A REVIEW ON PHASE CHANGE MATERIALS IN BUILDING CONSTRUCTION

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Abstract

This paper focuses on the collection and analysis of information from previous studies on phase change materials and their applications in structural engineering. Use of latent heat storage by phase change. Increasing energy demands for building temperature control, deplete natural resources. It is therefore an eco-friendly approach to temperature regulation at minimal cost. A class of phase change materials with high energy storage densities at low temperature swings suitable for a variety of applications. Various applications of applicable phase change material building components are also discussed in this white paper.

Keywords-Phase change material, Latent heat storage system, Solar energy.

Introduction

As demand of thermal comfort of buildings shows a rising trend, the corresponding consumption of energy is increasing. For example, France has seen the rise of 30% in energy consumption in past 30 years. About 46% of all energy demand and 19% of carbon emission are attributed by the housing and tertiary buildings. Mahdaoui M et.al [2] The thermal behavior of a brick-wall impregnating a PCM was modeled and simulated.

Thermal comfort today in buildings are majorly coped and dependent on external cooling and heating devices like AC, blower, HVAC systems etc. The energy efficiency of the buildings under a huge load due to the excessive use of such systems. Mahdaoui M et.al [2] A parametric study was conducted to improve the brick behavior and optimize PCM mass.[5]Phase Change material (PCM), n floor tiles for thermal energy storage.

Recently, the use of thermal energy storage systems aims to limit dependence on noin-renewable energy sources and contribute to more efficient and environmentally friendly use of energy.[5] In recent years, the construction industry has Awareness of sustainability in the world is growing and several initiatives are being developed. Recently, the potential applications of phase change materials (PCM) have attracted attention.

There is a strong demand for passive cooling technologies being created in the building industry to limit this exposure as well as reduce carbon emissions to the environment.

Heat is stored either by sensible heat storage or latent heat storage. Sensitive energy storage devices have been used for centuries, but they require a much larger volume to store the same amount of energy compared to latent heat storage devices. The principle behind the use of phase change material (PCM) is simple. As the temperature rises, the solid PCM absorbs potential melt and transforms into a liquid. This reaction is endoergic in nature. Similarly, when the temperature drops, the material undergoes a phase change from liquid to solid releasing the same amount of heat (latent heat of fusion). The reaction is naturally exothermic. Incorporating PCM into the walls of buildings is one way to complement the storage capacity of the building envelope, thereby justifying the use of renewable and non-renewable energies.[2] PCM into stone Incorporation improves the stability of the internal surface temperature.

Physical Consideration

A high energy efficiency building must have an energy efficient envelop that can ensure comfort of occupants with a minimum system energy requirement. From this we can say that the thermal energy storage in the envelop is a key factor. Inside a building room, the heat transfer processes between the surface of the wall are convective heat transfer between the air and the surface. The effect

of thermal energy storage in the building envelop is to reduce the indoor temperature fluctuations and to delay the air temperature extremum.
V A Lebedev et.al [4] The selection of phase change heat storage materials:

1.The main principles that control the choice of phase change materials are [4]
2.Having a melting temperature in the required working temperature range.
3.Having a high latent heat of fusion per unit mass in order to minimize the required amount of material. 4.High specific heat to increase the effect of sensible heat storage.
5.High thermal conductivity to reduce the time of charging and discharging.
6.The volumetric expansion and shrinking coefficients are required to be small through the phase transition.
7.Having a little or no subcooling during solidification.

