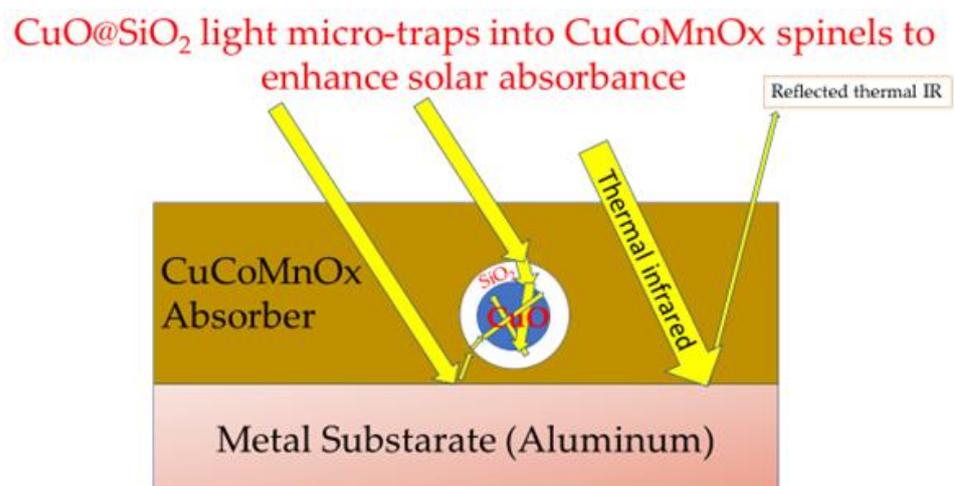


Figure 15. Mechanism of light absorption from the CuO@SiO_2 containers.

Alanod manufactures absorbent coatings that convert sunlight into heat, which all companies use today. Production is accomplished with extensive facilities, which are highly reliable but expensive to realize. The sol-gel technology proposed here has the advantage that these absorption coatings can be manufactured by a polymer chemist with low investment cost, demonstrating high repeatability, provided, of course, that the appropriate coating developed by this method is competitive (α and ϵ) with the current ones produced by the Alanod company. Once this has been achieved, the light traps added

to the outstanding coatings will further enhance their performance compared to these coatings, and they are expected to surpass those of Al₂O₃ coatings. This is likely to happen soon, and the potential of this technology will exceed all expectations.

10. Electricity Generation

In a past study, it was shown that light could be trapped in ZnO micro-containers. These ZnO-type hollow light traps are beautiful as photovoltaic sun solar cells due to their high surface area for absorbing incident light, high electron mobility, and low production costs. In one study, the ZnO spheres exhibited a 400–500 nm diameter, with a power conversion efficiency of 4.33% and a short-circuit current density of 9.56 mAcm⁻² [127]. To improve the coefficient of efficiency of ZnO microspheres, multi-shell spheres with well-defined structures were produced with a defined number of inner shells and controlled distances between them through the production process. This research showed that hollow ZnO microspheres with different shell structures exhibit various energy conversion efficiency factors. The quadruple shell microstructure is one in which sunlight reflects internally multiple times, losing its energy internally, raising its performance to 5.6% [128]. The corresponding spectrum of U.V./vis diffuse reflectance behaves accordingly. The multi-shelled ZnO hollow microspheres (M.S. ZnO HMS) were decorated with TiO₂ nano-tree (N.T.) [129]. The TiO₂ decoration significantly enhances light scattering and increases the specific area of ZnO HMS. The I–V tests show a significant enhancement of short-circuit current density (J_{sc}) by controlling M.S. Combining ZnO HMS shell numbers and M.S. ZnO HMS with TiO₂ NT reaches a power conversion efficiency (PCE) of 7.40% [129]. In addition, combining T.S. ZnO HMS with TiO₂ NT increases light-collecting efficiency and extends electron lifetime. Another approach was made using CdS and CdSe quantum dots to decorate the surface of the ZnO core/shell hollow microspheres to increase the light scattering of the ZnO hollow structure [130]. The new system improved power conversion efficiency by 76.22% and 21.74%, higher than in ZnO N.P.s and ZnO HMS [130]. Figure 16 describes the multiple reflections of sunlight on the inner walls of containers, which absorb more sunlight; in this way, the sun's energy is converted into electricity [129,130].

