Application of Phase Change Material (PCM) in building envelope for Cooling: A Review

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Abstract: India is a hot atmosphere nation. Another examination on environmental change in India has affirmed a quick ascent in surface temperatures in the previous 70 years. To get solace and increment profitability utilization of Air Conditioning is additionally expanding in private, business, institutional, open structures and so forth. Forced air systems are among the most pervasive buys for the developing Indian white collar class because of rising earnings, with climate control system deals expanding by 20 percent every year lately. While structures and advancement give endless advantages to society, they additionally have noteworthy natural and wellbeing impacts. At the point when being used, structures are in charge of a noteworthy extent of all our carbon emanations. The developing worries over the natural effects of structures have prompted expanding requests for increasingly ecological amicable structures and building materials. In this way it is currently important to create working so that it has least negative effect on condition. To accomplish this, building ought to be made by inventive materials and strategies that are eco-accommodating to the earth. The alluring solace conditions inside structure and its elements, for example, body's warmth misfortune and creation, stickiness, air development, radiation and so forth are assessed. In view of the diverse solace conditions in various seasons and areas, the right kind and amount of Phase Change Materials utilized can be assessed. In this study, number of contextual investigations and writing would be explored to recognize the utilization of Phase Change Material (PCM) inside the structure in such manner that indoor air temperature may be reduced.

Keywords: Phase Change Material, Building envelope, passive cooling, comfort conditions, thermal property, energy efficient building.

I. Introduction:-

Phase change materials offer incredible potential as an inactive warmth vitality stockpiling procedure to give vitality efficient. Because1 framework of their special normal for high stockpiling densities and latent warmth properties, PCMs give chances to more prominent vitality stockpiling in numerous applications for private structures. These applications incorporate, yet are not constrained to, sun based water warming, space warming/cooling, and waste warmth recuperation. Along these lines, any substance that ingests heat comes to either its softening or vanishing point without getting any more sweltering. Inert warmth is this sort of warmth stockpiling. Without inert warmth, PCMs would not have the capacity to act alone in controlling room temperature since when utilized in development they change from strong to fluid at 23-26°C. At the point when PCM dissolves, they ingest heat from the space to keep the room temperature stable. PCMs just come back to its unique strong state amid ventilation around evening time. These profitable properties of PCMs will drastically lessen cooling and warming vitality request if appropriately oversaw and executed.

I.I Properties of Phase Change Material

The following table-1 shows properties of Phase Change Materials (PCMs).

Table-1:- Properties of PCM

Properties			Economic Factors
Physical Properties	**Chemical Properties**	**Thermal Properties**	
Low variation of density during phase change.	Non-inflammable, non-explosive, and non-poisonous.	Solid and liquid phases must have high thermal conductivity.	Must be readily available in large quantities.
High density	Chemically stable	High specific heat	Low cost
During freezing, there must be little or no super cooling.	Compatibility with material containers.	The temperature of phase change must be suitable for application	Commercially viable

Low vapour pressure	No chemical decomposition	High latent heat per unit mass	

I.II Classification of Phase Change Materials

The following figure shows the classification of Phase Change Materials. (PCMs).

