Design of Phase Change Material Based Insulation for Building

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Abstract: This research paper tackles the critical environmental issue stemming from a drastic increase in atmospheric pollutants, including NOx, VOC, CO2, SOx, dioxins, and furans over the past decade. These pollutants have caused global concerns, such as rising temperatures, elevated CO2 levels, and the subsequent melting of polar ice caps, leading to rising sea levels. This environmental crisis is largely driven by the growing reliance on power plants to meet the escalating demand for electricity. Reports, including the World Bank's assessment of residential power consumption, have shown that approximately 40% of energy is used for cooling. This emphasizes the significant environmental impact of Heating, Ventilation, and Air Conditioning (HVAC) systems. To address this challenge, we propose a practical and sustainable solution using Phase Change Materials (PCMs) for cooling. PCMs, widely used in thermal energy storage (TES) in building construction, provide an innovative way to balance energy demand and supply efficiently. The research aims to improve indoor air temperatures and reduce thermal energy demand by introducing a PCM-based supplementary layer into composite walls, resulting in a substantial 16% reduction in cooling demand. This represents a significant step toward embracing sustainable, energy-efficient practices in building design and construction.

Key words: Phase Change Materials (PCMs), Building Insulation, Energy Efficiency, Thermal Energy Storage (TES), HVAC Systems, Global Warming, Sustainable Building Design

1. INTRODUCTION

In the last two decades, Phase-Change Materials (PCMs) have emerged as crucial components in the pursuit of energy-efficient solutions for building design and thermal management. Against the backdrop of a substantial surge in carbon dioxide (CO2) emissions, with buildings alone contributing to roughly 36% of greenhouse gas emissions related to climate change, the urgency to mitigate energy consumption and its environmental consequences has become increasingly evident [1]. Escalating energy costs have driven researchers worldwide to explore novel materials capable of alleviating the ever-growing demand for power, of particular concern is the rising energy consumption associated with heating and cooling systems, which are indispensable for maintaining thermal comfort in buildings [1]. Addressing this challenge is of paramount importance for enhancing building energy efficiency. However, it is essential to acknowledge that existing structures, which constitute a significant portion of our built environment, cannot be overlooked in this pursuit. An innovative approach to reducing energy demand involves thermal energy storage (TES), a technology capable of absorbing, storing, and releasing heat in response to prevailing environmental conditions [2]. Within this domain, latent heat thermal energy storage (LHTES) has garnered significant attention in recent years, with PCMs emerging as a pivotal choice due to their distinctive thermophysical properties, including a well-defined melting point range, heat of fusion, thermal conductivity, and density [1]. Additionally, PCMs offer compatibility with construction materials, chemical stability, recyclability, and the potential to reduce the size of Heating, Ventilation, and Air Conditioning (HVAC) systems [1]. One innovative approach to enhancing the heat conductivity of PCMs, without compromising their energy storage capacity, involves the use of composite materials featuring aluminum lattices that accommodate the PCM and graphite [1]. This design mitigates volume changes in paraffin and reduces subcooling in hydrated salts, resulting in notably enhanced thermal conductivity, with a remarkable 9% latent heat of fusion per unit mass of paraffin [1]. The significance of thermal mass in buildings cannot be overstated, particularly concerning temperature fluctuations in response to external and internal heat loads [2]. Expanding thermal mass can be achieved through the incorporation of sensible heat storage or latent heat storage methodologies [2]. As energy costs continue to rise, there is an opportune moment to deploy cutting-edge renewable technologies, especially for modern structures characterized by minimal energy demands. Recent advances in energy storage techniques have led to the exploration of Phase Change Materials (PCMs) owing to their ability to store a larger quantity of heat energy during phase transitions compared to sensible heat storage [3]. The growing gap between global energy supply and demand necessitates the development of thermally efficient and cost-effective thermal energy storage technologies. PCMs hold promise because they exhibit the capacity to store and release substantial amounts of energy at relatively consistent temperatures during the melting and solidification processes [3]. Latent heat energy storage systems offer the prospect of storing significant usable thermal energy, which can subsequently be harnessed during peak energy demand periods to maintain equilibrium between energy supply and demand [3]. In understanding the principles governing heat transfer, it's crucial to recognize two fundamental modes: sensible heat and latent heat. While sensible heat involves a temperature change in response to heat addition or removal, latent heat entails a change of phase without a corresponding temperature shift. PCMs, for instance, undergo phase transitions from solid to liquid within the range of 23-26°C when employed in building materials [4]. These transitions, when managed effectively, play a pivotal role in moderating room temperature. When PCMs melt, they absorb heat from the surroundings, thereby stabilizing indoor temperatures. Subsequently, during the cooling phase, they revert to their original solid state. When properly integrated into building materials (such as walls, roofs, floors, and other structural components), PCMs bolster the thermal mass of a structure and contribute to the stabilization of indoor surface temperatures [2].