Problems in phase change material,

V A Lebedevet.al [4]
The main problem associated with the PCMs is the number of cycles they can withstand without decreasing any of their properties. PCM must be ensure that it will be able to undergo repetitive cycles. Thermal cycling tests are carried out to ensure that the materials under test do not deviate from their PCM properties after long usage.
PCM has to be qualified to undergo many thermal cycles. Some materials exhibit changes within a relatively short time
It is significant to study the influence of thermal cycling on the melting temperature, latent heat of fusion due to their effect on the performance of the thermal energy storage system.
Organic material, the range of change in melting point temperature for stearic acid, acetamide, and paraffin wax are 1, 2, and -3 ºC respectively after 1500 thermal cycles. The change in the latent heat of fusion is -20.6%, -1.14%, and -26%, respectively. It is observed that acetamide and paraffin wax have good stability and they can be considered as promising PCMs.
Sari et al. [20]It is found that the range of change in melting point temperature for myristic, palmitic, and stearic acids with glycerol is -0.74ºC, -1.05ºC, and -0.38 ºC, respectively, after 1000 thermal cycles. It is observed that the range of change in latent heat of fusion is -1.6%, -5.4%, and 2.2% respectively
After 1000 thermal cycles, the melting point and latent heat of calcium chloride hexahydrate (CaCl2. 6H2O) did not change, according to Inorganic Material by V A Lebedev et al. [4]. In context of this, calcium chloride hexahydrate is regarded as a promising PCM for the heating and cooling processes in building applications.After one thermal cycle, it was discovered that the melting points of sodium hydroxide, di-sodium borate, and ferric nitrate varied by 2 oC, 4 oC, and -8 oC, respectively.
Ferric nitrate, barium hydroxide, sodium hydroxide, and di-sodium borate are not suitable as latent heat storage materials.

Advantages of PCM on environment

- Apart from traditional methods such as the use of polystyrene in cavity walls, eco-friendly materials are used.
- Decrease in carbon emissions.
- Can be helpful in both summers and winters to maintain thermal comfort.

Applications of PCM in building components

Bajenaru N et al. [1] built a net zero emission building in Maryland, USA. It's a great example of a zero-emission building, with the pcm used for temperature control and solar panels installed. They also used recycled building materials. Solar heat gains can enter the space thanks to the glazing system. SHGC0,25, U3,3 W/m2K, and a minimum daylight factor of 2 were all chosen to be ECBC compliant. The Solar Heat Gain Coefficient (SHGC) was recalculated with the external shading devices and a 30 cm retreatment of the windows from the facades plan in mind. External windows in the office have a wooden frame with a U value of 2,104 W/m2K, while those in the atrium have an aluminium frame with a thermal break and a U value of 1,801 W/m2K.
The structure was designed to meet the Energy Conservation Building Code (ECBC).
The window-to-wall ratio (WWR) was set at 40%, with variations depending on orientation: 50% on the North side to take advantage of natural light, 35% on the South and East, and only 30% on the West, where solar radiation is most strong.

While the eastern and western windows are covered by louvres, the southern windows are shaded by overhangs. Internal roller shades for glare reduction are installed in every window.

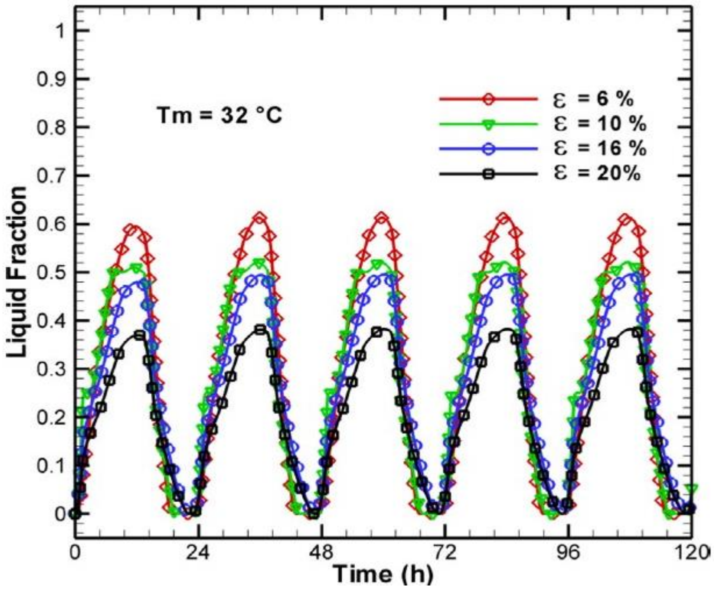
Baetens.R et.al [5] Phase change material used in the building walls ,alters the temperature profile within the walls. In summer we use the phase change material within the wall, it absorbs large amount of energy and material gets melt and provide cooling while in winter it emits same amount of energy and gets solidify and provide warming. Finally economic benefits can exceed energy savings within the wall.[5] Phase change material also used in floor tiles in the form of paraffin wax and salt hydrates. This material used the latent heat which released when the material changes liquid to a solid state. Some phase change material has a phase transition from solid-to-solid form. That type of phase change material is known as solid-state phase change materials. They have large latent heats, which makes them ideal for passive solar applications. In this they have made a prototype tile will be made from a mixture of quartz, binder and phase change materials. It is fact that with the addition of phase change material the structural properties will be compromised to some extent.

