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USE OF PHASE CHANGE MATERIALS IN THERMAL STORAGE SYSTEMS AS A DIFFERENT FAÇADE APPLICATIONS IN DIFFERENT CLIMATES

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ABSTRACT
Worldwide, the demand for environmental friendly energy is ever-increasing due to the rapid growth of the economy and living standards. Construction industry is the foremost consumer of material and energy resources has a great prospect for developing innovative energy-saving and thermally efficient construction materials. Phasechange materials (PCMs) as thermal energy storage systems are potential due to their tailored thermal mass and heat comfort. The selatent heat storage materials possess extremely high energy storage density than the convention alones. This work provides a comprehensive overview on the features of PCMs, their recent development,and futuretr ends with applications directed towards building architectures as different facade applications (Trombewall, wallboards, shutters...) in different climates.

Keywords: Phase change materials, thermal energy storage, building facades

INTRODUCTION

With the growing energy crisis, the approach of architects and engineers was changed by designing phase until application phase of construction.

Researchers who search for new and renewable energy sources findout developing energy storage devices also can be as important as developing new sources of energy.

Energy storage not only reduces the mismatch between supply and demand but also improves the performance and reliability of energy systems and plays an important role in conserving the energy [1] [2].

1- ENERGY STORAGE METHODS

The different forms of energy that can be stored include mechanical, electrical and thermal energy [3].

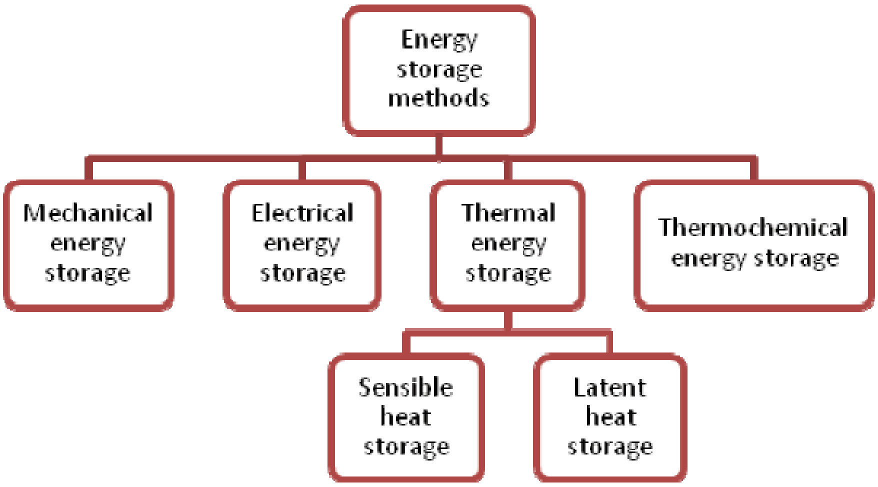

Figure 1 Different types of energy storage methods [4].

1-1- MECHANICAL ENERGY STORAGE

Mechanical energy storage systems include gravitational energy storage or pumped hydropower storage (PHPS), compressed air energy storage (CAES) and flywheels.

1-2- ELECTRICAL ENERGY STORAGE

Energy storage through batteries is an option for storing electrical energy. A battery is charged, byconnecting it to a source of direct electric current and when it is discharged, the stored chemical energy is converted into electrical energy.

1-3- THERMAL ENERGY STORAGE

Thermal energy storage can be stored as a change in the internal energy of a material as sensible heat, laten the at and thermo chemical or combination of these. An overview of the major technique of storage of solar thermal energy is shown in Fig. 2 [5].

