EXPERIMENTAL EVALUATION OF PARAFFIN BASED PHASE CHANGE MATERIAL ON THERMAL PERFORMANCE IN BUILDING

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Dedicated to my beloved family

To the most precious persons in my life, my parents, brothers, sisters, wives and my sweetheart beautiful sons and daughters.

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ABSTRACT

The construction industry being the foremost consumer of material and energy resources requires energy savings as well as thermally efficient materials. Extreme hot weather conditions require a substantial amount of electricity consumption for appropriate thermal comfort. This is an economic burden and detrimental for sustainable development unless alternative solutions are developed. Therefore, thermal energy storage systems are thought to be a suitable alternative for efficient and green energy implementation in building design. This thesis investigated tailored thermal mass and heat comfort aspects (thermal management) of newly extracted phase change materials (PCMs) called local paraffin obtained from petroleum as potential thermal energy storage (TES) systems in the context of Iraq. Systematic experimentations were performed in collaboration with the Ministry of Petroleum (Iraq) as the provider of indigenously extracted PCMs to evaluate its thermal performance. Experiments were conducted using three types of local paraffin that are low cost and available as by-products of oil extraction. Three various compositions of paraffin including PCM1 (60% oil + 40% wax), PCM2 (50% oil + 50% wax) and PCM3 (40% oil + 60% wax) were used to determine the suitable mixture for the hot and dry climate environment. The performance evaluation was based on thermal storage for energy conservation via a portable system. This experimental system was simplified as model designs for realizing the full-scale experiment. Experimental results revealed that PCM3 is the best due to its high energy storage capacity. Two identical test rooms were constructed to determine the effect of PCM3 incorporation on heat transfer in the range of 40-44 °C on the roof and walls. The heat flux and temperature distribution inside the room without and with PCM were measured. The room containing PCM3 displayed higher resistance to flow and heat transfer. Furthermore, the effect of PCM installed roof thickness changes on the thermal performance of full scale test room was determined. It was confirmed that the PCM thickness variation in the roof has significant effect on the thermal performance of full scale test room where a higher thickness achieved better thermal performance (lower heat flux penetration and enhanced thermal comfort). Overall, reduced internal heat flux and temperature fluctuations were achieved with PCM3 encapsulation in the test room. The research has established that the local paraffin, (PCM3) with a low thermal conductivity has prospects for the construction industry in terms of its low electrical energy consumption.

