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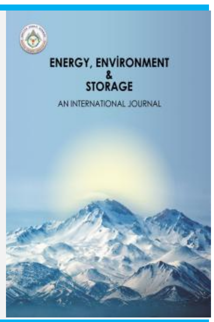

Phase Change Materials for Energy Efficiency in Building Components – Overview

Rachit Agarwal[1], Pradeep Rawat[1], Devendra Rai[2],Humaira Athar[1], Srinivasarao Naik B[1*]

[1]IBM Group, CSIR-Central Building Research Institute, Roorkee

[2]Department of Chemical Engineering, Indian Institute of Technology Roorkee

ABSTRACT: Energy demand in the building particularly insummer during peak hours due to outdoor climate and lack of sufficient high thermal mass construction materials. Advanced materials are required to reduce the recurring energy demand of buildings. This peak hour energy demand can be significantly reduced by using phase change materials (PCM). These PCMs are being incorporated into building components/ products in various ways. In this overview, the recent advances in the field of using different types of PCMs, parameters to be consider for building components, encapsulation of PCMs and influence of PCMs on thermal and mechanical properties of construction materials are briefly discussed. Importantly, behaviour of MPCM in building components is concisely elaborated in effective way.

Keywords: Energy demand, Phase change material, Thermal mass, Encapsulated phase change material
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1. INTRODUCTION

In India currently energy consumption in residential and commercial building accounts for 30% of total energy use and this consumption in raising 8% annually. Energy consumption in buildings is dependent on outdoor climate, building construction materials, naturally ventilated or air-conditioned, occupancy hours, thermal comfort expectations of occupants, office equipment and home appliances [1].Energy demand in the buildings can be accomplished either by using sensible heat or latent heat materials.Sensible heat materials have been used for centuries by builders to store/ release passively thermal energy, but larger volume of material is required in comparison of latent heati.e. phase change materials (PCMs) [2]. PCMs are commercially available in the market from -3 °C to 850 °C [3]. Day time, when the temperature above the melting point,the PCM absorbs heat during the material changes phase from solid to liquid. Atnight, when the temperature below the melting point,the PCM desorbs heat to ambient, during the material changes phase from liquid to solid. The PCMs are being successfully used as energy storage devices in heat pumps, solar engineering, space craft etc. The use of PCMs into the buildings is the incorporation of PCMs into the building components as these PCMs undergo phase transformation process and therefore, suffer from the problems of leakages.Most of the researchers have been working in the direction of micro/nano-PCM capsules to overcome these difficulties[4].Particularly in building, these PCMs are integrating in walls, mortar, concrete and paints for delay the heat transfer, peak load shifting, reduction of temperature fluctuation and enhancement of thermal properties of cementitious materials. In this report, information provided aboutPCMs which were used in the buildings by possible ways.

The importance of this study is highlighted for a better understanding of how phase change materials affect cementitious materials, as well as the mechanisms that cause mechanical qualities to be reduced and thermal properties to be increased. In addition, what factors need to be taken into account and offered should be evaluated before incorporating into any system.

2.HOW TO SELECT THE PCMS?

Before incorporating into buildings or thermal energy storage systems, PCMs should be select based on thermal, physical, kinetic and chemical properties

2.1 Thermal point of view:

PCM Thermal conductivity should be either high or low,which is depends on applications (buildings/thermal energy storage systems), thermal stability, and a high heat of fusion (H.F kJ/kg) of PCM should be high.

2.2 Physical point of view:

High energy density during phase transition and small volume change.

2.3 Kinetic Point of view:

No super cooling during PCM changes from liquid to solid.