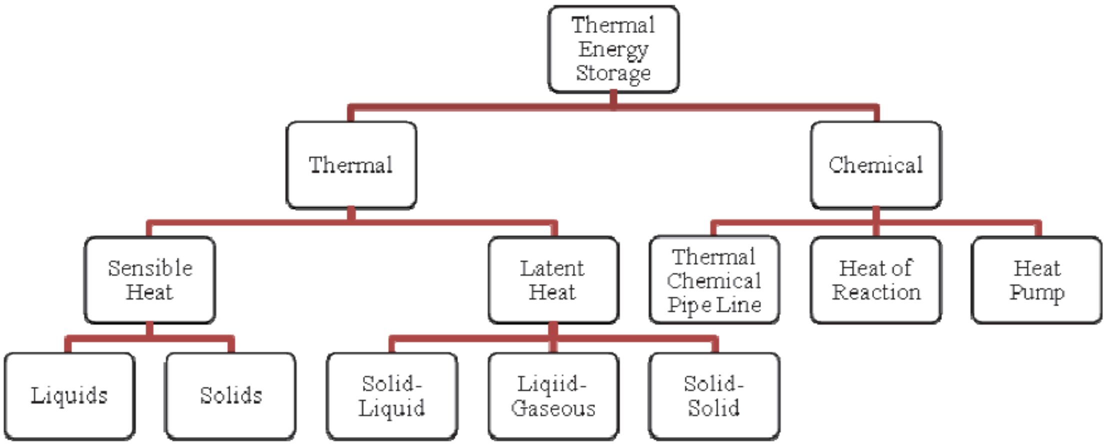

Figure 2. Different types of thermal storage of solar energy [4].

SENSIBLE HEAT STORAGE

In sensible heat storage (SHS), thermal energy is stored by raising the temperature of a solid or liquid. SHS system utilizes the heat capacity and the change in temperature of the material during the process of charging and discharging. The amount of heat stored depends on the specific heat of the medium, the temperature change and the amount of storage material [6].

LATENT HEAT STORAGE

Latent heat storage (LHS) is based on the heat absorption or release when a storage material undergoes a phase change from solid to liquid or liquid to gas or viceversa [6].

1-4- THERMOCHEMICAL ENERGY STORAGE

Thermochemical systems rely on the energy absorbed and released in breaking and reforming molecular bonds in a completely reversible chemical reaction. In this case, the heat stored depends on the amount of storage material, the endothermic heat of reaction, and the extent of conversion. From above thermal heat storage techniques, latent heat thermal energy storage attracts scientist's attention due to its ability to provide high-energy storage density and its characteristics to store heat at the constant temperature corresponding to the phase transition temperature of phase change material (PCM).

2- PHASE CHANGE MATERIALS

Phase change materials (PCM) are ''Latent'' heat storage materials. The thermal energy transfer occurs when a material changes from solid to solid, solid to liquid, liquid to solid; This is called a change in state, or ''Phase.''

2-1- SOLID TO SOLID

In solid–solid transitions, heat is stored as the material is transformed from one crystalline to another. These transitions generally have small latent heat and small volume changes than solid–liquid transitions. Solid–solid PCMs offer the advantages of less stringent container equirements and greater design flexibility [7].

- Change in the crystalline structure
- A small change in volume
- Smaller storage capacity than solid-liquid transition
- Less containment required and greater design flexibility

2-2- SOLID TO GAS, LIQUID TO GAS

Solid–gas and liquid–gas transition through have higher latent heat of phase transition but their large volume changes on phase transition are associated with the containment problems and rule out their potential utility in thermal-storage systems. Large changes in volume make the system complex and impractical [7] [8].

- Higher latent heat of phase transition
- Larger volume changes on phase transition
- Larger containment required
- An impractical and complex system

2-3- SOLID TO LIQUID

Solid–liquid transformations have comparatively smaller latent heat than liquid–gas. However, these transformations involve only a small change (of an order of 10% orless) in volume. Solid– liquid transitions have proved to be economically attractive for use in thermal energy storage systems. [7] [8]

- Inter mediate latent heat of phase transition, volume change
- Most practical and economical system

3- PCM'S PROPERTIES

Initially, these solid–liqui PCMs perform like conventional storage materials; their temperature rises as they absorb heat. Unlike conventional (sensible) storage materials, PCM absorbs and releases heat at a nearly constant temperature. They store 5–14 times more heat per unit volume than sensible storage materials such as water, masonry, or rock. For their employment as latent heat storage materials, these materials must exhibit certain desirable thermo dynamic, kinetic and chemical properties as will come bellow. Moreover, economic considerations and easy availability of these materials have to be kept in mind [9] [10].