ABSTRAK

Industri pembinaan merupakan pengguna utama bahan dan sumber tenaga yang memerlukan penjimatan tenaga serta bahan-bahan yang cekap haba. Keadaan cuaca panas melampau memerlukan sejumlah besar penggunaan elektrik bersesuaian dengan haba yang ada. Ini merupakan beban ekonomi dan menjejaskan pembangunan lestari melainkan penyelesaian alternatif dihasilkan. Oleh itu, sistem penyimpanan tenaga haba dianggap sebagai alternatif yang sesuai bagi pelaksanaan tenaga hijau serta efisien dalam reka bentuk bangunan. Tesis ini mengkaji jisim haba yang disesuaikan dan aspek keselesaan haba (pengurusan haba) bahan ubah fasa baru diekstrak (PCMs) yang disebut sebagai parafin tempatan yang diperolehi daripada petroleum sebagai sistem berpotensi penyimpanan tenaga haba (TES) dalam konteks Iraq. Eksperimen yang sistematik dijalankan dengan kerjasama Kementerian Petroleum (Iraq) sebagai pembekal PCMs asli yang diekstrak bagi menilai prestasi haba. Eksperimen ini telah dijalankan dengan menggunakan tiga jenis parafin tempatan yang rendah kos dan boleh didapatkan melalui hasil sampingan pengekstrakan minyak. Tiga komposisi pelbagai parafin terdiri daripada PCM1 (60% minyak + 40% lilin), PCM2 (50% minyak + 50% lilin) dan PCM3 (40% minyak + 60% lilin) digunakan untuk menentukan campuran yang sesuai bagi persekitaran iklim panas dan kering. Penilaian prestasi adalah berdasarkan penyimpanan haba bagi penjimatan tenaga melalui sistem mudah alih. Sistem eksperimen ini telah dipermudahkan menjadi reka bentuk model untuk merealisasikan eksperimen skala penuh. Hasil eksperimen menunjukkan bahawa PCM3 adalah yang terbaik kerana kapasiti penyimpanan tenaganya yang tinggi. Dua buah bilik ujian yang sama dibina untuk menentukan kesan penggabungan PCM3 terhadap pemindahan haba dalam julat suhu 40-44 °C pada bumbung dan dinding. Fluks haba dan taburan suhu di dalam bilik tanpa dan dengan PCM telah diukur. Bilik yang mengandungi PCM3 menunjukkan rintangan yang lebih tinggi kepada aliran dan pemindahan haba. Selain itu, kesan PCM yang dipasang dengan ketebalan bumbung berubah terhadap prestasi haba bilik ujian skala penuh telah dikenal pasti. Adalah disahkan bahawa perubahan ketebalan PCM pada bumbung mempunyai kesan yang signifikan ke atas prestasi haba bilik ujian skala penuh yakni ketebalan yang lebih tinggi memperolehi prestasi haba yang lebih baik (penembusan fluks haba yang lebih rendah dan keselesaan haba dipertingkatkan). Secara keseluruhan, fluks haba dalaman berkurang dan suhu berubah-ubah diperolehi dengan pengkapsulan PCM3 di dalam bilik ujian. Kajian ini menunjukkan bahawa parafin tempatan (PCM3) dengan kekonduksian haba yang rendah mempunyai prospek dalam industri pembinaan dari segi penggunaan tenaga elektrik yang rendah.

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LIST OF ABBREVIATIONS

ASHRAE	-	American Society of Heating, Refrigerating Air Conditioning Engineers
BS	-	Butyl Stearate
BTU	-	British Temperature Unit
CF	-	Carbon Fiber
CSM	-	Compact Storage Modules
DSC	-	Differential Scanning Calorimeter
EG	-	Expanded Graphite
HDPE	-	High Density Polyethylene Erythritol
HVAC	-	Heating, Ventilating and Air Conditioning System
LHS	-	Latent Heat Storage
LHTES	-	Latent Heat Thermal Energy Storage
MMA	-	Methyl Methacrylate
MEPCM	-	Microencapsulated Phase Change Materials
PCES	-	Phase Change Energy Solutions
PCMM	-	Phase Change Material Mortar
PCMs	-	Phase Change Materials
PEG	-	Polyethylene Encompassed Glycol
REFM	-	Reference Mortar
SEM	-	Scanning Electron Microscopy
SHS	-	Sensible Heat Storage
SS	-	Shape-Stabilized
St	-	Styrene
TES	-	Thermal Energy Storage
UF	-	Urea formaldehyde

LIST OF SYMBOLS

Cp	-	Specific capacity of heat (kJ/kg K)
Cp_L	-	Specific heat of liquid PCM (kJ/kg K)
Cp_s	-	Specific heat of solid PCM (kJ/kg K)
h_{sl}	-	Solid–liquid enthalpy change (kJ/kg)
T	-	Temperature (°C)
T_∞	-	Ambient temperature (°C)
U	-	Heat transfer coefficient
h	-	Enthalpy (kj/kg)
R	-	Thermal resistance (°C)
k	-	Thermal conductivity of aluminum
TWh	-	Tera Watt-hours
T_m	-	Melting temperature
k_S	-	Thermal conductivity of PCM at solid state
k_L	-	Thermal conductivity of PCM at liquid state
ρ_S	-	Density of PCM at solid state (kg/m^3)
ρ_L	-	density of PCM at liquid state (kg/m^3)
α_S	-	Thermal diffusivity of PCM at solid state
α_L	-	Thermal diffusivity of PCM at liquid state
h_0	-	Room outside heat transfer coefficient
h_i	-	Room inside heat transfer coefficient
q_s	-	Heat flux in w/m2
T_{Roof}	-	Roof temperature
T_{amb}	-	Ambient temperature
α	-	Absorption coefficient