Phase Change Material [5] also used in concrete in building components. Phase change materials can store and release energy at specified temperature ranges. The most of the work done on the incorporation of PCM into building components is common in plasters. The concrete have a higher thermal energy compared to other building materials, it enables the concrete to have high energy saving advantage compared to other building materials.

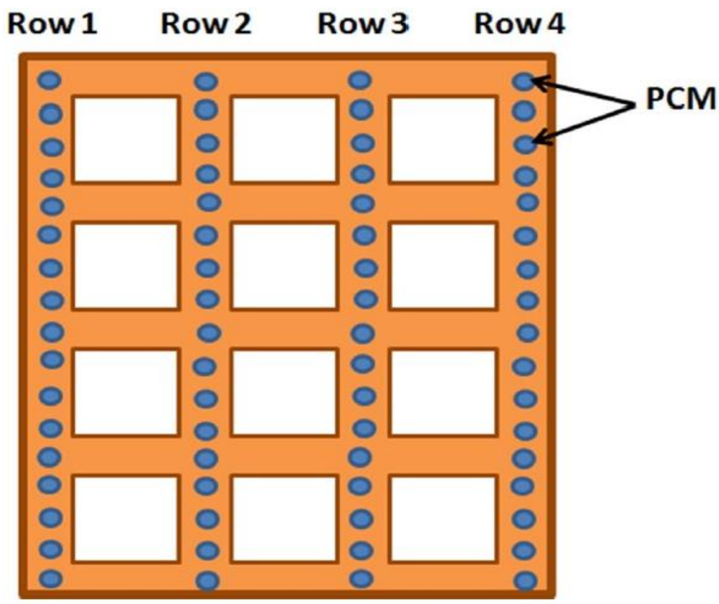
Mahdaoui.M et.al [2] Thermal Building bricks with phase change material (PCM),

the thermal behavior of the hollow brick (12 alveoli) impregnated by a PCM was numerically investigated. These building elements were widely used in building construction in regions such as Mediterranean, which presents a poor thermal behavior in hot areas, thus the objective of the present work is the enhancement of the storage capacity and insulation resistance of this latter through its integration by a phase change material. Infuse PCMs in porous materials such as gypsum, plaster, and mortar boards are the widespread way for Latent Heat Thermal Energy Storage in building elements. The studied clay brick is of twelve air cavities surrounded by cylindrical

PCM capsules are equidistant in four-millimeter diameter (Dpcm = 4-mm). A hollow brick sized (30cm*20cm*15 cm) is calculated with a 2D model and the brick with 16% PCM mass shows the best performance among the examined PCM portions. The molten fraction of the PCM integrated into the hollow brick is presented shows liquid fraction versus time for the four PCM portions 6%, 10%, 16%, and 20%.