2. METHODOLOGY

To get a solution for a setup resembling the characteristics of a room inside the building is considered. Considering the same a setup the following cross-section is made.to calculate percentages reduction in cooling load. by using thermocouple, temperatureis taken inside and outside the room. After taking inside and outside temperature we will measure the temperature of the aluminum sections. This temperature difference is denoted by δt1.the above setup is the one with which will be comparing the difference that our application arrangement makes, for that a setup containing PCM is used.

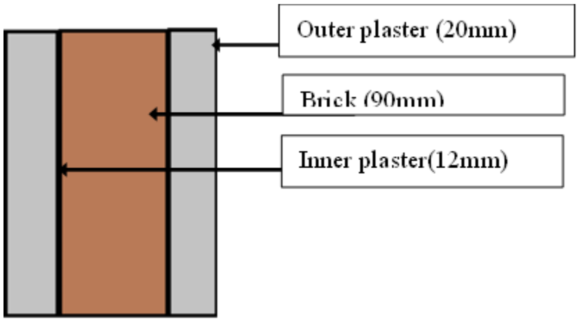


Figure 1: Room without PCM

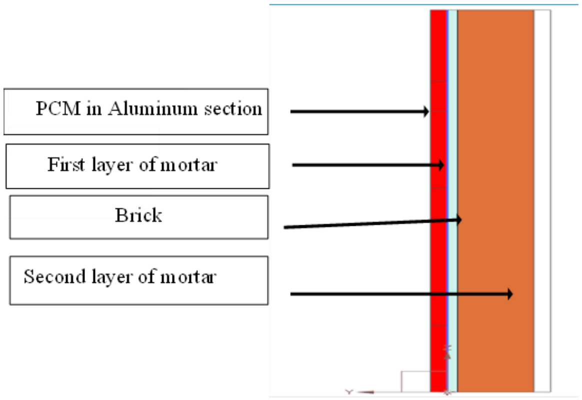
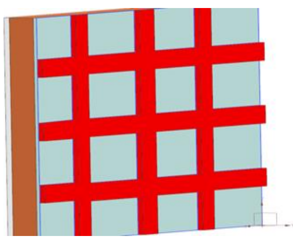


Figure 2: Room with PCM (PCM inside the aluminum section on the interior sides)



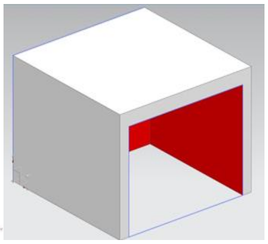


Figure 3: Isometric view of the wall

Figure 4: Insulated room

In the first case (fig. 3), there are three layers that contain brick, the first layer of mortar and the second layer of mortar. In the second case (fig.4), there are four layers that contain PCM in the aluminum section, the first layer of mortar, the brick, and the second layer of mortar. By providing necessary arrangement in 1st case next 2 layers will apply on interior surface of room. Inside a room aluminum channel will placed and PCM (paraffin wax) filled in room. Temperature will betaken inside and outside the room. This temperature difference is denoted by δT_{pcm}. Paraffin wax is chosen as a PCM because it has high heat of fusion, low thermal conductivity and available in large temperature range. Cooling load reduction is calculated by using the formula which is given by -$\{[\delta T_1 - \delta T_{pcm}]/ \delta T_1\}*100$. Where, δT_1= temperature difference without PCM δT_{pcm}= temperature difference with PCM (paraffin wax). In 3rd case, we will be filled paraffin wax (PCM) in a cavity of brick we are along more researchon it.