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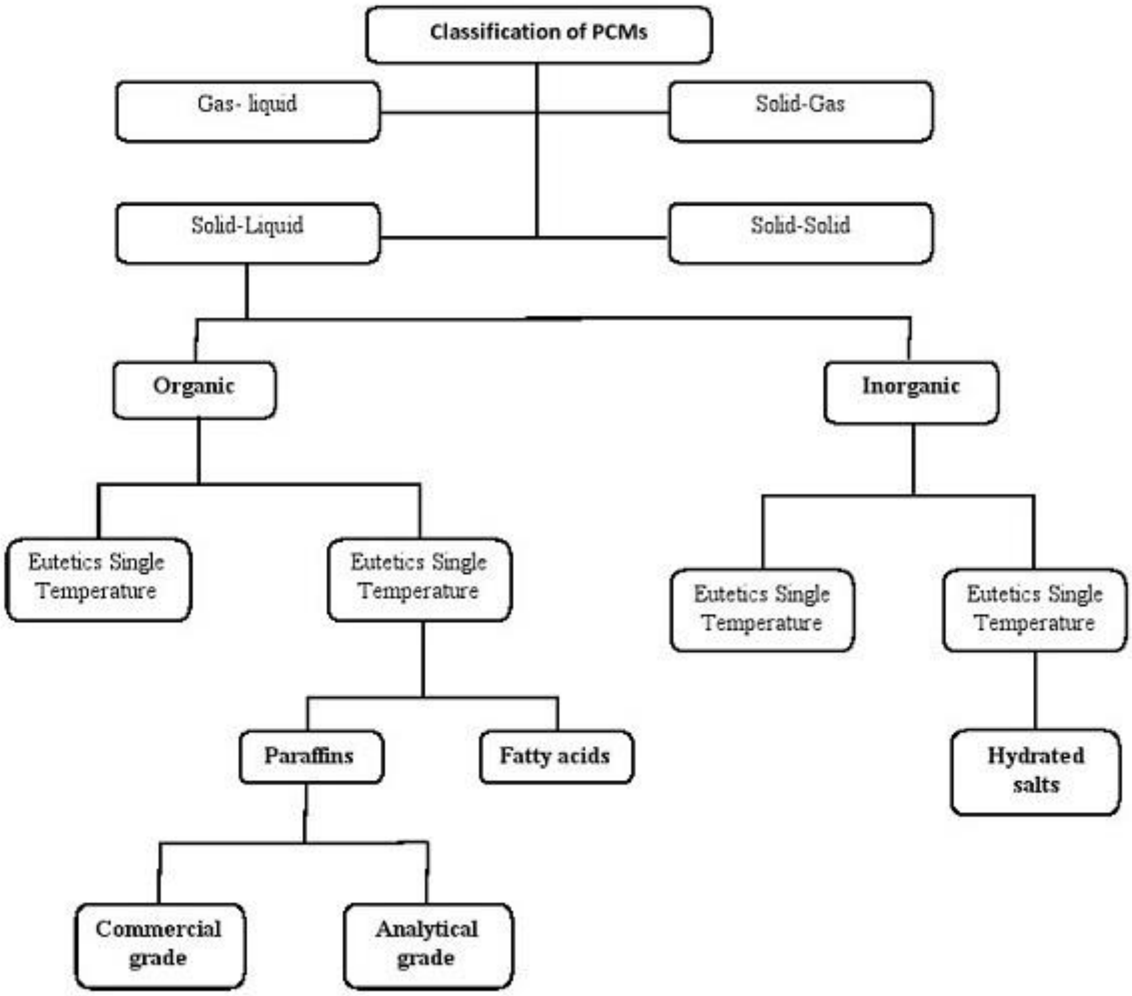

Figure 1:- The classification of Phase Change Materials (PCMS)

II. Literature review on use of Phase Change Materials in Building envelop for Cooling

The following are the earliest research paper review based on Phase Change Material for its use in Building envelop for cooling.

Abhat A (1983) have reported comprehensive lists of possible candidates for latent heat storage covering a wide range of temperatures. Not all PCMs can be used for thermal storage. An ideal PCM candidate should fulfil a number of criteria such as: high heat of fusion and thermal conductivity, high specific heat capacity, small volume change, non-corrosive, non-toxic and exhibit little or no decomposition **[1]**

Adel Ghoneim et al. (1991) explained that the use of thermal storage walls that serve both as solar collector and thermal storage is well known. He carried out Simulation study for comparison the performance of collector – storage walls using masonry and PCMs and evaluation the e effect of the thermal properties of Phase Change materials on the performance of collector-storage walls. He concluded that the PCM and its packaging should be chemically compatible to insure long term durability of the containers. Also the container must also provide an efficient heat transfer surface for energy exchange. **[4]**