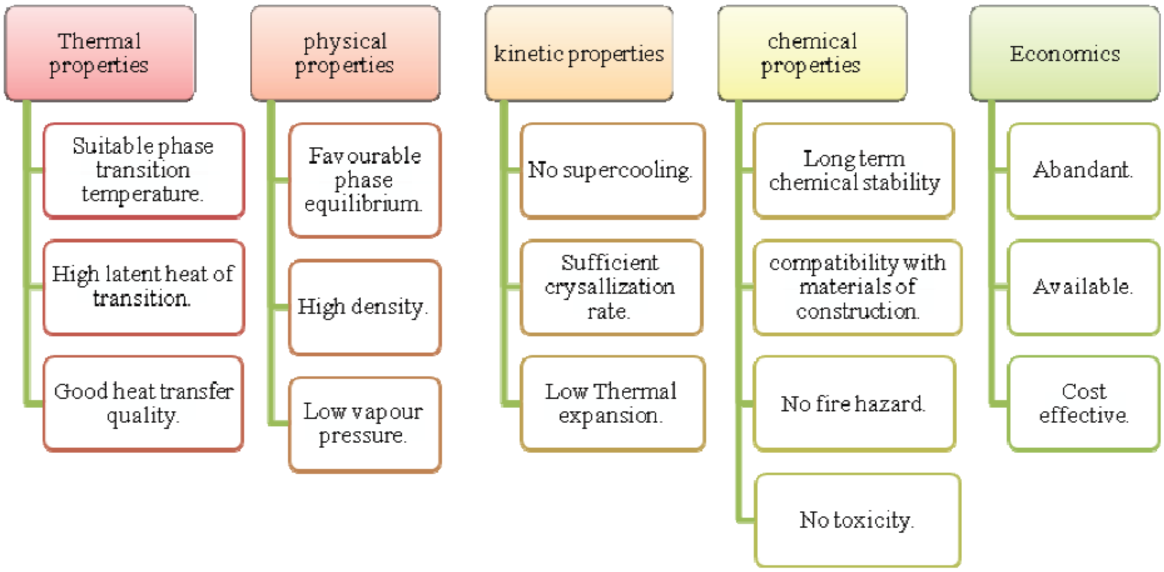

Figure 3. Desirableproperties of PCMs [5].

3-1- THERMAL PROPERTIES

- Suitable phase-transition temperature,
- High latent heat of transition,
- Good heat transfer.

For selecting a PCM in a particular application, the operating temperature of the heating or coolings hould be matched to the transition temperature of the PCM. The latent heat should be as high as possible, especially on a volumetric basis, to minimize the physical size of the heat store. High thermal conductivity would assist the charging and discharge of the energy storage.

3-2- PHYSİCAL PROPERTIES

- Favorable phase equilibrium,
- High density,
- Small volume change,
- Low vapor pressure.

Phase stability during freezing and melting would helpful for setting heat storage and high density is desirable to allow a smaller size of the storage container. Small volume changes on phase transformation and small vapor pressure at an operating temperature suitable to reduce the containment problem.

3-3- KINETIC PROPERTIES

- No super cooling,
- Sufficient crystallization rate,

Super cooling has been a trouble some aspect of PCM development, particularly for salt hydrates. Super cooling for more than a few degrees will interfere with proper heat extraction from the store, and super cooling can prevent it entirely.

3-4- CHEMICAL PROPERTIES

- Long-term chemical stability,
- Compatibility with materials of construction,
- No toxicity,
- No fire hazard.

PCM can suffer from degradation by loss of water of hydration, chemical decomposition or incompatibility with materials of construction. PCMs should be non-toxic, non-flammable and non-explosive for safety.

3-5- ECONOMIC PROPERTIES

- Abundant,
- Available,
- Costeffective.

Low cost and large-scale availability of the phase change materials is also very important.

4- CLASSIFICATION OF PCMS

PCMs are categorized as Organic, Inorganic and Eutectic materials.

4-1- ORGANIC PCMS

Organic PCMs are carbon-based compounds. These are generally classified as paraffin and non-paraffin. The latent heat of fusion of the PCM increases with an increase in molecular weight or number of carbon atoms. The advantages of organic PCMs are its chemical stability and high latent heat of fusion, but the main disadvantage is its low thermal conductivity.

- **PARAFFINS**

Paraffin consists of a mixture of n-alkanes CH3-(CH2)-CH3 into which the crystallization of the (CH3)- chain is responsible for a large amount of energy absorption. The latent heat of fusion of paraffin varies from nearly 1 g to g between C to C which makes them suitable for building and solar applications. Paraffin is safe, reliable, predictable, less expensive and non-corrosive. They are chemically inert and stable below 500 °C, show little volume changes on melting and have low vapor pressure in the melt form. Fort hese properties of the paraffin, system-using paraffin usually have a very long freeze–meltcycle. The melting point of alkane increases with the increasing number of carbon atoms [11].

