Investigation on composite phase change materials for energy-saving buildings

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Abstract. The building envelope plays a critical role in providing structures with the required energy and thermal comfort performance. Recent studies that concentrate on novel approaches and methodologies have incorporated improvement solutions in this area. The primary strategies used here are examined in order to pinpoint cutting-edge and successful approaches, with an emphasis on phase change materials (PCM). A growing number of building materials are incorporating PCMs due to their improved phase transition heat-storage and release capabilities. In this study, the melt impregnation process was used to create composites made of petroleum wax and metallic foam with a 90% porosity and pore densities of 10 PPI, 20 PPI, and 40 PPI. Two identically sized building models were constructed from gypsum board. Foam insulation board was used to cover the roof of the reference model, while phase change board made of 40 ppi copper foam composite was used to conceal the experimental model's roof. There was a steady flow of heat during the heat transfer experiment.

1. Introduction

Due to rising population numbers, fast urbanization, and high occupant thermal comfort standards in contemporary culture, the building industry is the world's most concerning energy user [1]. The major consumers of energy worldwide are buildings., according to the International Energy Agency (IEA), with the building envelope accounting for 35% of total energy use and 38% of CO_2 emissions in 2018 [2]. In order to enhance energy efficiency and decarbonize the built environment, many strategies should be practically implemented, particularly in poorly performing buildings situated in warm climates [3]. Phase change materials (PCM) have demonstrated a desirable impact of reducing the thermal load, leading to a spectacular energy savings [4–7], among other successful solutions, when included into building envelopes. Because PCMs have a tremendous capacity to store energy used in the process of melting and solidifying, they are used to minimize cooling and heating loads through the building envelope while maintaining an acceptable level of thermal comfort [8–11]. In order to get the best thermal behavior and maximum performance, new forms of PCM are being considered in this field of study, along with a variety of other approaches.
Because phase change materials (PCMs) can absorb or release large amounts of latent heat, they are used in energy-efficient buildings, interior warming, textiles, the military, aerospace, and other sectors [12–14]. The two primary types of phase transition materials used in heat storage are inorganic and organic. The majority of inorganic materials are metals and alloys, molten salts, crystalline water and salts, etc. In addition to having a stable melting point, better thermal conductivity, and a high heat storage density, inorganic materials are typically neutral [15,16]. The extensive applications of crystal water and salts are hampered by issues like super cooling and phase separation [17]. High phase transition

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temperature metals and metal alloys have strong exothermic speeds, quick heat storage, and thermal conductivity [18]. Fatty acids, polyols, and paraffin make up the majority of organic materials [19]. When it comes to curing, organic materials have superior molding properties in comparison to inorganic materials. Additionally, they often do not exhibit supercooling or phase separation phenomena. Although organic substances are inexpensive, safe, and stable, they have drawbacks such as limited energy storage density, low thermal conductivity, and easy volatility [20–23].

Buildings currently consume over 32% of all energy consumed, and their combined greenhouse gas emissions from residential and commercial structures now make up 30% of all emissions. As a result, attaining building energy conservation has emerged as the primary objective of national and international energy policies, and it is crucial to mitigate environmental pollutants and the energy crisis [24]. The following are the main characteristics of utilizing thermal storage technologies to reduce energy use in buildings: First, Ice and water are examples of low temperature heat storage materials that are utilized for controlling air conditioning load and cold storage [25]. Second, including latent heat storage material into the building materials will raise the structure's thermal inertia and lessen room temperature variations, which will lower the need for air cooling or heating and accomplish the goal of energy-efficient construction. For example, phase change materials are applied to concrete, walls, floors, and ceilings in combination with building envelopes or construction materials. Thirdly, latent heat storage material with a temperature of between 50 and 60 degrees Celsius are frequently used in heat absorption-based heating systems, such as passive or active solar greenhouses [26].

To sum up, phase change materials are excellent at both thermal insulation and heat storage. By absorbing a significant quantity of heat through phase change, a building's interior temperature variations can be lessened, increasing indoor comfort and lowering its indoor energy usage. Conventional organic phase transition materials, on the other hand, exhibit poor curing and molding effects along with limited heat conductivity. In addition to having a poor application effect, the conventional method of increasing thermal conductivity by adding metal particles and nonmaterial will eventually induce condensation and aggregation after several cycles of melting and solidification. The new metal foam materials are lightweight, have excellent skeleton structure, good heat conductivity, and absorb sound, among other qualities. The article suggests employing a porous framework structure to include petroleum wax, an organic phase shift agent, into the foamed copper. This approach has the potential to enhance the composite material's thermal conductivity while also streamlining the process of preparing a fixed-form material for construction purposes. In this study, composites made of petroleum wax and copper foam with varying pore densities and porosities were investigated for thermal conductivity. The use of phase-change composite materials made of petroleum wax and copper foam in buildings for energy conservation has been studied experimentally. The goal of the study is to lower greenhouse gas emissions from building energy use by examining the energy-saving capabilities of PCM composites in building models and their effect on interior temperature regulation.