W. Saman et al (2001) reported that a phase-change energy storage system consisting of sections of different materials with different melting temperatures is proposed for air conditioning applications. He placed Phase Chang Materials (PCMs) in thin flat containers and air is passed through gaps between them. A semi-analytical model has been developed and calculations carried out using finite elements methods. The model developed are being used to evaluate the performance of the storage system in the conjunction with reverse cycle air-conditioning systems to shave up peak loads and to find the optimum design and mass ratio of different PCMs at different climate conditions for space heating and cooling. **[17]**

Kang Yanbing et al. (2003) proposed a kind of innovative building energy efficiency system—Night Ventilation with PCM Packed Bed Storage (NVP) system. The mathematical model of NVP system is built to analyze its thermal behavior. It is concluded that the NVP system model provides guidelines for thermal performance analysis, system optimum design and system optimum control for NVP system. Also, its thermal performances including the effect of decreasing the room temperature and energy consumption are studied. The experimental results showed that NVP system can prominently improve the thermal comfort level of indoor environment. **[10]**

M. Ravikumar et al. (2008) explained that as the demand for refrigeration and Air conditioning has been increased during the last decade, the cool storage systems can be used to the economic advantage over conventional cooling plants. He carried out the tests on transient heat transmissions across different roof different structures. It was found that when installing PCM in the withering course region then nearly uniform roof bottom surface temperature was maintained **[14]**

PSS. Shrinivasan et al. (2008) explained that due to climatic change, increasing thermal loads in buildings and rising living standards, comfort cooling in buildings is becoming increasingly important and the demand for comfort cooling is expanding very quickly around the world. The tests on transient heat transmissions across different roof structures were conducted. It was found that when installing PCM in the withering course (WC-mixture of broken bricks and lime mortar) region nearly uniform roof bottom surface temperature was maintained. **[13]**

Albert Castell et al. (2010) reported the results of an experimental set-up to test phase change materials with two typical construction materials (conventional and alveolar brick) for Mediterranean construction in real conditions. Several cubicles were constructed and their thermal performance throughout the time was measured. For each construction material (macro-encapsulated) PCM is added in one cubicle. Then the cubicles have domestic heat pump as cooling system and energy consumption is registered to determine the energy savings achieved. It is concluded that the PCM can reduce the peak temperatures up to 10c and smooth out the daily fluctuations. Moreover, in summer 2008, the electrical energy consumption was reduced in the PCM cubicles about 15%. Also, these energy savings resulted in reduction of the CO_2 emissions about 1 to 1.5 kg/year/m^2. **[5]**

V. Antony Aroul Raj et al. (2010) reviewed the concept of Green building is gaining importance in the present energy scenario and related environmental issues. Free cooling or ventilation cooling is truly a green concept since even 1 g of carbon is not burnt for the purpose of cooling. The major challenges and facts posed in the use of Phase Change Material for free cooling system design such as thermal resistance of air and PCM, geometry of encapsulation are discussed. Free-cooling concept is site specific and climate dependent. It is suitable for the interior and desert regions. It is found that free cooling system requires heat transfer augmentation on air and PCM side. It also requires lesser charging time which can be achieved by larger surface area per storage volume **[16]**

A. Waqas et al. (2011) explained that In hot and dry climatic conditions of South Asia, summer night temperatures are low, and phase change material (PCM) based heat storage technique could be used as heat sink to reduce ambient air temperature during hot day times, as an alternate of current ventilation techniques for the building sector. The influence of air flow rates and melting point of PCM on the availability of comfort temperatures at storage unit outlet has been studied. It is concluded that the feasibility of PCM storage unit as a heat sink to keep ambient air within comfort limits during the hot day time in summer season **[3]**

Esam M. Alawadhi et al. (2011) reported about the thermal effectiveness of a building's roof with phase change material (PCM). The considered model consists of a concrete slab with vertical cone frustum holes filled with PCM. The thermal effectiveness of the proposed roof PCM system is determined by comparing the heat flux at the indoor surface to a roof without the PCM during typical working hours. The n-eicosane shows that best performance among the examined PCMs and the conical geometry of the PCM container is the best in term of thermal effectiveness. **[7]**