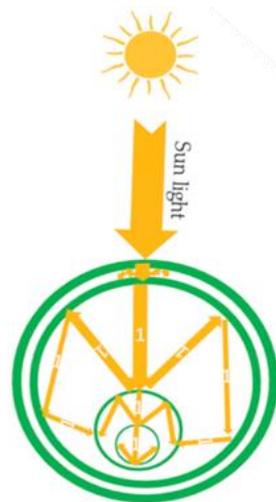


Figure 16. Containers with multiple inner walls that reflect sunlight internally trap it after multiple reflections and convert solar energy into electricity.

The ZnO and CuO@SiO₂ micro-containers entrap the sunlight to generate electricity and thermal energy. Therefore, these microstructures will be helpful soon for producing power from sunlight, which we call from now on “micro-traps of light”.

n-eicosane@SiO₂/CdS can be used not only for solar energy storage but also in the solar photocatalytic discharge of industrial wastewater, solar photochemical cleaning of organic water pollutants, etc. The capsules showed high solar photocatalytic activity in organic

dyes under natural sunlight. The microcapsules also exhibit fluorescent function due to the outer CdS cortex [131]. With the capsules having multiple properties for many applications simultaneously, this development opens their use in many different technologies.

11. Conclusions

The text was written to approach young scientists who want to start their careers in the field of encapsulated PCMs and company engineers to understand the possible commercial potential of the encapsulated PCMs. The encapsulation of PCMs involves scientists with deep knowledge of polymer chemistry synthesizing and improving existing shells to cope with the repeated operation cycles of these systems. We also require the involvement of experienced technologists from research centers, universities, and industry to develop and improve these systems with a view to their commercial exploitation. The potential of this technology is enormous, and one can solve many problems related to the absorption and storage of solar energy. From this literature review, we are at the beginning of such an activity, which must continue with a growing dynamic to solve the energy problems that generate developed and even developing countries. More is needed for these ideas to remain at the level of research study, but the industry must immediately invest in commercial exploitation through state funding. The benefits will be enormous if you consider a building with solar collectors on its roof. In the basement, a storage device with PCM is encapsulated in containers to store the excess thermal energy produced during a sunny day and return the heat to the building at night to maintain a constant temperature. One can think of cooking stoves so that using energy-intensive appliances in houses is minimized in their service to reduce a home's energy costs. Buildings with PCMs are of great benefit because the internal temperature will stabilize at an average temperature comfortable to humans, and there will no longer be a need for heating or cooling these buildings in countries at the level of current energy needs. The future impact of this technology is enormous, and this article aims to raise awareness in industry and propose ways to collaborate with scientists utilizing containers to protect PCMs so that all these ideas can find practical application soon. Because the scientific field has many shortcomings, one urgently needs to establish the requirements and specifications of these technologies so that an industrialist can give some guarantees for their product. The new prospects of developing light traps to absorb solar energy and turn it into heat are in their infancy and need to be improved. Here, the sunlight absorption coating incorporating light traps must possess absorbance at values above 95% to be enhanced for these coatings to be commercially valuable. Also, converting solar energy into electricity is a promising new technology with potential for application; however, it needs further intensive work to improve its performance. The coming years will be a giant field of action that young scientists must enter with many new ideas for developing new materials and seeking further applications. We also expect more support from theoretical scientists to study the behavior of PCMs inside a single container as a function of its size, wall thickness, and materials to be used, as well as to optimize the devices under construction to supplement the experimental data and reduce the amount of practical work. A theorist can incorporate PCMs in various materials such as plasterboard and bricks and determine the benefit of incorporating PCMs in these structural components. This way, they will shorten the development time for new innovative materials. Such cooperation between theorists and experimentalists will dramatically reduce the development time of new products and technologies.

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