3. RESULTS AND DISCUSSION

Due to the fact that the exterior temperature must be computed from the real setup, an additional reference was needed to obtain the temperature and other characteristics that were impossible to calculate due to the pandemic condition. All of the values were derived from a valid reference study titled "Study of Thermal Conductivity of Reinforced Concrete Plate" [10]. The reinforced concrete composite wall (RCCW) is a new type of thermal insulation wall for construction that blends a reinforced concrete structural wall with a thermal insulation layer. Create an organic system by combining the polystyrene panel and the concrete overlay The three layers are interconnected. They are linked together by a specified number of links. The steel bars and links in the concrete have been observed to alter the thermal insulation qualities of RCCW in prior research. The thermal performance of the entire structure is affected by the concrete's conductivity.

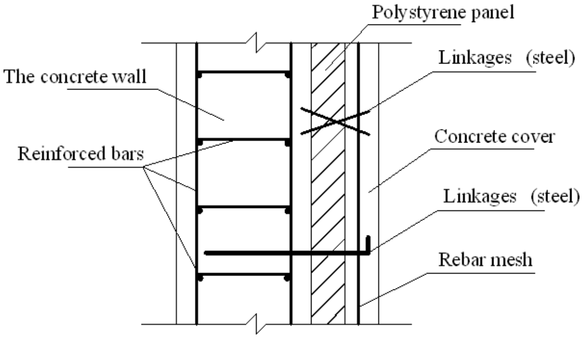


Figure 5: Forms of RCCW [10]

By considering the given Setup for the simulation of the heat conduction through the wall, we get the temperature parameters for the simulation and hence the following data was referred as givenin the table [10]

Temperature		Heat flux (W/m^2)	Thickness	[W/(mK)]
Cold Surface	Hot Surface			
28.33	39.26	290.55	0.054	1.4354

Table 1 Results and discussion

These parameters were derived from actual experimentation by the authors of the study cited in the references section for the above information. These values were entered into the mat lab programme to calculate the inner wall temperature using the code provided in the following report.

MAT-LAB PLOT

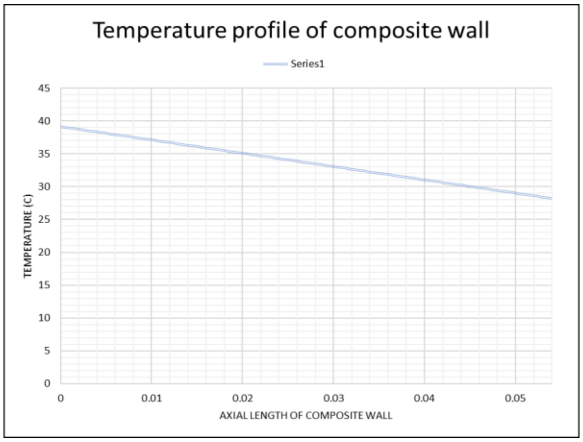


Figure 6: Temperature profile of wall

We can calculate the temperature of the inner wall by using data from the reference paper as input.The heat insulated by the PCM wall is calculated using this temperature as an input. ANSYS fluent solidification/melting module receives this temperature. The cross-section of the wall is used as the geometry for the ANSYS component in this module, and we must derive the setup. The cross-section of the wall is used as the geometry for the ANSYS portion in this module, and the setup isused to produce a solidification/melting profile for the heat absorbed and emitted by the PCM material (paraffin wax). To construct meshing for the same, face and edge meshing choices are used. The inflammation option was ignored in this case because the surface was constructed instead of a geometry that took into account the wall's cross section. After taking into account all of the above data, a serial processing fluent module is started to analyses the PCM solidification/melting. A gravitational acceleration (9.81 m/s^2) is considered, as it will affect the flow of the liquid PCM material. the material specification was specified in the fluid section, the following properties for the same were considered. Density 750kg/m^3 (bounciness) Specific heat cp 1800 j/kg-k thermal conductivity – 2 w/m-k viscosity-0.00181kg/m-s. Thermal expansion coefficient 0.0012/K pure solvent melting heat 174000 j/kg solidus temperature 294K