Corresponding author: srinivas@cbri.res.in

2.4 Chemical point of view:
Along-term chemical stability of PCM (functional contained in PCMs should not be react with other materials), non-toxicity and no fire hazard.
2.5 Economic Point of view: Cost effective and PCM should be easily available.
3. TYPES OF PCMS
Phase change materials are divided into three categories (i) Organic (ii) Inorganic (iii) Eutectic mixture
3.1 Organic PCMs
The organic phase change compounds are chemically stable, no super cooling, non-corrosiveand nontoxic.Organic PCMs are subdivided in two groups (i) Paraffins (ii) Non paraffins. Paraffins are chemically inert,have low thermal conductivity and large volume change. The non-paraffins such as fatty acids have high heat of fusion than paraffins and have small volume change.
3.2 Inorganic PCMs
Inorganic PCMs have high heat of fusion,good thermal conductivity, are cheap and nonflammable.Most of them are corrosive to metals. Most inorganic PCMs are hydrated salt. Hydrated salts have a high energy density and high thermal conductivity.Disadvantage is that undergoes super cooling.
3.3 Eutectic Mixture
Eutectic mixture is a mixing of more than one PCM material. Eutectic mixtures have sharp melting point and energy density is slightly higher than that of organic PCMs. Eutectics are divided in three groups (i) Organic – Organic (ii) Inorganic – Inorganic (iii) Organic – Inorganic [1, 5].The desired temperature range of eutectic mixture can be designed according to Schroder's equation (1) [6]

$$\ln x_A = \frac{\Delta H_A}{R}\left(\frac{1}{T} - \frac{1}{T_f}\right) \quad (1)$$

where x_A and ΔH_A are the molar fraction and latent heat of fusion kJ/kg of compound A, respectively. T and T_f are the melting temperature °C of the mixture and compound A. R is gas factor 0.8314 kJ/ K. mol.

3.4 Commercial availability of PCMs
In the market, the companies/industries such as BASF, Microtek and Rubitherm are commercializing the encapsulated PCMs (EPCMs/MPCMs) with the name of DS5001X, RT 5, and RT 25 etc. within temperature range of below ambient to above 100ºC (Table 1)[3, 7-11].

Table 1 Commercially Available MPCM companies

Company Name	**Commercial name of PCM**	**Website**
Microteck BASF, Dayton	Micronal and MPCM	Product Data Sheets - Microtek Labs[11]
RAL quality association PCM, Germany	Rubitherm GmbH	rubitherm technologies gmbh-PCM-Phase change Material (pcm-ral.org)[10]
PCM energy, UK	-------	PCM Products | Phase Energy Ltd (phase-energy.com)[12]
Climator, Sweden	ClimSel	PCM-ClimSel (climator.com)[9]
Thermofin	------	CRISTOPIA : Thermal energy storage solution - THERMOFIN[7]

4. INCORPORATION OF PHASE CHANGE MATERIALS INTO BUILDING COMPONENTS
The PCMs are incorporated in construction materials by, immersion and encapsulation methods

4.1 Immersion
In the immersion technique, the construction elements (concrete, brick blocks, and wallboards), which are dipped into the liquid PCM (at above melting point), absorbs the PCM in the pores contained in the building materials by capillary actionunder the vacuum pressure **Fig. 1**[13]. It is reported that PCM may leak [14-16] especially after subjected to many thermal cycles. Also, it may affect the mechanical and durability properties of the construction elements. These essentials points need to be considered for building components.

