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Energy Investigation into Integrating Phase Change Materials and Thermal Insulation for Passive Cooling in Buildings

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Abstract

Passive cooling in buildings is a crucial area of research aimed at reducing energy consumption and mitigating the urban heat island effect. Integrating phase change materials (PCMs) with thermal insulation presents a promising avenue for enhancing passive cooling strategies. This study explores the development and characterization of bio-based PCM derived from coconut oil, a renewable and abundant resource. The PCM is processed using a simple and cost-effective method, making it accessible for widespread applications. The thermal properties of the PCM are investigated through differential scanning calorimetry (DSC), revealing a high latent heat of fusion and a narrow phase transition temperature range. The PCM's thermal stability and compatibility with conventional building materials are evaluated, demonstrating its suitability for building envelopes. The study also assesses the long-term stability and reliability of the PCM, highlighting its potential to enhance energy efficiency and reduce carbon emissions in various applications, including building HVAC systems and thermal energy storage units. The utilization of coconut oil as a PCM presents a sustainable and economically viable solute for effective thermal energy management.

Keywords: Bio-based PCM, Compatibility, Phase change materials, Thermal properties, Thermal energy storage

I. Introduction

Innovation in several sectors, including building and home renovation, has been spurred in recent years by the search for sustainable and environmentally friendly solutions [1]. The use of phase change materials (PCMs), which are substances that can store and release thermal energy during phase transitions, to improve building energy efficiency is one of the most cutting-edge examples of these breakthroughs [2]. There have been concerns over the environmental effect of traditional PCMs due to their reliance on synthetic chemicals. A novel approach based on bio-based PCMs made from sustainable materials has emerged as a result of this [3]. Coconut oil bio-based PCM is one such potential possibility. Coconut oil is a great material for PCMs because of its inherent phase-change capabilities and its wide range of uses. This natural chemical has been gaining popularity since it is plentiful, biodegradable, and has a minimal environmental effect. It is extracted from coconuts. Coconut oil is useful for PCM applications because it can withstand different climates and seasons due to its variable phase transition temperatures [4-6].

The incorporation of bio-based PCM into coconut oil has the potential to revolutionise paint mixing and other home applications [7]. To achieve regulated absorption and release of heat energy, paint compositions are enhanced with microencapsulated coconut oil [8]. Not only does this novel method enhance paint's insulating characteristics, it also helps lower energy usage in homes [9]. This means homeowners can enjoy a cosier interior while cutting down on their energy consumption from HVAC systems [10, 11]. In addition, the use of bio-based PCM in coconut oil is perfectly in line with the larger goal of encouraging a circular economy [12–13]. Reusing coconut oil, a natural byproduct that is frequently thrown away or not used, helps the environment and promotes sustainable practices in the paint industry [14–17]. In addition, using renewable materials lessens the need for fossil fuels, which in turn lowers the emissions of greenhouse gases linked to traditional PCM manufacturing [18-19].

1.1 Motivation of the paper

In order to mitigate the impacts of urban heat islands and lower energy usage, passive cooling is an essential construction component. A possible and intriguing approach is the combination of thermal insulation with phase change materials (PCMs). In order to improve passive cooling solutions, this work investigates the creation of bio-based PCMs using coconut oil. Our goal in this research is to show that coconut oil PCM can improve energy efficiency and reduce carbon emissions in building applications by studying its thermal characteristics, stability, and compatibility. Providing a long-term, financially sound answer to the problem of thermal energy management in buildings is the driving force.

II. Background study

Bhamare, D.et al. [1] When it's feasible to keep the structure from absorbing direct sunlight, this method comes in handy. It has shown to be a useful tool in climate-controlled areas where there were no restrictions on building size and structural modifications can be easily included. Aesthetics and building structural needs were more important considerations with this method. This means that the literature on solar and heat management techniques need further focus on structural, aesthetic, and economic considerations. When it comes to vegetative roofs, for instance, the extra soil mass and water retention leads to a membrane structural imbalance. Problems like water hammering, leaks, or debris might result from this structural imbalance. Research into vegetative roof design and installation for passive cooling of buildings was therefore necessary, with a focus on structural peripherals such as walls, vents, etc., to ensure the roof membrane's structural integrity.