2. Materials and Methods

The melt impregnation process was used to create three different types of phase transition materials made of wax made from petroleum wax and metallic foam with pore densities of 10 ppi, 20 ppi, and 40 ppi and a porosity of 90%. Research was done on how copper foam affected composite materials' thermal conductivity. The PCM building model and the reference building model were two cubic building models used in the heat transfer experiment. Both models had the same size and constant heat fluxes. The study looked into how building models' energy use was affected by materials that change phases, such as petroleum wax composite and copper foam.

2.1 Making composite materials

This experiment used petroleum wax with a 27°C melting point., taking into account the building's comfort level. Its thermal stability was evaluated by repeatedly melting and solidifying the wax. A refrigerator set at 0°C was used to cool the petroleum wax sample after it had been melted in a water bath maintained at a constant temperature of 70°C. This process was used 50 times to repeatedly melt and solidify the sample. A differential scanning calorimeter was used to measure the sample's thermal characteristics (DSC). After 50 cycles, the test revealed that petroleum wax has a melting point of about 27°C and that there has been little change in the latent heat of fusion.

To create a composite material, latent heat storage material is uniformly poured into the spaces left by the copper foam. This enhances latent heat storage material's thermal conductivity and curing molding action. This research project, petroleum wax at 27°C, pore densities of 10 ppi, 20 ppi, and 40 ppi, and copper foam with 90% porosity were chosen, respectively, to create composite phase transition materials.

After being fully submerged in the molten petroleum wax liquid, copper foam samples with porosities of 90% and pore densities of 10 ppi, 20 ppi, and 40 ppi were put in a refrigerator to solidify, accordingly. After the sample had fully set, it was removed, and the cutting process eliminated any extra petroleum wax.

3. Experimental method

Combinations of phase change materials and building materials, including concrete, walls, windows, and ceilings, have been used in construction envelopes numerous times. The south exterior wall of the building envelope and the roof have the largest cooling and heating loads. The latent heat storage material was placed on the roof because the experimenters determined that it would leak more easily due to gravity if it were positioned against the south external wall. Two identically sized, windowed cubic building models were constructed out of gypsum board, and a continuous heat source was used to mimic solar light. The reference model employs a thermal insulation foam board, while the PCM building model contains a composite phase change board composed of petroleum wax and 40 PPI copper foam.

In accordance with their increasing pore density, three copper foams of equal porosity rise in weight and price. For the heat transfer experiment, 40 PPI copper foam was chosen with the intention of applying it to building materials. Melt impregnation was used to create composite materials out of petroleum wax and copper foam. The reference model's roof used an insulating foam board of 300 × 300 × 5 mm, while the PCM model's roof used a composite phase change board made of 40 ppi metal foam and petroleum wax. To stop phase change materials from leaking, tin foil was used to seal the phase change board and the insulation foam board. The building model measures 300 × 300 x 300 mm in dimensions. There are two gypsum boards that make up the wall. There are two 200 × 100 mm double-glazed windows on the south exterior wall. One of the two models' roofs had a foam insulation board covering it, and the other had a composite phase change board.

In order to replicate sunlight, a steady heat source with a continuous 800 W heat flux was used during the experiment. During the heating process, the temperature was recorded using the data acquisition board, with a 5 s acquisition frequency. Every building model features six internal measuring points and one external measuring point. The center of the roof is the external measuring point, and the centers of the floor, ceiling, and walls are the locations of the six interior measurement points. The radiant heat source faced the south wall, which has a double-glazed window, directly across from the building models, which were positioned inside a well-insulated box. When the thermocouple's real-time data creates a computer curve and the temperature at each place stays constant, the experiment is terminated. For six hours, the temperature was continuously recorded. Although the humidity change is negligible and disregarded, it will nevertheless have an impact on the temperature change within the model during the experiment. Due to the limited size of the experimental model, the envelope load, personnel load, lighting load, and wet load were not taken into account while computing energy usage.

4. Results and Discussion

Figures 1-4 display the temperature change curves for the building model's floor, wall, ceiling, and roof with and without phase change. Temperature change curves for the roof and ceiling of building models, incorporating phase change materials, are shown in Figures 1 and 2. The PCM model's and the reference model's external roof curves were compared and found to be nearly identical at each acquisition point. This suggests that the two models' heating conditions during the experiment were similar. However, the phase change material's melting process is clearly responsible for the PCM model's apparent lag in temperature rise. It is evident that the PCM model's internal temperature change increases to 26.5°C before starting to decline.