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CHAPTER 1

INTRODUCTION

1.1 Background of Research

The energy needed to cool and heat buildings is considered critical in countries where air conditioning and cooling/heating systems are utilised in residential and commercial buildings. Because of the increase in energy demands from these systems, proper insulation in floors, roofs and walls of buildings is essential in decreasing the rate of thermal flow during winter and summer seasons. The choice of a reliable insulation material by evaluating its heat characteristics in every weather condition would go a long way in improving the building's economics. Moreover, the development of an ideal lagging duration for thermal flux entering into buildings through energy storage constitutes other means of regulating the quality of interior air. Storing energy could be undertaken through latent and sensible forms. In sensible heat storage (SHS), storing energy may only be achieved by altering the liquid or solid temperature. The SHS mechanism uses the thermal capacity as well as the shift material temperature in the discharging and charging processes. The quantity of conserved heat is dependent upon the storage material quantity, the change in temperature and the specific thermal medium (Sharma *et al.*, 2009). The global increase in human population is likely to increase the demand for energy in future. Control systems utilised for maintaining interior comfort are commonly classified as heating, ventilation and air-conditioning (HVAC) systems. These systems explain why buildings have high-energy demands. In latent energy storage, storage of energy is undertaken by modifying the phase of the material and through latent heat. The energy is preserved in the PCM in a latent form. A PCM refers to a substance containing maximum fusion heat, which, through melting and solidification at a given temperature, can store and release significant energy quantities. Thermal absorption and release occur when there is change of materials state from liquid to solid or solid to liquid; in view of this, PCMs are categorised as latent heat storage (LHS) (Farid *et al.*, 2004; Khudhair and Farid, 2004). PCMs refer to compounds that melt into liquid under a slight temperature increase. Through such a process, they absorb, store, and discharge significant quantities of thermal energy called latent heat. This energy drives the phase transitions without changing the materials' temperatures. Sensible thermal energy relies on the material's specific thermal capacity as well as the change in temperature (Dincer and Rosen, 2002). In addition, the paraffin has many distinct and useful attributes such as high heat of fusion; wide temperature variation, negligible super cooling, and low vapour pressure melt, low cost and easily available.

Moreover, the PCM heat conductivity is not significant as that for bricks. Thus, PCMs may function as storage materials and as insulators. Due to such benefits, PCM application as building materials was used in the last 10 years. The properties of PCMs make them ideal for conserving energy. Materials to be utilised in phase change heat-energy storage should have significant latent heat as well as high heat conductivity. They ought to have a melting temperature existing in the operation practical range, melt congruently under lower sub-cooling and exhibit chemical stability, affordability, non-toxicity and non-corrosion.

The present research is an attempt to implement PCM extracted paraffin from petroleum in country which produces oil with hot and dry climate to be used as a building material. To evaluate the thermal performance of this paraffin; appropriate materials are selected, test rooms are made using these materials, experiments are attributes on PCMs constructed test rooms, practical realizations are made by constructing prototype model and full scale test rooms under hot climatic conditions.