Liquid Fraction versus time for different PCM Mass



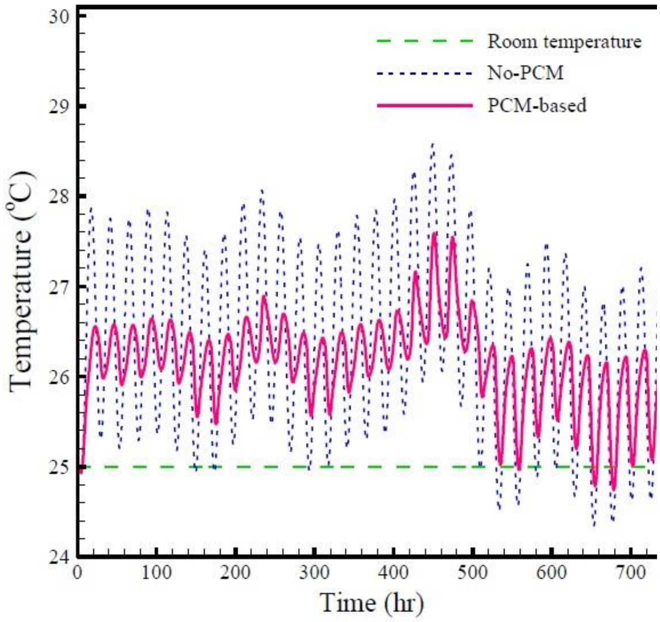
Brick with vertical PCM rows.

Z.X. Li et. al [3] It has researched reduction of the Heat transfer in buildings by embedding phase change material in multi-layer walls included layers of cement, clay brick, and plaster with thicknesses of 3 cm, 15 cm, and 2 cm, respectively.

Hence, the overall thickness of the wall, without taking the PCM into account, were 20 cm with a height of 1 m. In order to assess the PCM performance, layers of which with thicknesses of 1 cm, 2 cm, and 4 cm were added to the base wall.

Effect of the presence of PCM in the wall: -

As a mentioned earlier, PCMs of multiple thicknesses were added to the wall. but the effect of installing PCM of type RT-27 with a thickness of 1 cm is investigated. The temperature of the interior surface for the wall with and without PCM is demonstrated in Figure below.



Temperature distribution on the interior surface of the wall equipped with PCM (thickness=1 cm, RT-27) compared to that of the wall with no PCM.

The heat flux transferring the room decreases by increasing thickness, since heat flux is a function of temperature. The total amount of heat transfer to the room was calculated and presented in Table below for three different thicknesses.

Total amount of heat transfer to the room for three different thicknesses [RT-27].

PCM Thickness (RT-27)	Heat transfer to the room [kJ]		Reduction percentage
	PCM-based wall	No PCM wall (conventional wall)	
1 cm	27,250	30,987	12.06
2 cm	23,937	30,987	22.75
4 cm	19,016	30,987	38.63

room by 12.06%. This reduction can be further improved by increasing the thickness.

The amount of heat transfer to the room decreases by increasing the PCM thickness.
By installing a PCM near to the exterior, a larger portion of it melts, allowing it to offer a better performance in reducing the heat transfer to the room. The sum of energy stored in the wall is increased by increasing the percentage of PCM in the wall. However, the amount of stored energy is not directly related to the PCM percentage. In other words, although it can be concluded that increasing the PCM thickness always leads to reduction of heat transfer through the wall, this reduction has a decreasing trend as PCM thickness increases. The double increase in the thickness of the PCM leads to less than a doubled reduction in the heat transfer.

Method of PCMs incorporation into concrete,[6]

There are 3 main ways to incorporate PCMs into concrete, and it can be classified into direct, impregnation, and immersion method. Marani A et.al [6]

Direct Method - Powdered or granular PCMs can be applied directly when mixing concrete's components (i.e., cement, water and aggregates). However, before the PCMs are added to the concrete mixture; they must first be enclosed in a capsule. This method is known as the direct method.
We have two types of encapsulations - Micro capsulation and macro capsulation.
Microencapsulation involves containment of PCMs

in small capsules whereas in macro capsulation containment of PCMs is in packets like panels, pouches, or tubes.

Microencapsulation is more effective than microencapsulation because it allows the PCMs to be incorporated easily and in a cheap way into construction materials.