J. Liang et al. [3] "Gap" design The basic TE-polarized and TM-polarized light propagation can be replicated using O-PCMs optical waveguides. Even for materials with low extinction coefficient values, the findings demonstrate that these authors "gap" structure successfully suppresses the loss. These authors findings open the door to the possibility of including O-PCMs into cascading networks that prioritise low loss waveguide devices.

Leccese et al. [6] Numerous studies in the literature have shown that the thickness, characteristics, and placements of the layers significantly impact the overall dynamic thermal behaviour of multi-layered exterior walls. Typically, the time lag, decrement factor, and dynamic thermal transmittance were used to describe the dynamic thermal performances of walls. Twenty separate walls were quantitatively compared with respect to the identical thermal transmittance value and examined for changes in dynamic thermal transmittances, degradation factors, and temporal delays.

Nazi et al. [7] In comparison to a completely insulated room, PCM with a higher u-value and ventilation provides free cooling better for spaces with planned air conditioning, which does not utilise air conditioning all day, according to the simulation results. However, compared to PCM with ventilation and insulation alone, PCM with insulation was less effective. For PCM to discharge effectively, nighttime ventilation was required. Meanwhile, completely insulated rooms provide greater energy savings than PCMV installations for rooms that utilise cooling all day, including data centres and information technology rooms. Mould was more likely to grow on walls with a high U-value in a tropical climate because of the high humidity and low nighttime temperatures. A low-cost and efficient way to prevent mould growth in buildings with high U-values in this climatic zone was to install night ventilation systems. These systems also lower the cooling demand during the day.

S. S. Saseendran et al. [10] There was a considerable correlation between the propagation loss and phase shift caused post crystallisation and the film stoichiometry of MoOx thin films. An alternative to chalcogenide-based phase transition materials for integrated photonics might be MoOx, thanks to its tuneable stoichiometry and further process optimisation.

T. Singh and R. R. Mansour [13] Both series and shunt configurations of inline RF SPST switches based on chalcogenide GeTe materials have been produced. To implement a latching mechanism and achieve zero power consumption in steady state operation, this research showcases RFPCM switches that have been manufactured with integrated micro-heaters. The Roff-to-Ron ratio was high. Improving the design of the integrated micro-heater, with a focus on the SPST shunt switches, was one area that will be addressed in future work.

Torres-Rodríguez et al. [15] A comprehensive method for simulating heat gains in unconventional wall designs was laid forth in this research. Commercially accessible technologies were used to verify the suggested analytical model via simulations. Based on the refractive behaviour of incoming rays passing through theThermal Transmission Instrument (TTI) and towards the cooper foil absorber, this theoretical model was developed. Passive heating and cooling systems can have their heat flow rates calculated using the suggested mathematical approach.

Yao et al. [17] To demonstrate how common passive design solutions can enhance indoor comfort conditions while decreasing energy demands of a typical apartment block in various cities of the Hot Summer and Cold Winter zone in China, a comprehensive parametric analysis based on dynamic thermal simulations was conducted. The three cities selected for this purpose were situated in different parts of the Yangtze River: Chongqing, Changsha, and Shanghai, in that order.

2.1 Problem definition

In order to find efficient passive cooling solutions for buildings, this research investigates the possibility of combining thermal insulation with phase change materials (PCMs). In particular, it seeks to improve energy efficiency and reduce the impact of the urban heat island by studying the creation and properties of bio-based PCMs made from coconut oil.

III. Materials and methods

A bio-based phase change material (PCM) produced from coconut oil was developed and characterised using an experimental technique, which is detailed in the materials and methods section. The procedure for testing the PCM's thermal characteristics, stability, and compatibility with standard construction materials is outlined here. Among the techniques used are thermal characterisation using differential scanning calorimetry (DSC), evaluation of long-term stability, and suitability evaluation for building envelopes.