- **NON PARAFFINS**

Non-paraffin organic materials are the most common of the PCMs and they involved varying properties. Buddhi and Swaney [10] have conducted an extensive survey of esters, fatty-acids, alcohols and glycols suitable for energy storage. These materials generally have a high heat of fusion but low thermal conductivity, inflammability, toxicity, and instability at high temperatures. Although fattyacids are some what better than other non paraffin organics, they are even more expensive than paraffin [9].

These materials are flammable and should not be exposed to excessively high temperatures, flames or oxidizing agents. Fewnon-paraffin’s are tabulated in Table 3.

Fattyacids have high heat of fusion values comparable to that of paraffins. Fattyacids also show reproducible melting and freezing behavior and freeze with no super cooling [12, 13]. The general formula describing all the fattyacids is given by CH3(CH2)2n.COOH and hence, qualify as good PCMs. Their major drawback, however, is their cost, which is 2–2.5 times greater than that of technical grade paraffins. They are also mild corrosive.

4-2- INORGANIC PCMS

Inorganic PCMs are generally classified as salt hydrate and metallics. The main advantages of inorganic PCMs are its low cost and good thermal conductivity, but it is corrosive in nature with the construction materials.

- **SALT HYDRATE**

Salt hydrates were investigated because of their low cost which is determinant in most projects. Moreover, inorganic PCMs permit high density storage because they have high volumetric latent heat storage capacity and their conductivity may be twice as high as that of organic materials. Salt hydrates may be regarded as alloys of inorganic salts and water forming a typical crystalline solid of general formula AB.nH2O. The solid–liquid transformation of salt hydrates is actually dehydration of hydration of the salt, although this process resembles melting or freezing thermo dynamically. A salt hydrates usually melt to eithert o a salt hydrate with fewer moles of water, i.e.

Most salt hydrates also have poor nucleating properties resulting in super cooling of the liquid before crystallization beings. One solution to this problem is to add a nucleatingagent, in which provides then ucleation which crystal formation is initiated. Another possibility is toretain some crystals, in a small cold region, to serve as nuclei.

Salt hydrates are the most important group of PCMs, which have been extensively studied for their use in latent heat thermal energy storage systems. The most attractive properties of salt hydratesare: (i) high latent heat of fusion per unit volume, (ii) relatively high thermal conductivity (almost double of the paraffin’s), and (iii) small volume changes on melting. They are not very corrosive, compatible with plastics and only slightly toxic. Many salt hydrates are sufficiently inexpensive for use in storage [14].

- **METALLIC**

Metallic PCMs are low melting point metals such as Galiumand metal eutectics. These have not yet been investigated thoroughly because of their weight. However, when the volume is a major issue, they could be considered as they have high latent heat of fusion and very high conductivities compared too ther PCMs. A major difference between the metallics and other PCMs is their high thermal conductivity.

4-3- EUTECTIC

Eutectic PCM is a mixture of two or more PCMs in order to achieve a desirable melting point. The melting point of the PCM is one of the major criteria for selecting PCM for different climate and storage applications [15]. The eutectic PCM can be further divided into eutectic PCMs for low temperature cooling systems and eutectic PCMs for high temperature cooling systems. Also, it can be categorized as organic eutectic PCMs and inorganic eutectic PCMs [16]. Eutectics are generally better than straight inorganic PCMs with respect to segregation [9].

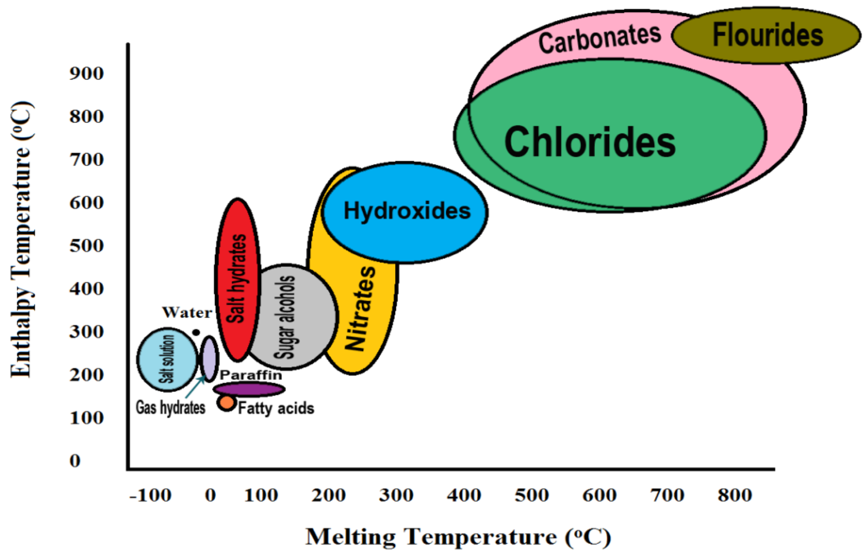

Figure 3. The typical range of melting temperature and enthalpy of PCMs [40]