Liquids temperature 297K a 100 iteration were done with a 20 time stepping giving a higher number of total iterations. After doing all the iterations a counter was created for the inner surface of the wall to get the temperature profile for the melting of the PCM material which wasdone in the results section of the ANSYS fluent module of the ANSYS 2019. This gives us the following temperature profile.

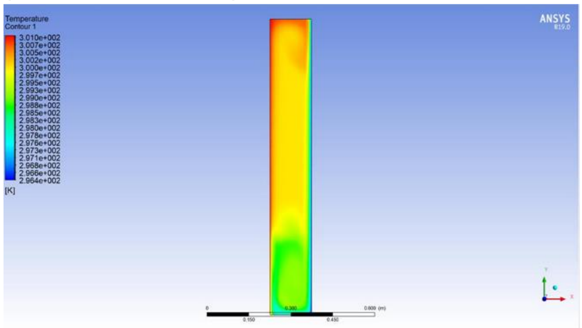


Figure 7: Simulation (Solidification / Melting) of PCM

As shown in the figure the most of the heat was absorbed by the leftmost section of the pcm material which caused the melting. After melting a total of 4.665 ^{0}C temperature drop was shownas a result of the analysis. For the conventional building when the outside temperature is 39.26 thetemperature inside the room is reduced to 28.31^{0}C as per the reference taken from the reference paper derived from the readings taken on actual setup. As per the Ansys fluent solidification melting temperature profile a total of 4.66^{0}C temperature drop is observed after applying a 15 cmlayer of aluminum imbedded PCM Layer on the inside of the room walls. As a result of using PCM as an Insulation material, The inner temperature of wall is 23.65^{0}C.

Reduction in temperature

The Reduction In Temperature Which Is Caused By Using Phase Change Material As A Insulation Material For Residential Building Is Calculated As Follow

$$\text{Reduction in Temperature} = \frac{\text{Temp.Without pcm} - \text{Temp.With pcm}}{\text{Temp.Without pcm}} * 100$$

$$= \frac{28.31 - 23.65}{28.31} * 100$$

$$= 16\ \%$$

Percentage of temperature reduction after applying a 15 cm layer of aluminum imbedded PCMlayer on the inside layer of the room wall was 16%.

4. CONCLUSIONS

In the realm of smart materials, particularly Phase Change Materials (PCMs), our exploration centered on the application of Paraffin wax reveals an intriguing capacity for substantial temperature modulation. This research underscores a pivotal observation, where measurable temperature variations are achieved by employing two distinct setups and scrutinizing their thermal profiles over time.

Drawing on the foundation of theoretical calculations, the potential of PCM, exemplified by Paraffin wax, emerges as a promising facet in the domain of building insulation. The research advocates the integration of PCM in existing systems as a means to bolster overall efficiency, heralding a paradigm shift in insulation practices. Furthermore, PCM proves instrumental in elevating the thermal comfort within insulated buildings. By harnessing the properties of PCM, we effectively curbed cooling demands while concurrently regulating interior temperatures. The insulation of south-facing walls yielded even more pronounced benefits, reducing electricity consumption and alleviating the cooling burden, particularly during peak loads. In conclusion, our study illuminates the multifaceted advantages of employing Paraffin wax-based PCMs, demonstrating their potential in revolutionizing building insulation. The results underscore enhanced thermal comfort, significant energy savings, and a strategic approach to redefining construction materials' thermal characteristics, exemplified through the integration of PCM within material layers. This marks a pioneering step in mitigating cooling burdens, aligning with the imperative of energy efficiency in our built environments.

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