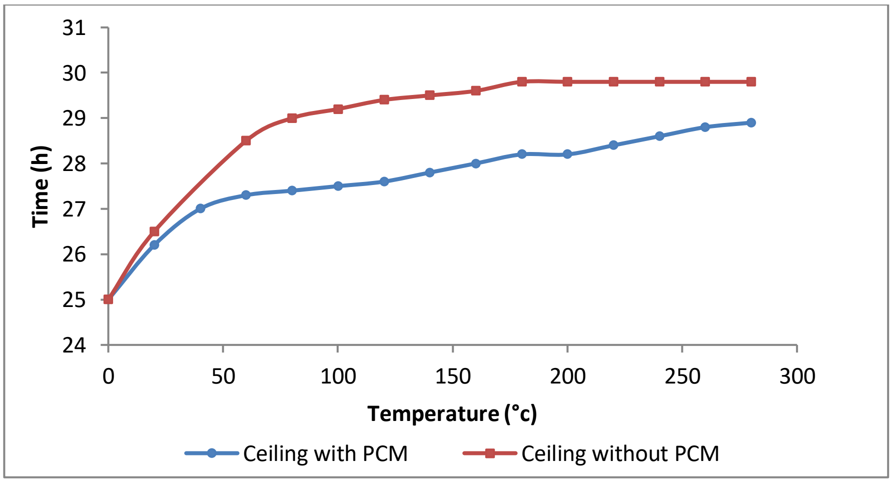

Fig. 1. Temperature change curves for the ceiling with and without phase change.

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The phase-change material melts at this point because it is absorbing heat. As long as the phase-change material's heat transmission continues throughout the melting process, the building model's interior temperature will rise while the heat transfer process through the other walls stays constant. Nonetheless, there was a noticeable decrease in the temperature change when compared to the reference model without a phase transition. In comparison to traditional thermal insulation foam board, the investigation indicated that the copper foam roof heat storage insulation board dramatically lowered the greatest inside temperature by 1.5°C and postponed its emergence by 2 hours.

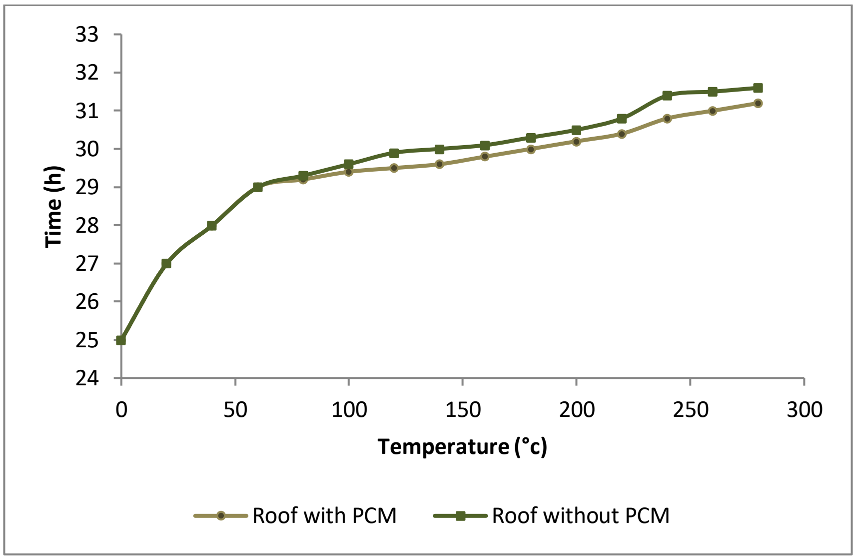

Fig. 2. Temperature change curves for the roof with and without phase change

The south wall's temperature change curve inside the building model is shown in Fig. 3. Because of the double-glazed window on the south wall and the radiant heat source located in the south, the temperature change curves for both phases of phase change are identical. The temperature change curves are essentially the same since the east and west walls have identical heating conditions. The east and west walls' rates of temperature rise are slower than that of the south wall. Because of its internal temperature change curves, which mimic the shaded surface of the actual building, the north wall's temperature rise rate decreases as the outside temperature rises. A comparison of temperature changes near the center of the floor in a building model regardless of phase-change materials is shown in Fig. 4.