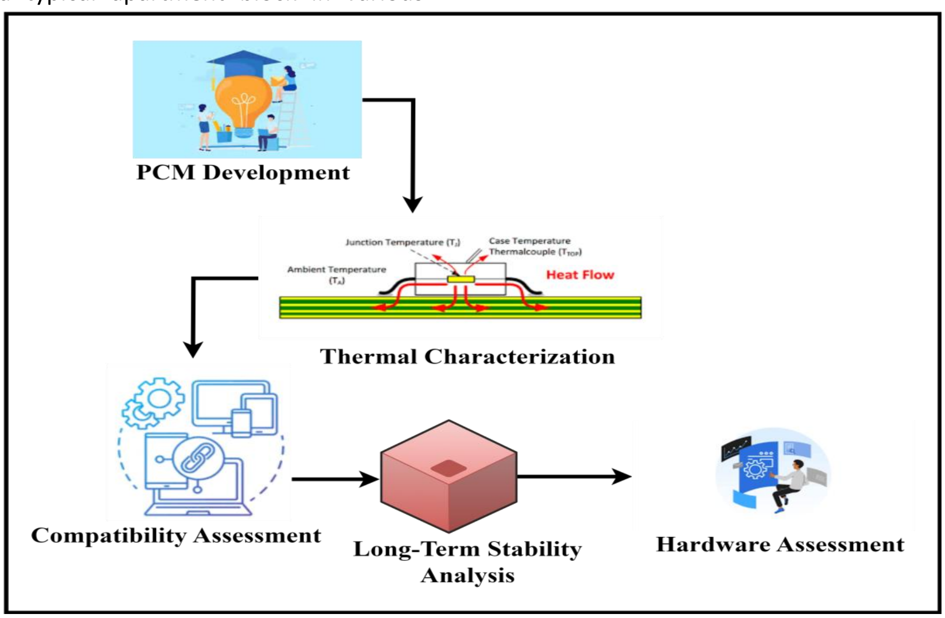

Figure 1: Overall architecture

3.1 Materials of house structure

3.1.1 Plywood

Engineered from thin layers of wood veneers or plies joined together with glue, plywood is an incredibly useful and adaptable engineered wood product. The final product is made stronger and more stable by stacking these plies in such a way that their grain directions are perpendicular to one another. The cross-grain structure makes the material more dimensionally stable than solid wood by reducing the impact of wood's inherent expansion and contraction caused by variations in humidity. Plywood goes through a multi-stage production process. Wood veneers, sourced from both softwoods like pine, spruce, or cedar and hardwoods like oak, birch, or maple, are hand-picked and prepared in the first step. After that, a panel is formed by stacking and pressing these veneers together with heat and pressure. Common layouts include three-ply, five-ply, or multi-ply panels, however the number of layers and arrangement of the plies can vary.

Figure 2: Plywood

3.1.2 Thermocol

Insulation material that is often used to decrease heat transmission through building components is thermocol, which is sometimes called expanded polystyrene (EPS) foam or styrofoam. Its superior thermal insulation qualities make it a great choice for reducing heat loss via a building's exterior. Walls and roofs insulated with thermocol provide a barrier that reduces the rate of heat transfer. Thermocol foam's closed-cell structure prevents heat conduction by trapping air pockets inside its matrix. The limited transmission of heat through polystyrene, due to its poor thermal conductivity, further decreases heat transfer. Thermocol helps keep the inside of a home at a pleasant temperature and lowers the heating bill in cold weather by lowering the amount of heat that escapes to the outside. This has the potential to greatly reduce energy consumption and enhance thermal comfort for building inhabitants.

Figure 3: Thermocol

3.1.3 Light

To make a room seem warmer than it really is, many people turn to 200-watt incandescent bulbs. Contemporary light-emitting diode (LED) bulbs are more efficient and create less heat than their incandescent predecessors, which mainly provide light while emitting a considerable amount of heat. Still, when more heat is required, incandescent lamps are occasionally turned on for their heating capabilities. Turning on a 200-watt incandescent bulb causes it to emit both light and heat as a result of the filament's resistance to current flow. The space is warmed by the radiation that is sent into space. When extra heat is required in a small space or zone, such as a greenhouse, workshop or bathroom, this heating technique is often used. When it comes to maintaining interior comfort, specialised heating systems like electric heaters, gas furnaces, or radiant heating systems can often be more efficient and cost-effective.