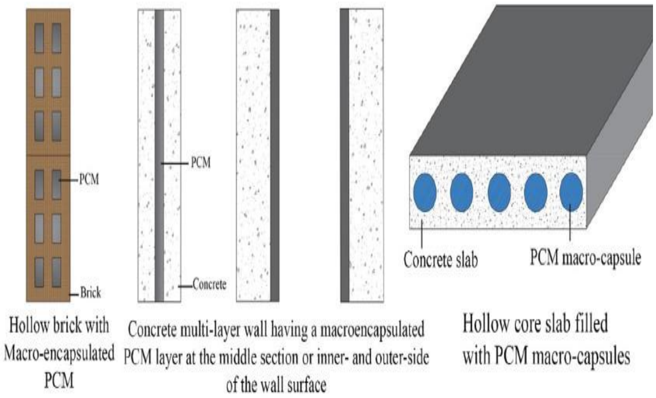


Fig. Schematic cross-section of PCM macro-encapsulated wall and floor configurations.

Impregnation Method- In this method PCM can also be incorporated into concrete using impregnation technique which can be carried out by first drying the aggregate at a specific temperature, to remove the moisture in the porous aggregate. Then the aggregates were soaked in the desired melted solution of PCM for a minimum of 24 hours to allow the pores of the aggregates to be saturated with the PCM.

Immersion Method- Immersion method entails soaking of porous concrete products in molten PCM in a similar way as impregnation method.

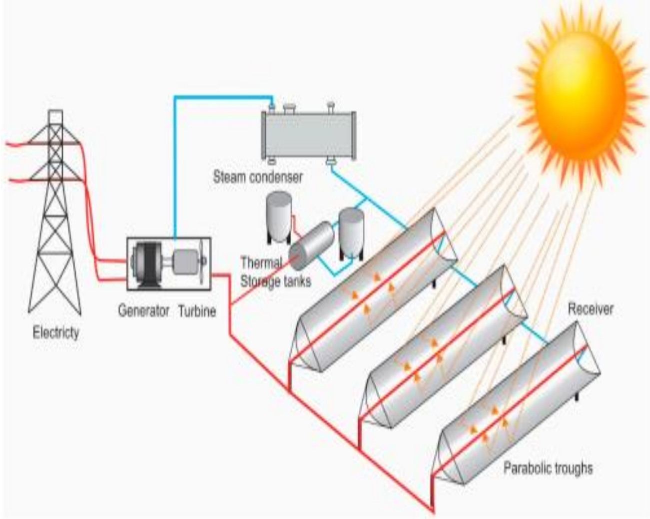
Phase change materials for solar energy usage and storage, Mofijur.M et.al [7]

The effective use of solar energy requires a storage medium that can facilitate the storage of excess energy, and then supply this stored energy when it is needed. This method of storing thermal energy from soar is through the use of PCMs.Solar energy is a renewable energy source that can be utilized for different applications in today's world. The effective and efficient use of solar energy requires a storage medium that can facilitate the storage of excess energy, and then supply this stored energy when it is needed. Worldwide, primary energy consumption increased by 1.5% in 2018 compared to consumption levels in 2017.Thermal energy storage may be able to assist during electric utility grid stress. To store energy, we uses the systems such as batteries or PCMs can be used. The different forms of energy storage are presented in Figure.

Classification of energy storage systems:

PCMs Solar Power Generation [7]

For household use [7], solar energy is currently the most popular source of renewable power generation in terms of annual investment and offering benefits. More recent designs for SEGS have used expensive synthetic oil as storage media and achieved an increase in working temperatures, from the former 300 ◦C up to 400 ◦C



Alqaed.S et.al [9] Using phase change material (PCM) to improve the solar energy capacity of glass. PCM helps to improve energy storage performance is to use advanced materials and elements in building coatings. Those Dense exterior walls were made with high thermal insulation properties and absorbent with heat-retaining elements can be made by intelligently combining products to store latent heat based on PCMs. In that study, the thermal behavior of glass in the presence of PCM (Decane) has been investigated by molecular dynamics simulation. As we know that, the use of phase-change materials can prevent energy loss, reduce energy costs, and while changing the phase of materials, quickly has a positive effect on the energy efficiency of the building.