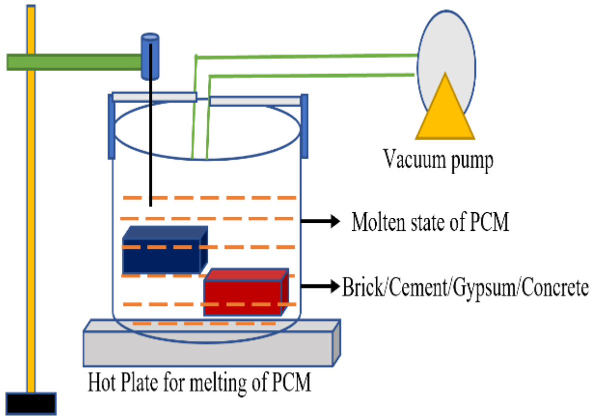

Fig.1 Immersion method

4.2. Encapsulation
In this technique, PCMs are encapsulated in either polymer shell or inorganic shell before incorporation into construction materials. PCM encapsulation should (a) meet the requirement of strength, durability, thermal stability of polymer/shell (b) it protects the PCM as a barrier, from destructive interactions with the surrounding (c) have enhance surface area for heat transfer. There are two types of encapsulation methods one is microencapsulation, and another is macro-encapsulation [3, 17, 18].
4.2.1. Microencapsulation
Encapsulation is a tiny particle where in PCM as a core material which is surrounded by polymer as a shell (Fig.2)[17]. The phase change temperatures in between ambient to 80 ^{0}C can be prepared with this technique. There are two methods of micro-encapsulation: Physical and Chemical methods [19]. Thephysical method includes Fluidized bed process and spray drying (SD) while the chemical methods include In Situ Polymerization (ISP), Complex Coacervation (CC), Phase Separation (PS) and Suspension- Polymerization (SP). Preparation methods of encapsulated techniques and PCMs by literature givenin Table2[20].Borreguero et al. (2011)[21] developed encapsulations of paraffin (RT27) with and without carbon nanofibers (CNFs) utilising the spray process and a coated shell made of polyethylene-ethylvinylcetate (LDPE-EVA). The smooth, sphere-shaped microcapsules have a particle size range of 0.1 to 5.0 m. Latent heat of fusion (LHF) and

encapsulation efficiency (EE) were 80% and 92 J/g, respectively (Fei et al., 2008) [22]. Using sophisticated coacervation, Xiao et al. (2014) [23] created microcapsules with a lavender oil core and a gelatin exterior, as well as gum. On the appearance, average particle size, yield, and EE, several values including pH value, C/S ratio, shell concentration, agitator speed, cross-linkers, and homogenization rate were studied. pH 3.5, C/S 3:2, 1% shell concentration, 450 rpm speed, and glutaraldehyde as a cross-linker were the ideal conditions for creating the microcapsules. The EF, loading capacity, and yield were each 65.8 1.0%, 66.0 0.3%, and 61.3 7.0%, respectively. Phase change material (PCM) microcapsules were created by Deveci and Basal in 2009 [24] using n-Eicosan as the core and silk fibroin (SF) and chitosan (CHI) as the shell. For the coacervation procedure used by Butstraen and Salaün (2014)[25] to encapsulate coloured oil, the following parameters were optimised: pH 3.6, weight ratio of chitosan to acacia gum combination of 0.25, C/S 0.1, and emulsion period of 15 min at 11,000 rpm. In-situ polymerization was used by Hong and Park (1999) [26]to successfully create microcapsules using aromatic Margin oil as the core material and melamine formaldehyde as the shell material. They found that the microencapsulation effectiveness was about 87% and that the particle size was below 10 µm. The capsules were created by Liang et al. (2015) [27]using n-octadecane and SiO_2, with a latent heat of silica PCM of 109.5 kJ/kg.Tris (hydroxyethyl) methyl amino methane, SiO_2, and its latent heat of about 146 kJ/kg were combined to create capsules by Wu et al. in 2015[28].

Table2. Micro-encapsulation Techniques

Method	Particle size (µm)
Spray Drying	0.1 - 5000
Coacervation	2-1200
Sol-Gel	0.2 to 20
Interfacial Polymerization	0.5 - 1000
Suspension Polymerization	2-2000
In situ-Polymerization	5-300 nm

The most used polymers are Melamine – formaldehyde (MF), Urea Formaldehyde (UF), Poly styrene (PS), Poly methyl methacrylate (PMME), Melamine-urea formaldehyde (MUF), Silica oxide (SiO_2), Titanium oxide (TiO_2) etc.

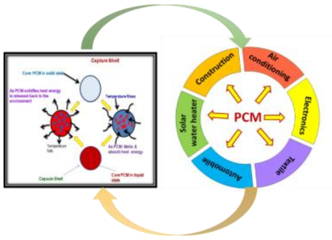

Fig.2 Behaviour of MPCM into different applications

4.2.2 Macro-encapsulation

In this technique, a significant quantity of PCM can be packed in a container such as tubes, spheres and panels for subsequent used in construction elements [29]. The macro-encapsulation is available in various configurations like flat plate, cylinder shell, tube and spherical (Fig.3)Also, it may affect the mechanical and durability properties of the construction elements. Shin et al.2015 [30], sodium acetate trihydrate containing 2.5 wt% expanded graphite had a thermal conductivity of 1.85 W m-1 K-1, which was much greater than Ffor pure samples, 0.3 W m^{-1} K^{-1}.