Figure 4: Light

3.1.4 Digital temperature sensor

A digital temperature sensor is a piece of electrical equipment that can detect and show the digital temperature of its environment. Thermistors, infrared sensors, and integrated circuit temperature sensors are just a few of the technologies used by these sensors to reliably detect changes in temperature and transform them into processable digital data. Indoors, a digital temperature sensor is usually put in a prominent spot near the control panel of the HVAC system or any other critical place where the temperature has to be monitored. The sensor detects changes in the surrounding temperature and reports them digitally in real time; these measurements are usually shown on an integrated screen or interface. Some digital temperature sensors can have the added capability of sensing and displaying outside temperatures in addition to inside temperatures. One common method is to link the sensor wirelessly to other devices, such as weather stations or other temperature sensors installed outside the home. Homeowners can easily keep tabs on both interior and outdoor temperatures with the digital display of data, which allows for better management of HVAC systems. By analysing this data, we can find ways to make the space more comfortable, save energy, and prevent problems like temperature imbalances or HVAC breakdowns.

Figure 5: Digital temperature sensor

3.1.5 HW Battery and connector

Digital temperature sensors, like many other electronic equipment, rely on portable power sources called HW batteries, which stands for hardware batteries. Because of their small size and low weight, these batteries are ideal for powering tiny electrical devices and sensors. The ability of a digital temperature sensor to operate without an external power source is provided by its HW batteries. The temperature detecting element, microprocessor, and display are all powered by the batteries that come with the sensor. The HW batteries are linked to the digital temperature sensor via the connection, also called a battery connector. Its purpose is to provide a solid electrical connection between the sensor and the batteries. It can be simple to insert and remove the batteries from the connection because it has terminals or pins that match those on the battery pack.

Figure 6: HW Battery and connector

3.1.6 Wire

The digital temperature sensor, the light, the battery, and the plug point are all electrically connected via the wire, which acts as a conductor. It enables the devices to receive electrical power from the source (battery or plug point) and transmit it to the linked devices so that they can operate properly. The specified usage of the wire is to link the battery to the digital temperature sensor. This is how the sensor gets its power from the battery, which is what makes it work as a temperature sensor. In order for the sensor to get the power it needs to function, the cable must be able to carry current from the battery to the device. Connecting the lamp to the wall outlet is another common usage for the cable. When switched on, this connection will enable the light fixture to draw power from the mains electrical supply and shine its light. Connected to the power source, the wire carries current from the wall outlet to the light bulb, generating light.

Figure 7: Wire

3.2 Materials for concrete slab

3.2.1 Cement

One of the most essential components of concrete slabs is cement. Aggregates (crushed stone or gravel), water, and sometimes additives or admixtures are held together by it, since it acts as a binding agent. In order to make a concrete slab, the aggregates and cement are combined in the right amounts to get the required strength and durability. To make sure that all of the aggregates and cement are well combined, the mixing procedure must be done in a comprehensive manner. After that, water is added to start a chemical process called hydration. In this process, the cement particles combine with water to create a solid matrix. Achieving the desired consistency and workability of the concrete mixture requires precise control over the quantity of water supplied.

Figure 8: Cement

3.2.2 Paint

Coatings made of paint are multipurpose and can improve the look of surfaces while also protecting them from things like moisture, abrasion, and ultraviolet radiation. This includes concrete slabs. The paint matrix in PCM-enhanced formulations contains PCM particles. These PCM particles can manage environmental temperature changes by absorbing and releasing thermal energy during phase transitions like melting and solidifying. Paint with PCM added to it creates a thermal barrier when put on a concrete floor; it soaks up heat when it's hot and releases it when it's cold. This method improves thermal comfort and energy efficiency by reducing temperature swings in the room or area where the slab is installed.

Figure 9: Paint

3.3 PCM Development

The primary goal of the phase change material (PCM) development process is to convert coconut oil into an excellent PCM that can be used for passive cooling. Coconut oil is first extracted from its coconuts using techniques like solvent extraction or cold pressing. The crude coconut oil is refined many times after extraction to make it more suitable for PCM applications and to increase its purity. Filtration is a typical refining process that involves passing crude oil through filters to eliminate trash, solid particles, and other contaminants. Coconut oil is refined by filtration to remove impurities that detract from its PCM function. To further enhance the purity and consistency of the filtered coconut oil, it can be subjected to further purification operations after filtering. If the oil still contains water or other contaminants, methods like centrifugation or sedimentation can be used to remove them. To enhance its thermal qualities and phase change characteristics, coconut oil can undergo filtration as well as chemical changes or additions. To modify the PCM's melting point or improve its thermal conductivity, for instance, certain additives or surfactants could be added. To make the PCM more stable and reliable during heat cycling, chemical treatments are another option. Assuring effective energy storage and release during thermal cycling is the objective of producing a PCM with a small phase transition temperature range and a high latent heat of fusion. The development phase sets the stage for the PCM's performance to be characterised and tested in passive cooling applications later on. To begin building the plywood framework, launch CAD and create a new component file. With the PCM containment needs in mind, determine the general size and layout of the tiny home. Use extrusions or sweeps to make the various building blocks, such as walls, roof, and floor. For maximum structural support, use joints or links between parts. Put in some doors and windows to make it seem more like the genuine thing. To correctly depict the behaviour of plywood under PCM testing circumstances, material attributes must be used.