N.A. Yahaya et al. (2011) investigated the effectiveness of PCM integrated with gypsum board as ceiling panels in relation to building energy saving. The indoor air temperature of single space houses and the effect of PCM ceiling panels were predicted by using the explicit form of numerical method and specific heat capacity method respectively. It is found that the application of PCM ceiling panels could effectively reduce the energy consumption through active cooling systems. **[12]**

Camila Barreneche et al. (2013) presented Phase change materials (PCMs) as materials with high thermal energy storage (TES) capacity due to the latent heat stored/released during phase change, able to reduce the energy demand of buildings when incorporated to construction materials. The materials tested have a gypsum or Portland cement matrix which incorporates 5wt % and 15wt % of micro-encapsulated PCM. It is concluded that the PCM addition produces a reduction in the thermal conductivity of the samples. It is also found that the incorporation of 5wt % PCM in ordinary Portland cement matrixes is more beneficial than to add this PCM amount in gypsum matrixes from the thermal properties point of view. **[6]**

A. H Mosaffa et al. (2014) reported that free-cooling is a concept developed for air conditioning applications, in which coolness is collected from ambient air during night and released into the room during the hottest hours of the day. Energy and exergy analyses are performed for a free cooling system using a LHTS unit employing multiple PCMs. The effects of inlet air temperature and air flow rates on the performance of the system are investigated. It is than concluded that the increase in exergy efficiency due to reducing inlet air temperature is more significant the air flow rate during charging process. **[2]**

Francesco Guarinoa et al. (2015) find out that Phase Change Materials (PCMs) would allow for mostly isothermal phase change within normal thermal comfort range. In order to face the typical challenges of the Mediterranean climate, the following concept was elaborated: the idea is to use the phase change mechanics as a substitute to the thermal inertia of massive walls to obtain a similar effect in lightweight structures. A simulated test room was arranged and through parametric analysis, the potential of PCM for energy efficiency in connection to natural ventilation strategies was assessed. The simulation results vary according to the configuration analyzed but in all cases, cooling consumption reduction reached at least 40 % with the use of PCMs. also air temperature during peak hours in summer can be reduced by more than 7 ^{0}C – 8 ^{0}C. **[8]**

Morshed Alam et al. (2017) compared the effectiveness of passive and free cooling application methods of Phase change materials (PCMs) when used as energy efficient retrofitting in a residential building. In passive application, PCM was installed in the ceilings of the house. In free cooling application, outdoor air was supplied to the indoor after passing it through a PCM storage unit. He made between the comparison is made between the effectiveness of passive and free cooling application methods of Phase Change Materials (PCM) when used as energy efficient retrofitting in a residential building. In passive application, PCM was installed in the ceilings of the house. In free cooling application, outdoor air was supplied to the indoor after passing it through a PCM storage unit. The study was carried out using building simulation software energy-plus V 8.4 and computational fluid dynamics (CFD) software ANSYS V.15.1. It is found that, for the studied house, free cooling application of PCM is more effective than passive application in reducing the internal zone temperature. Also under typical summer climate conditions of Melbourne, free cooling application resulted in up to 1.80 ^{0}C.reduction in zone air temperature compared to only 0.50 ^{0}C. When PCM was applied as passive storage. **[11]**

II.I MAJOR FINDING FROM LITERATURE REVIEW

The following table shows the different criteria considered by different Authors.