According to Jin et al. [31], the best place for PCM pouch systems was 1/5 L away from the internal surface of walls (where L was the wall thickness). According to Fang [32], PCM tube systems positioned at a distance of (3/16)L from the inner surface would result in significant peak reductions. The various ideal positions discovered through these investigations suggest that various factors can affect such a site. To learn more about the impact of various variables, including wall orientations, PCM system thicknesses, and PCM thermal characteristics, some researches were carried out.

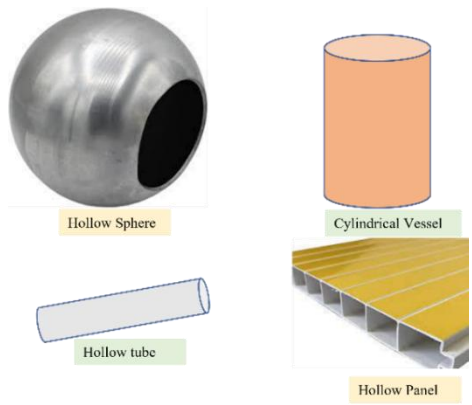

Fig 3 Macro-encapsulation materials for PCM

4.2.3Shape-stabilized PCM

In this technique, shape stabilization supports polymers such as high- density polyethylene (HDPE), Styrene and Different molecular weight of Polymers etc. The PCM and supporting material is melted and mixed with each other at high temperature and poured into ant three-dimensional mould.The supporting material is cooled to below the glass transition temperature until it becomes solid (Fig.4). The mass of the PCM can be incorporate up to 80%. These panels can be used as retrofitted to the building [29, 33, 34].

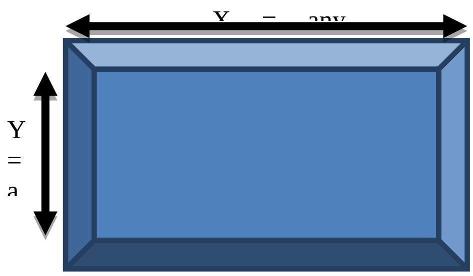

Fig 4.Shape stabilized PCM

Shape-stabilized PCM is being prepared by researchers according to their specifications (Fig.4). There are certain key dimensions that have not yet been investigated.

5. EFFECTS OF PCM ON THERMAL PROPERTIES OF BUILDING COMPONENTS

Thermal conductivity and specific heat are considering parameters for building component Micro-PCMs (melting point 23ºC and heat fusion 100 kJ/kg) were mixed into the concrete. Thermal conductivity of the concrete is reduced as the percentage of PCM increased [35]. Eutectic mixture (melting point 21 ºC and heat of fusion 126.652 kJ/kg) was incorporated into the gypsum by immersion method.Specific heatof phase change wallboards increasedas compared with specific heat value of gypsum.According to research by Jayalath et al. (2016) [36], cementitious materials' thermal conductivity decreased by 37% when 5% microcapsules were added.Using 30% microcapsules, according to Xu and Li (2013)[37], increased thermal energy storage capacity by up to 5.438 kJ/kg.Gypsum thermal conductivity was examined by Jaworski and Abeid in 2011 [38]. 100% gypsum's thermal conductivity dropped from 0.35 W/ m.K to 0.25 W/ (m.K). Gypsum's 0.1 W/m thermal conductivity was discovered at a PCM concentration of 30%. Using microcapsules, K. Zhang et al., 2020 [39] studied thermal conductivity. Gypsum materials' test results are 0.4707 W/ m.K, 0.3361 W/ m.K, 0.3011 W/ m.K, and 0.2537 W/ m.K, respectively, and these values correspond to microcapsule contents of 0, 5 wt.%, 10 wt.%, and 20 wt.%.It was thoroughly examined how M-PCM integration affected important characteristics as compressive strength, flexural strength, apparent density, porosity, and thermal behaviour. The apparent density and thermal conductivity of GC decrease with M-PCM incorporation (5 and 10%), but GC porosity rises with increasing M-PCM dose [40].