Figure 10: PCM Development

We mixed an in-house mixture of PCM with paint and painted concrete after extracting PCM from the coconut oil. Then, we needed to analyze the PCM. Plywood sheets measuring 75 cm, 45 cm, and 60 cm were used to construct the house's mini-structure. Thermocol acts as a thermal barrier, preventing heat from escaping the home. The installation of a 200-watt bulb allowed for the production of heat inside the housing construction. We have chosen three examples for the reading: one using simply concrete, one including concrete and paint, and the third involving PCM combined and applied.

IV. Results and discussion

The purpose of this research is to assess how well PCM for houses, which utilise green technology, mitigate climate change. Performance of PCM employed in home construction was the main topic of debate. Only in one of the three instances did readings occur with concrete, and that was before the addition of any PCM or paint to the building. For the second scenario, we have already painted the concrete and recorded the measurements. The third scenario involves combining paint with PCM, then painting the concrete and taking a reading. All three of the instances shown in the flow diagram saw an improvement in performance.

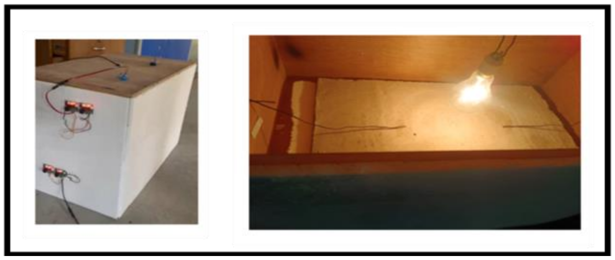

Figure 11: Industrial setup

Figure 11 shows an industrial setup. An industrial setup is a complex environment for various industrial operations, such as manufacturing, production, and processing. It typically combines machinery, equipment, infrastructure, and processes to achieve specific production goals.