5- PCM INTEGRATION METHODS

Incorporating PCMs into light weight indoor surfaces (walls, ceiling sor floors) is an effective way of increasing their effective thermal capacity. Another means of application is incorporating a PCM in the building's thermal envelope (external walls/roof, windows/shutters, ventilation system), such that the PCM can more easily discharge heat at night to the environment. In all cases, the integration method should be carefully assessed. The three most widely used techniques of integrating PCMs into building elements are immersion, directin corporation and, encapsulation [17, 18, 19-20].

- Immersion involves immersing the building material into melted PCM; the material absorbs the PCM by capillary action.
- In the case of direct incorporation, the PCM is added directly into the construction material during the production process, such as mixing PCM powder with gypsum powder during the manufacturing of the gypsum board.
- Encapsulation comes in two forms, micro encapsulation and macro encapsulation; in micro encapsulation, particles or droplets of PCM are surrounded or coated with a continuous film of polymericmaterialtoproducecapsules, while in macro encapsulation, the PCM is contained in larger containers (bags, tubes) before integration into the building.

6- MAJOR APPLICATIONS OF PCMS IN BUILDINGS

6-1- PASSIVE STORAGE SYSTEMS

The application of PCMs in building can have two different goals. First, using natural heat that is solar energy for heating or night cold for cooling. Second, using man made heat or cold sources. In any case, the storage of heat or cold is necessary to match availability and demand with respect to time and also with respect to power. Basically, three different ways to use PCMs for heating and cooling of buildings are:

- PCMs in building walls;
- PCMs in other building components other than walls;
- PCMs in heat and cold storage units

PCM TROMBE WALL

Traditionally Trombe walls relay on sensible heat storage, but because of the potential for greater heat storage per unit mass, the PCM Trombe wall is an attractive concept still awaiting successful implementation. A wall filled with PCM is constructed on the south-side window of a house. The wall is heated during the day by incoming solar radiation, melting the PCM. At night the heat is withdrawn to warm the house. For a given amount of heat storage, the phase change units require less space than water walls or mass Trombe wall sand are much lighter in weight [10] [22].

PCM WALL BOARDS

The wall boards are cheap and widely used in a variety of applications, making them very suitable for PCM encapsulation [42].

PCM SHUTTER

In this concept, shutter-containing PCM is placed outside of window areas. During day time they are opened to the outside the exterior side is exposed to solar radiation, heat is absorbed and PCM melts. At night we close the shutter, slide the windows and heat from the PCM radiates into the rooms [10] [22].

PCM BUILDING BLOCKS

Building blocks or other building materials impregnated with a PCM are used in constructing a building, resulting in a structure with large thermal inertia without the large mass associated with it [41].

AIR-BASED HEATING SYSTEM

Morrison and Abdel Khalik [43] and Jurinak and Abdel Khalik [44] studied the performance of air-based solar heating systems using phase change energy storage units. The main objectives of their work were: 1. To determine the effect of the latent heat and melting temperature of phase change material on theair-based solar heating system and 2. To develop an empirical model of significant phase change energy storage units.

FLOOR HEATING

Floor is also an important part of a building and heating and cooling of buildings were tried using it.

6-2- ACTIVE STORAGE SYSTEMS

FLOOR HEATING

Mostly active floor system can be used for off peak storage of thermal energy in buildings. Thus, peak loads may be reduced and shifted to night time when electricity costs are lower [45].

CEILING BOARDS

Ceiling boards are an important part of the roof, which are utilized for heating and cooling in buildings.

7- REVIEW ON DİFFERENT PROPERTIES OF PCMS

Cost, space, weight, and the design of the system all play a major role when it comes to select the appropriate material. In general, a system analysis is required to determine which material will be used according to the specific application.

PCMs that are commercially available in the market can also be used for different climates and thermal energy storage applications and have different chemical properties.