The thermal conductivity of incorporated MPCM into building materials were calculated theoretically by using the Maxwell eq. (2) which describes about the thermal conductivity of MPCM in building materials. Based on this model, the MPCM particles were unreacted with binding material and dispersion of MPCM in binding material homogeneously (Lecompte et al., 2015)[41].

$$k_{eff}=k_{bm}\frac{k_{MPCM}+2k_{bm}+2\emptyset(k_{MPCM}-k_{bm})}{k_{MPCM}+2k_{bm}-\emptyset(k_{MPCM}-k_{bm})} \quad (2)$$

k_{eff} Effective thermal conductivity of incorporated MPCM into building material (W/m.K), k_{MPCM} thermal conductivity of MPCM (W/m.K), k_{CP} thermal conductivity of building material, Ø is the volume fraction of MPCM. The specific heat of inclusion of MPCM building material was determined using the following eq. (3) and enthalpy of incorporated MPCM1 into the cement paste at phase transition temperature was determined using eq. (4) [42].

$$C_{peff} = (1-\emptyset_{MPCM})C_{pbm} + \emptyset_{MPCM}\, C_{pMPCM} \quad (3)$$

$$H_{\text{enthalpy of MPCM into bm}}$$

$$\text{at phase transition temperature} = \int_0^{Tmp} C_{peff}\,\Delta T \quad (4)$$

C_{peff} Specific heat of incorporated MPCM into building material(J/kg.K), C_{pcp} specific heat of building material (J/kg.K), C_{pMPCM} specific heat of MPCM (J/g.K),$\emptyset_{MPCM}$ volume fraction of MPCM. Tmp melting point of MPCM (K), H enthalpy of MPCM into building material (^oC)

The thermal diffusivity of building material with MPCM was calculated using the following eq. (5)

$$\propto=\frac{k}{\rho C_p} \quad (5)$$

Where, ∝ is thermal diffusivity (m^2/sec), ρ is the actual density of building material with MPCM samples and C_p specific heat of building material sample, J/kg.K.

6. MECHANICAL AND PHYSICAL PROPERTIES OF PCMS INTO BUILDING COMPONENT

Researchers have been studied mechanical properties of micro-PCMs into the concrete, cement, gypsum and brick. Compressive strength of building component decreased with addition of micro-PCMs. Compressive strength of concrete has been studied at 28 days by increasing micro-PCMs. Compressive strength of concrete significantly decreased while micro-PCMs dosage increased.

To enhance compressive strength of buildings components, nano materials are adding such as nano-SiO2, TiO2 and Carbon nano tubes (CNTs).Two kinds of dissimilar nano materials were used, one was nano silica (NS) which was in colloidal state and another one was nano titanium, (NT) in amorphous state, in mortars. The influence of nano materials NS and NT on the fresh and hardened state properties of these self-compacting mortars was studied. They concluded that the use of nano materials in repair and rehabilitation mortars has significant potential but still needs to be optimized [43]. Microcapsules were introduced to the cement-based system by Zhu et al. in 2021[44]. Porosity and density were assessed. As the microcapsule concentration was raised, the density decreased and the porosity rose. This effect can be explained by the fact that the LWA's pore structure is altered by the presence of microcapsules, which causes a drop in density as porosity rises. In place of PCM, Sukontasukkul et al. 2019 [45]investigated water absorption using light-weight aggregates (LWA). The density of the cement-based system (CBS) increases when LWA is substituted with PCM-LWA, and the absorption reduces. The density rises from 1747 kg/m3 to 1903 kg/m3 as the LWA is replaced by the PCM-LWA up to 100% by volume. The absorption decreases by 2.20-1.75% when the PCM-LWA totally replaces the LWA. In order to increase density and reduce absorption, denser aggregates (PCM-LWA) must be used in place of porous aggregates. Eddhahak-Ouni et al. (2014) [46] looked at the mechanical properties of PCC with micro-encapsulated paraffin PCM (Micronal DS 5001X). The samples containing 1%, 3%, and 5% microencapsulated PCM by volume, respectively, had compressive strengths that were 16%, 24%, and 32% lower than the reference sample (without PCM). A concrete tile system with microencapsulated paraffin was devised and tested by

Narain et al. in 2016 [47]. (Micronal DS 5008). Compressive strength was reduced by 25% when cement-based system (CBS) was used with 20% PCM per volume.

