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A newly composed paraffin encapsulated prototype roof structure for efficient thermal management in hot climate

Hussein J. Akeiber [a,*], Mazlan A. Wahid [a], Hasanen M. Hussen [b], Abdulrahman Th. Mohammad [c]

[a] Department of Mechanical Engineering, University Technology Malaysia, Malaysia
[b] Department of Mechanical Engineering, University of Technology, Baghdad, Iraq
[c] Baqubah Technical Institute, Middle Technical University, Baghdad, Iraq

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ABSTRACT

For efficient thermal management in the building under hot weather condition a new paraffin composition as suitable PCM is needed. Several notable attributes of paraffin wax including thermo-physical properties, open air atmospheric condition, economy, and environmental amiability make them suitable PCM for incorporation in the building. Thus, new PCM with massive storage of heat or cold in a specific volume is demanded. Iraqi local paraffin waxes as PCM are proven to be highly prospective due to their high-vitality thickness and isothermal conduct. However, thermal performance optimization of new PCM is pre-requisite to determine its effectiveness in hot climate location. We prepare three new PCM compositions with different oil to wax ratios from the crude petrochemical feed stock waste using fractionation followed by de-waxing and crystallization. The melting temperatures and flash points of these paraffin waxes are ranged between 19 and 44 °C and 177–256 °C, respectively, which upon encapsulation in the prototype roof construction are demonstrated to produce thermal comfort in rooms under hot climate (Iraq). Furthermore, these indigenous PCMs (local paraffin) are abundant, environmental friendly, economic and save electricity cost and HVAC (heating-ventilating air conditioning) systems. Experimental results displayed much reduced temperature fluctuation and internal heat flux of the prototype room than the commercial PCMs. Temperature profiles and solar irradiances inside the room on hot summer days in Bagdad showed remarkable electricity saving. This newly extracted PCM being non-flammable and thermally comfortable are truly secure for buildings construction worldwide.

1. Introduction

In the 21st century, finding an efficient and affordable green renewable energy sources is the foremost priority. Globally, the environmental affable energy is ever-demanding because of the rapid growth of economy and living standard. Building industry being the principal consumer of material and energy resources is highly potential for developing innovative energy saving and thermally efficient construction materials. To fulfill such ever-growing energy demand, a suitable alternative is to create energy stockpiling gadgets, which are as significant as developing new energy sources. In this regard, paraffin wax as PCM (phase change material) has emerged as a rising star material in the building construction. However, its potency is not fully exploited yet. Thus, PCMs asthermal energy storage systems is efficient methods for storing thermal energy [1]. According to the Memon study [2], the PCM can be integrated in buildings by direct incorporation (directly mixed with the construction materials), immersion (construction elements and wall boards are dropped into the liquid PCM), encapsulation (PCM surrounded with construction elements), shape-stabilization (high density polyethylene used to fabricate shape-stabilized PCM) and form stable composite PCMs (a composite PCM which retain an optimum/maximum percentage of PCM). To overcome such bottleneck, recyclable waste yet green materials such as local paraffin waxes are considered.

Rezaei et al. [3] reported the energy economy and efficiency of various PCMs with different melting temperatures. Based on the lumped-parameter method, Yuefeng et al. [4] developed an analytical temperature model and estimated the enthalpy difference function of two types composite materials made from

* Corresponding author. Tel.: +60 1111261344.
E-mail address: husseinUTM@yahoo.com.my (H.J. Akeiber).

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Nomenclatures

h_o	Heat transfer coefficient (W/m^2 K)
q_s	Heat flux (W/m^2)
T_{sol_air}	Sol temperature (°C)
T_{amb}	Ambient temperature(°C)

Greek symbols

α	Absorbtion coefficient
R	Thermal heat resistance (m^2 K/W)
U	Overall heat transferee coefficient (W/m^2 K)
K	Thermal conductivity (W/m K)
X	thickness (m)

inorganic salts. It is acknowledged that the calculated melting point and the enthalpy difference of the binary eutectic, $LiNO_3$—$NaNO_3$, LiCL—NaCL, and Li_2CO_3—Na_2CO_3 are consistent with the one obtained using standard methods. Several investigations are made to determine the performance of PCM integrated building walls. Romero-Sanchez et al. [5] evaluated the thermal performance of PCMs incorporated natural stone. Various experimental and computational studies are conducted on constructed concrete pilot houses to improve the thermal properties of natural stone by exploiting the associated latent heat storage phenomenon. These pilot houses are covered with trans-ventilated facade designs via the “Spanish Bateigazul” natural stone. Upon PCMs implementation, an improvement in human comfort and a reduction in energy consumption are revealed.