	PCM	Type	Melting Point	Latent heat of fusion	PCM Type	PCM application	Climate/Region	Results	Reference
Organic	paraffinic-PCM	Paraffin	29 °C	170 kJ/kg	microencapsulated	attic roof	Temperate climate (East Tennessee)	reduce peak-hour loads by 25–44 % when compared to non-PCM systems	38
	BASF-micronal PCM	Paraffin wax	23 °C		microencapsulated	gypsum wallboard	Mediterranean (Greece)	decrease of the decrement factor by a further 30–40% and an increase on the time lag of approximately 100 min	29
	Paraffin RT20	Paraffin	36.7 °C	246 kJ/kg	encapsulated	Free cooling and air-conditioning		free cooling technique reduces the size of the mechanical ventilation system	39
	BASF-micronal PCM	Paraffin wax	21-26 °C		immersion	Paints or adhesives			33
	Octadecane (CH3(CH2)16CH3)	Paraffin	25.6 °C		immersion	Wallboard	Hot and dry (Dayton)	cooling load savings were close to 16 %.	31
	Octadecane (CH3(CH2)16CH3)	Paraffin	25.6 °C		encapsulated	Ceiling Systems	Cold and dry (Colorado)	the annual heating cost can be reduced by an average of 24 %.	32
	n-hexadecane, n-heptadecane, and n-octadecane	Paraffin	19-24 °C	228-244 kJ/kg	immersion	Gypsum Board and Interior Plaster Products		reduce interior space temperature swings and absorb solar gains coming through 2.4 Impregnated Concrete Blocks and Ceramic Masonry 29	32-33
	n-octadecane	Paraffin	24 °C	143 kJ/kg	immersion	wallboard.			33
	dodecanol (C12H26O)	fatty alcohol	24 °C		immersion	Concrete Blocks			35
	Methyl palmitate(C17H34O2) - Methyl stearate(C19H38O2)	non parafin	30.5 °C/39 °C	205 kJ/kg	immersion	gypsum wallboard	Humid subtropical (Florida)		27-33
	Butyl stearate (C22H44O2)	non parafin	16–20.8 °C		immersion	gypsum wallboard	oceanic climate (Canada)		28
	Butyl stearate (C22H44O2)	non parafin	16–20.8 °C		immersion	Concrete Blocks			35
	tetradecanol (C14H30O)	fatty alcohol	38 °C		immersion	Concrete Blocks			35
In organic	Calcium chloride hexahydrate (CaCl2H12O6)	Salt Hydrate	29 °C	140 kJ/kga	encapsulation	PCM wall	Cold and mild	an 8.1 cm PCM wall has slightly better thermal performance than a 40-cm thick masonry wall.	21-38
	Lauric acid (C12H24O2)	Fatty acid	49 °C	170 kJ/kg	microencapsulated	Window shutters	Tropical wet and dry (India)	the heat storing capacity of the cell due to the presence of PCM increases up to 4 °C for 4–5 h	22
	sodium sulfate decahydrate (Na2SO4.10H2O)	Salt Hydrate	32 °C		microencapsulated	Trombe wall	Cpld climate		23-24-25
	Stearic acid (CH3(CH2)16 COOH)	Fatty acid	69 °C	199 kJ/kg	microencapsulated	windows/walls	Tropical wet and dry (India)	transmittance of the phase change material was more than the glass for the same thickness	26
	polyethylene glycol PEG600 (H(OC2H2)n OH)	Fatty acid	20–25°C	146 kJ/kg	vacuum impregnation	Composite PCM		low temperature-thermal energy storage Energy a	30
	Calcium chloride hexahydrate (CaCl2.6H2O)	Salt Hydrate	30 °C		encapsulation	Inner Sun shading	Hot and Dry		36
	Calcium chloride hexahydrate (CaCl2.6H2O)	Salt Hydrate	30 °C		encapsulation	Trombe wall			37-38

Table-1 Review on different properties of Organic PCMs

8- CONCLUSION

This article encompassed the PCMs thermo-physical properties, their encapsulation, and characterization techniq ues to gether with domestic and commercial applications. It is established that PCMs as TESS at various temperature ranges are non corrosive. They exhibit reproducible melting, and freezing characteristics even after a large number of thermalcycles.

For building applications, PCMs must meet thermal comfort criteria in terms of phase change temperature (between 8 and 30 oC). In addition, PCMs selections for construction management must consider properties such as chemical stability, fire characteristics, and compatibility. The use of LHS with PCMs in the walls, ceilings, and floors displayed a significant impact on reducing the temperature fluctuation by storing solar energy during the sunlight hours for passive solar heating. It is also efficient for off-peak thermal storage, ventilation, and cooling.

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