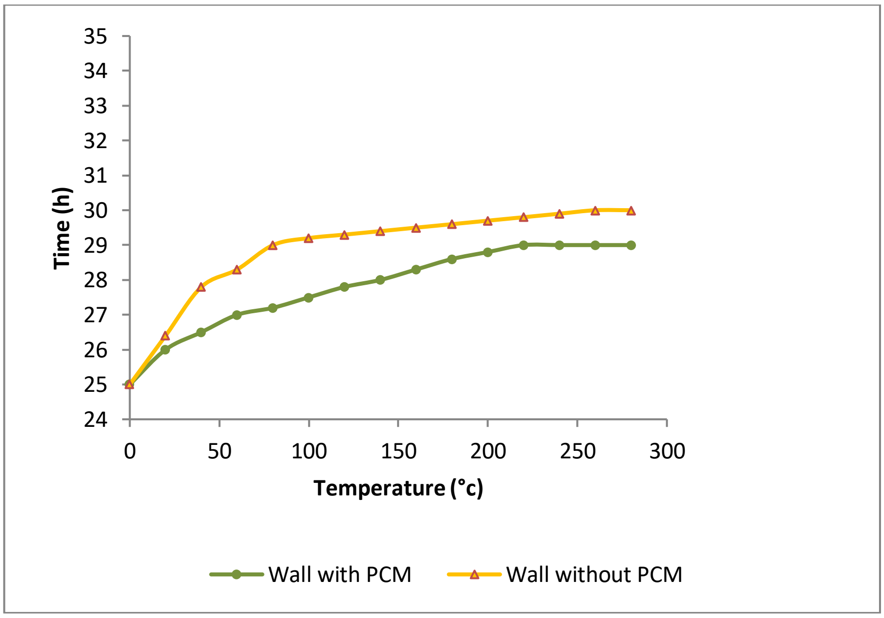

Fig. 3. Temperature change curves for the wall with and without phase change

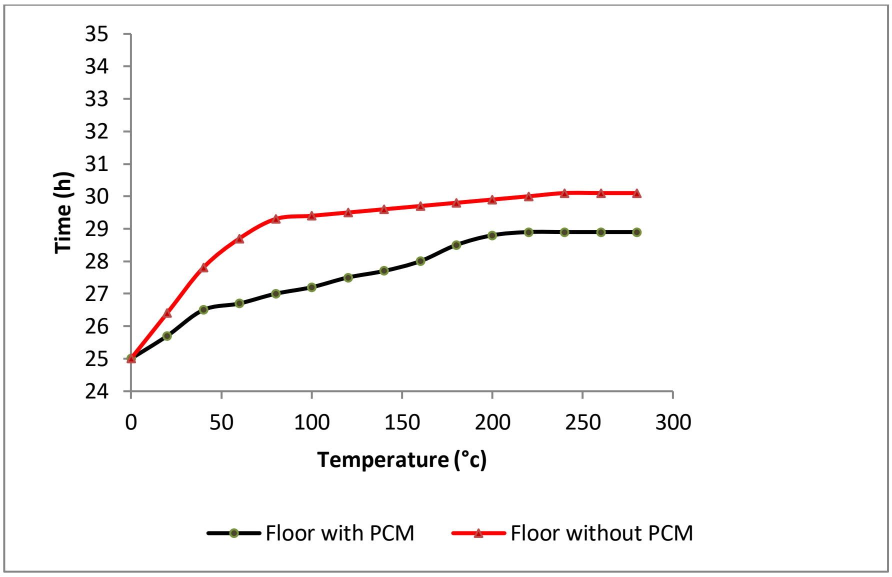

Fig. 4. Temperature change curves for the floor with and without phase change

For most civil structures, including residential, office, and commercial ones, the summertime internal design temperature falls between 25 and 28 degrees Celsius, depending on thermal comfort needs and central air conditioning system design. The experiment's temperature was used to determine the building model's hourly cooling load, with the design temperature in this article being 25 °C. The indoor cooling load grows in tandem with the external and indoor temperatures; nevertheless, there is some hysteresis in the phase change composites board model. This is explained by the fact that the latent heat storage material melts at a slower rate of temperature increase. The amount of cooling required indoors tends to stay consistent with the temperature. When compared to conventional insulating foam board, the usage of copper foam composites board in a building model can dramatically cut energy consumption by as much as 19%.

To summarize, a building model made by using copper foam composite latent heat storage insulation board did not achieve the maximum interior temperature for two hours, a 1.5-degree Celsius reduction in the maximum interior temperature, and a 19% reduction in indoor energy consumption. Consequently, utilizing phase-changing materials such as copper foam composite can greatly minimize indoor temperature swings and indoor energy usage.

5. Conclusion

This research describes the process of fabricating phase change composite materials by melting impregnation. Heat transfer studies are carried out and a 40 ppi copper foam PCM composite was selected for use in constructing models because of its practicality and affordability. We arrive to the following findings.

- Materials built with petroleum wax and copper foam composites have higher pore densities, which boost thermal conductivity three to six times. This is influenced by the copper foam's structure, whereby a higher pore density reduces the composite material's heat conductivity. The same porosity is used to observe this effect.
- The PCM building model had a noteworthy ability to postpone indoor temperature by 2 hours in comparison to the reference model. This resulted in a reduction of up to 1.5°C in indoor temperature as well as a 19% decrease in maximum indoor energy use.

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