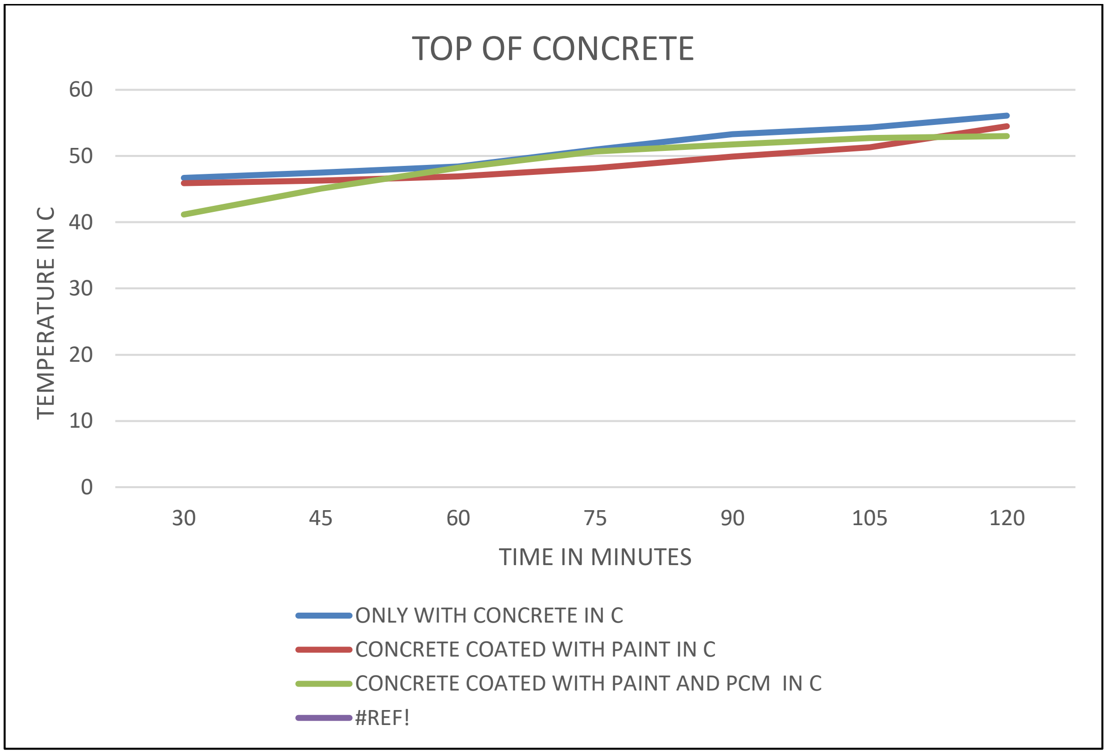

Figure 12: Temperature distributions in topof the concrete

To have a better grasp of the system's thermal behaviour, we analyzed temperature fluctuations over time in great detail for our research. The effects of temperature variations on the system's stability and performance are illuminated by this examination. We used temperature sensors that were carefully positioned throughout the system to record the temperature as it was happening. The temperature changes were accurately represented throughout the experiment since measurements were obtained at regular intervals. The system's thermal reaction is dynamic, as seen by the temperature vs. time graph. Time is shown on the x-axis in minutes, hours, or days (based on the experiment's scale), while temperature is shown on the y-axis in degrees Celsius (°C) or Fahrenheit (°F). As the experiment progresses, the graph shows the temperature's evolution graphically.