Table 2: Important criteria considered in different research papers

Sr no.	Authors' details		Thermal Analysis	Heat Exchange Analysis	Mass Ratio Analysis	NVP model	CO_2 Emission Analysis	Thermal Conductivity	Energy & Exergy Analysis	Simulated Test Room	Building Simulation Software
	Name (Year)	**Country**									
1.	Abhat A (1983)	Stuttgart	×					×			
2.	Adel Ghoneim et al. (1991)	USA		×							×
3.	Kang Yanbing et al.(2003)	Australia			×			×			
4.	W. Saman et al. (2001)	China		×		×					
5.	M. Ravikumar et al. (2008).	India	×					×			
6.	PSS. Shrinivasan et al. (2008)	India	×		×						
7.	Albert Castell et al. (2010)	Spain	×					×			

8.	V. Antony Aroul Raj et al. (2010)	India	×	×				×			
9.	A. Waqas et al. (2011)	Thailand	×					×			
10.	Esam M. Alawadhi et al. (2011)	Kuwait			×	×					
11.	N.A. Yahaya et al. (2011)	Malaysia	×	×				×			
12.	Camila Barreneche et al. (2013)	Spain		×				×			
13.	A. H Mosaffa et al. (2014)	Iran							×		
14.	Francesco Guarinoa et al. (2015)	Italy	×					×		×	
15.	Morshed Alam et al. (2017)	Australia	×					×			×

* (×) indicates various criteria's regarding Phase Change Material done in their research work.

III. CONCLUSION

Based on critical literature review, the following conclusion is drawn.

1. Using two different measurement techniques: different scanning calorimetry and thermal analysis, the melting freezing behaviour of heat storage materials are determined.
2. The container used to store the PCM must also provide an efficient heat transfer surface for energy exchange between the storage material and the building.
3. The NVP system model provides guidelines for thermal performance analysis, system optimum design and system optimum control for NVP system. The experimental results showed that NVP system can prominently improve the thermal comfort level of indoor environment.
4. It was found that when installing PCM in the withering course region then nearly uniform roof bottom surface temperature was maintained.
5. The free-floating experiments show that the PCM can reduce the peak temperatures up to 1^0C and smooth out the daily fluctuations. Moreover, in summer, the electrical energy consumption was reduced in the PCM cubicles about 15%. These energy savings resulted in reduction of the CO_2 emissions about 1 to 1.5 kg/year/m^2
6. Free cooling system requires heat transfer augmentation on air and PCM side. It also requires lesser charging time which can be achieved by larger surface area per storage volume.
7. The n-eicosane shows that best performance among the examined PCMs and the conical geometry of the PCM container is the best in term of thermal effectiveness.
8. The application of PCM ceiling panels could effectively reduce the energy consumption through active cooling systems.
9. The PCM addition produces a reduction in the thermal conductivity of the samples. The incorporation of 5wt % PCM in ordinary Portland cement matrixes is more beneficial than to add this PCM amount in gypsum matrixes from the thermal properties point of view.
10. The increase in exergy efficiency due to reducing inlet air temperature is more significant the air flow rate during charging process.
11. The simulation results vary according to the configuration analysed but in all cases, cooling consumption reduction reached at least 40 % with the use of PCMs. Air temperature during peak hours in summer can be reduced by more than 7^0C - 8^0C.
12. Full-scale testing and numerical modelling were found to be the most popular investigative methods used for experimental and theoretical analysis of PCMs.
13. It is found that, for the studied house, free cooling application of PCM is more effective than passive application in reducing the internal zone temperature. Under typical summer climate conditions, free cooling application resulted in up to 1.8 ^{0}C reduction in zone air temperature compared to only 0.5 ^{0}C when PCM was applied as passive storage.

IV. ACKNOWLEDGMENT:-

I thankfully acknowledge to Prof. (Dr.) I.N. Patel, Principal, Birla Vishvakarma Mahavidyalaya, Vallabh Vidyanagar, Prof. (Dr.) L.B. Zala, H.O.D., civil engineering department Birla Vishvakarma Mahavidyalaya, Engineering College, Vallabh Vidyanagar, Dr. Jayeshkumar pitroda, associate professor, civil engineering department, PG coordinator construction engineering and management, Birla Vishvakarma Mahavidyalaya, Vallabh Vidyanagar, for their m0tivation and support to carry out this research.

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