7. BASIC PARAMETERS FOR APPLICATION OF PCM IN DISTINGUISH APPLICATIONS

Based on overview, the following flowchart is drawn (Fig.5) for application of PCM in thermal energy storage system and building applications for reduction of energy demand [48]and it will be helpful to reduce burden on natural resources depletion

8.BEHAVIOUR OF MPCM IN BUILDING COMPONENTS

As the dosage of MPCM (shell : polymer) is increased, in cementitious material, thermal properties such as thermal conductivity and specific heat may be varied and also effects on mechanical properties such as compressive strength and flexural strength. In Fig.6, the briefly explained for above properties.

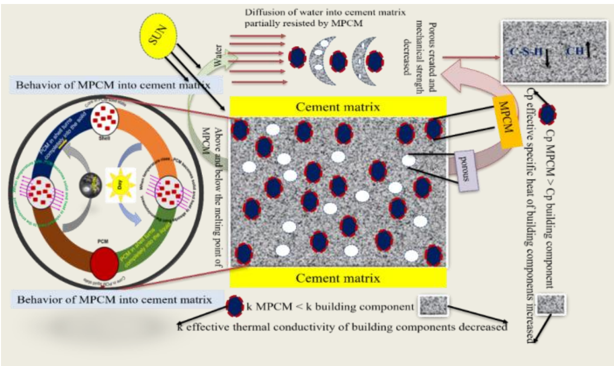

Fig.6 PCM plays in cementitious materials[49, 50]MPCM has a low thermal conductivity and high specific heatas compared to the building component. its effective total thermal conductivity is lowered than the control sample and higher specific heat. Themechanical properties are reduced.MPCM partially counterattacks the obligatory of water, therefore essential hydration products such as C-S-H is reduced as well as CH is increased. The C-S-H is principal product for improving the mechanical properties whichcanbe improved by incorporating inorganic shell (Fig. 6).

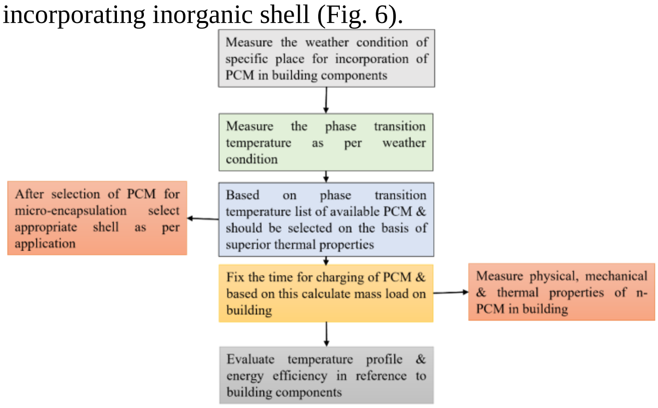

Fig.5 Flow chart for PCM design in different application9. Conclusion

9. CONCLUSION

When selecting PCMs, their phase change temperature should be close to the average room temperature and comparison of thermal properties of PCMs at the average temperature, in that high latent heat of fusion, energy density must be select for the buildings. Otherproperties such as long-term thermal and chemical stability of PCMs considered. Successfully, polymers were used as shell to PCMs by different encapsulation methods, but their physic-thermal properties should be considered during selection of polymers. Shape stabilized PCM can be incorporate into interior of the building by retrofitting, it can enhance overall heat transfer coefficient. Thermal conductivity is decreasing, and specific heat is increasing, so PCMs may incorporate outside of building component. For this purpose, need to be analyze which temperature is suitable to the building component. Researchers have been studied mechanical properties of micro-PCMs into the concrete, cement, gypsum and brick. Whereas compressive strength is decreasing, while PCMS dosage increased. Compressive strength of PCMs building component can be enhance by adding nano materials

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