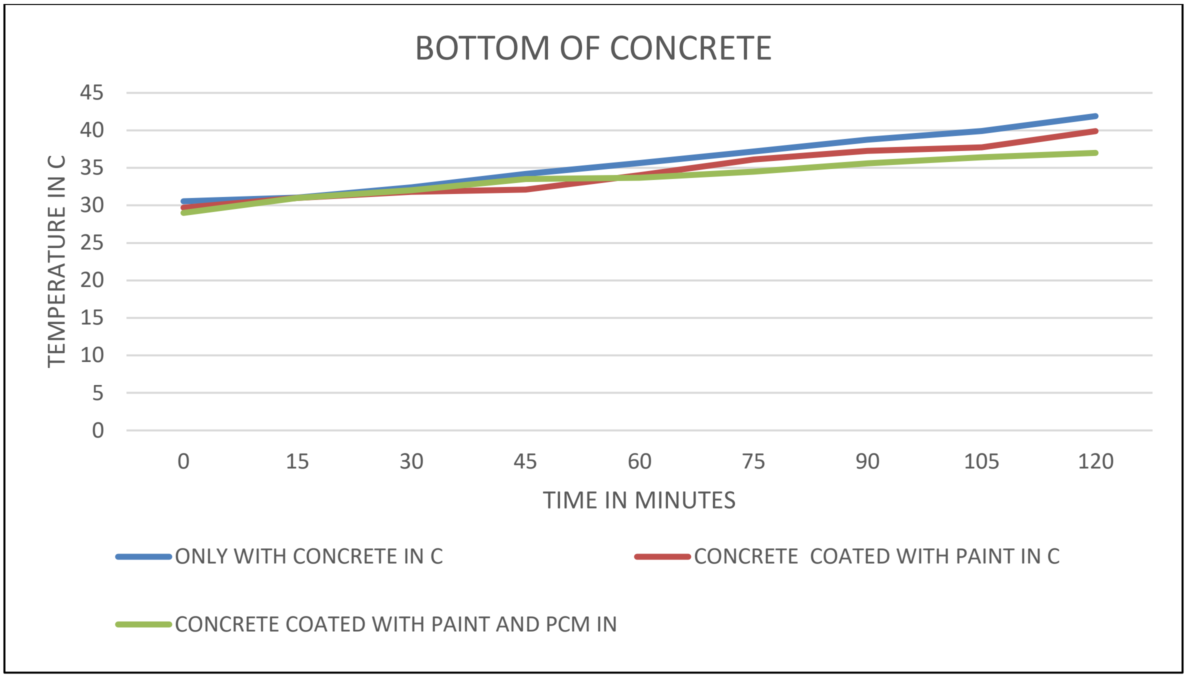

Figure 13: Temperature distribution in bottomof the concrete

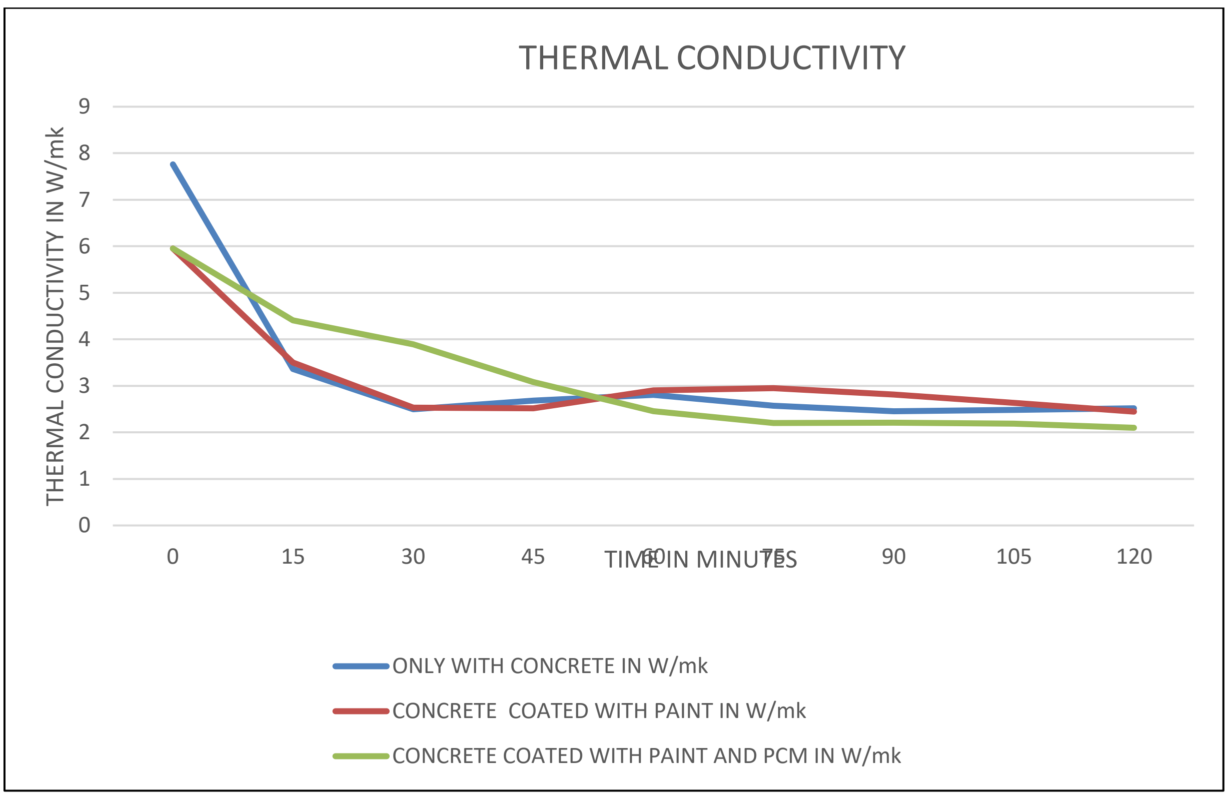

Figure 14: Temperature distribution in bottom surface

V. CONCLUSION

A potential approach to improve household energy efficiency and thermal comfort is the use of bio-based phase change materials (PCMs) made from coconut oil. Reducing dependence on non-renewable resources, this sustainable and environmentally friendly approach provides a renewable alternative to existing PCM sources. Paints made with coconut oil PCM help keep interior temperatures in control, which means less money spent on HVAC and less pollution from using fossil fuels. Easy application and integration are guaranteed by coconut oil PCM's compatibility with current construction materials. It helps create a better interior atmosphere since it is non-toxic and biodegradable. Coconut oil PCM improves passenger comfort due to its enhanced heat storage capacity. Aligning with worldwide efforts to mitigate climate change and attain carbon neutrality objectives, the use of PCM in paints derived from coconut oil promotes sustainable construction techniques. In conclusion, employing bio-based PCM in coconut oil house paints is an admirable move towards eco-friendly and energy-efficient home solutions. It shows promise for a better future for the environment and the people who live in it.

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