Rathore.S.K. P et.al[8]The optimal PCM thickness value is Recent research has concentrated on the use of different substances in glazing windows in order to decrease heat transmission through building apertures. In that work, the thermal performance of a double-glazed window unit

combined with the phase change material (PCM) was examined experimentally and compared to that of a normal double-glazed window. That technical grade paraffin was used as a PCM in a 12 mm gap between double-glazing unit and the investigation was conducted for a whole representative day. The indoor thermal atmosphere, inner glass temperature, energy consumption through glazed window were assessed along with the transmittance of the glass containing PCM. Supported that the transmittance was good enough during the day time to allow sufficient light inside the room to enter. Further,
the PCM curtailed the temperature fluctuation, inner glass temperature and energy consumption through the window significantly.
Additionally, the PCM considerably reduced temperature variations, interior glass temperatures, and energy consumption through the window.

Conclusion

The application of PCM in global construction is the main topic of this paper. The varied ways that PCM is applied in various climates, as well as the thermal-physical characteristics that make it acceptable for use in construction, are discussed. The following fresh discoveries can be made in light of the main aspects:

1. The comfort of zero energy building is more as compared to the conventional building due to the favorable inside ambience. All the equipment and the natural ventilation are controlled by the operative temperature and all the simulations were performed with 10-time steps per hour. It has a rotary heat exchanger with an efficiency of 65% that operates in a free cooling mode between 20°C and 26°C.
2. The thermal behavior of a hollow brick (12 alveoli) impregnated with a PCM was numerically investigated, and the goal of this work is to improve the storage capacity and insulation resistance of this latter by incorporating a phase change material.
3. The effect of incorporating PCMs into conventional building walls in Isfahan, Iran, was numerically investigated in this study. By installing a PCM closer to the exterior, a larger portion of it melts, allowing it to perform better in terms of heat transfer reduction. The amount of energy stored is not proportional to the PCM percentage. In other words, increasing the PCM thickness always results in a reduction in heat transfer through the wall, with a decreasing trend as PCM thickness increases. A twofold increase in PCM thickness results in a less than twofold reduction in heat transfer.
4. The thermo physical properties, such as melting point temperature, latent heat of fusion, specific heat, and thermal conductivity, are used to select a latent heat storage material. The primary issue with PCMs is the number of cycles they can withstand without losing any of their properties. PCM must be designed so that it can go through repetitive cycles.
5. The risk of PCM leakage is a fundamental problem with adverse effects on the mechanical, thermal and durability properties of PCM integrated construction composites. Hence, the researchers have proposed various techniques to eliminate such harmful outcomes of PCM-integrated materials. In the present critical review, such methods have been categorized into four main groups, namely microencapsulation, shape-stabilized phase change materials (SSPCMs), porous aggregate inclusions, and microencapsulation. The advantages and disadvantages along with the supporting materials for the production and depiction of such composite materials are reviewed and critically talk about.
6. The principle behind phase change materials is favorable. Excess energy at raised temperatures is stored and given back at a definite temperature, resulting in an increased thermal mass in a narrow temperature range. Relatively high energy (potential energy) savings have been reported in writings, but current properties of the available phase change materials do not yet seem optimal for wide-spread building applications. Hardly any materials are known with a transition around comfort temperature, and those existing do have a relatively low heat of fusion.
7. PCMs can play a significant role in storing higher amounts of energy, which is linked with the latent heat of the phase change. Also, PCMs support a target oriented settling temperature by the fixed temperature of the phase change. The

energy storage capacity of PCMs in the heat recovery of solar power plants is affected by several factors. Two forms of heat transfer, heat conduction and convection occur during the phase change process inside the PCM. Improved heat transfer techniques can increase heat conduction and overpower heat convection. To ensure better and more cost-effective PCM performance in energy storage applications, it is recommended that the available information be consolidated to provide better facilities to end-users.

8. By simulating a room with a solar aerator, the effect of using PCM on the wall instead of the concrete wall has been studied.The number of air conditionings in the room for the above two walls during the day and night has been checked.
9. Enhancing the thermal energy storage capacity of the building envelope by incorporating PCM is one of the sustainable methods of regulating indoor temperature.
   A series of research results can have important and directive significance for the practical application of PCM in building.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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