Izquierdo-Barrientos et al. [6] examined the influence of PCMs in external building walls. Different external wall configurations of a typical building are analysed by varying the PCM layer location, ambient conditions, wall orientation, and materials phase transition temperature. One dimensional (1D) numerical model of transient heat transfer is developed and solved using a finite difference technique. Interestingly, regardless of the wall orientation or the PCM transition temperature variation no significant reduction in the total heat loss (during winter) and heat gain (during the summer) is evidenced. Kuznik and Virgone [7] compared the thermal performances of PCM copolymer composite wallboard. A test room is constructed with two identical enclosures (Test Cells 1 and 2) each of volume 3.10 m × 3.10 m × 2.50 m, which are bounded on five sides by constant temperature regulated air volumes. The sixth face (glazed facade) isolated the test cell from a climatic chamber. In the presence of PCM, the air temperature inside the room is found to drop at 4.2 °C. Furthermore, room with PCM copolymer composite wallboard did not show any thermal stratification than the one without the composite.

Alvaro et al. [8] evaluated the environmental impact of a typical Mediterranean building composed of PCMs. A LCA (life cycle assessment) is carried out to highlight the critical issues related to three hypothetical scenarios by varying the temperature control systems, PCM types, and weather conditions. The inclusion of PCM in the building envelope is found to significantly reduce the energy consumption during building operations. However, the global impact of PCMs throughout the lifetime of the building remains insignificant. The use of hydrated salts (SP-25 A8) revealed a lower manufacturing impact (~75%) than paraffin (RT-27). Conversely, the LCA (life cycle assessment) for real cubicles exhibited an impact reduction of 37% when disposal polyurethane (PU) is added to the reference cubicle (REF).

Waqar et al. [9] assessed the effect of using phase change materials in buildings. The experimental results show that the using of PCM structures has significant advantages for space heating application. Navarro et al. [10] analysed the PCM performance in terms of internal thermal gains. Experiments are performed on three different cubicles each having internal dimension of 2.4 m × 2.4 m × 2.4 m located in Puigverd de Lleida, Spain. These cubicle systems are constructed as follows: (1) the REF is built by a traditional brick based on two layers with an air gap and without insulation; (2) the PU cubicle is built using a traditional brick with 5 cm and 3 cm of spray foam PU in the walls and in the roof, respectively; and (3) the PCM cubicle is built with a PCM layer in the southern and western walls as well as on the roof. The results during summer showed that the PCM cubicle stores the heat produced by the internal loads, thus limits the heat dissipation to the outer environment. The REF revealed higher temperature fluctuations (from 27.5 to 24 °C) in its envelope than other cubicles (28–26 °C) with insulation. Pasupathy et al. [11] both experimentally and theoretically studied the thermal performance of an inorganic eutectic PCM-based system for energy conservation in buildings. They conducted the experiment by designing two rooms one without PCM on the roof and the other with PCM panel between the bottom concrete slab and the rooftop wedge. Except the rooms ceiling, all walls are insulated by 6 mm thick plywood to determine the individual effect of PCM panel on the roof at varying room temperatures (27 ± 3 °C). The PCM panel consisted of 2 m × 2 m stainless steel having thickness of 2.54 cm. The stainless steel panel accommodated an inorganic salt hydrate (48% $CaCl_2$ + 4.3% NaCl + 0.4% KCl + 47.3% H_2O) as the PCM.

This paper reports the optimized thermal management of newly extracted PCMs (paraffin) from petroleum as potential TES systems suitable for building roof construction in Bagdad, Iraq. Three types of paraffin (PCM1, PCM2, and PCM3) are prepared for performance optimization. The evaluation is based on the thermal storage for the energy conservation via a portable system. This experimental system is a simplified model design for realizing the full scale experiment. Temperature inside the room is recorded by distributing thermocouples at various locations. Hourly temperature profiles and solar irradiances are recorded on hot summer days (August) in Baghdad. Results on temperature contours and entered heat flux in the prototype room are analysed and compared.

2. Incorporation methods of PCMs into construction

According to Hawes et al. [12], there are three prominent methods for integrating PCMs into the conventional construction materials. These include direct incorporation, immersion, and macro-encapsulation. The melting and freezing temperatures of PCMs are found to alter slightly when incorporated in building materials. It is worth to describe briefly each of these methods. (a) Direct incorporation: It is the simplest method in which liquid or powdered PCMs are straight added to building materials such as gypsum, concrete or plaster during production. No extra equipment is needed in this method. However, the leakage and incompatibility with construction materials are the main drawbacks. (b) Immersion: In this method, the building structure components including gypsum, brick or concrete, are dipped into melted PCMs to get them absorbed into their internal pores with capillary mediated elevation. Some researches affirmed the leakage problem not suitable for long-term use. Although, direct incorporation and immersion have different operation processes, but they both incorporate PCMs straightforwardly in conventional construction materials. (c) Macro-encapsulation: Here, the PCMs are encapsulated in a container such as tubes, spheres or panels. RUBITHERM produces a kind of PCM panels called CSM (construction solutions model),