1.2 Problem Statement

Lately, numerous experimental researches were performed on PCMs to determine the feasibility of applying them as high performance building construction materials in terms of thermal management. Iraq being a major producer of crude petroleum oil and related products, from which paraffin is highly abundant at low cost. Despite their availability, local paraffin as PCMs for building purposes are not explored yet. Thus, it is vital to explore the possibility of using locally extracted paraffin as a thermal storage material in hot and dry climate buildings' construction, where the consumption of electricity is too high and expensive for maintaining the air conditioning and heating/cooling systems in the nation. Moreover, except for three months over the year, hot and climate region as well as majority of the Gulf States face severe summer with temperatures as high as 55°C. During such extreme hot weather condition the sensitive expensive devices and technology housed in the building faces problem due to sudden power cut and major shut-down. Failure of such costly equipment often causes high economic losses for the nation as such as DNA device which inside building. To beat such high heat climate and discomfort during summer days, huge air-conditioning set-ups are prerequisite in the building architecture to keep them cool and comfortable. This is quite expensive and not environmentally friendly. Therefore, alternative economic routes are needed to be developed such as using local paraffin as useful PCM.

In terms of national economy and power budget, maintaining such an air-conditioning system using a traditional electricity production is quite expensive. Simultaneously, it causes environmental pollution due to large amount of fossil fuel burning. In this view, there is an urgent necessity to exploit such locally extracted inexpensive paraffin as PCMs for building construction. So far, not much research is dedicated to inspect the efficiency and potency of these PCMs as a high performance building material suitable for thermal management. It is necessary to extract paraffins and use them as prototype and full scale materials to construct test rooms and to evaluate their thermal performance. Upon successful prototyping, these PCMs can be implemented in full scale to construct rooms and their careful evaluations must be made in terms of thermal performance, temperature distribution under ambient condition, latent heat formation, heat storing capacity and thermal expansion, and so on.

It is essential to select the best PCM from the composition that have the necessary attributes as PCMs required for thermal comfort. Yet, the local paraffin as PCM is not yet implemented in hot climate region buildings and their thermal efficiencies during peak summer season is not assessed. Literatures reveal that these PCMs may be a suitable choice as building construction material in terms of economy and environmental friendliness. In this regard, present research is the first attempt to exploit locally extracted paraffins as thermal storage materials under hot weather condition. To realize their commercial viability, a full-scale evaluation is essential. Then, it can be implemented on large scale to achieve the objectives. This study is not only limited to Iraq but also to other nations where similar hot climate prevails throughout the year.

So far, no investigations are carried out to realize the implementation of local paraffin as thermal storage materials in the building construction in the nation. Furthermore, thermal performance and heating/cooling efficacy of such paraffin as PCMs is far from being understood. Thus, implementation, evaluation, and practical realizations of paraffins as building construction materials are imperative. This development is expected to have great implication on national economy in terms of electricity consumption and environmental pollution arising from burning of fossil fuels.

From the comprehensive literature review it is evidenced that majority of the previous researches (about 60%) focused on the commercially available organic PCM (paraffin) for building passive cooling although few used inorganic PCM. Undoubtedly, different types of paraffin are widely popular as PCM. It is obvious that interests on paraffin as PCM is ever growing due their high heat of fusion, considerable compatibility with most of building envelope material and excellent chemical stability.

An efficient PCM composition with unique physical and thermal specifications is lacking for building management to control the temperature fluctuation inside the buildings. The hydrocarbon is local paraffin wax with chemical composition C_nH2_{n+2} are expected to be suitable for this purpose. Moreover, all other earlier researchers dealt with commercially available paraffin from the industry. It is worth mentioning that the composition of these standard paraffins varied depending on the nature of crude oil and their sources. Thus, they are often unstable and produce more heat flux. It is necessary to extract a new paraffin composition with melting temperature that can vary over a wide range (typically between 15 to 60 °C). This wide temperature variation is believed to be very much suitable for countries where the temperature changes over the year are wide.

Previous researches implemented the paraffin only in the roof or within the wall structure where the maximum environmental temperature not exceed 30 °C. However, in practical situation especially in hot and dry country the temperature variation over the year is large and the maximum summer temperature can reach up to 55 °C. Thus, the suitability of these extracted materials requires a testing around this temperature by making suitable prototype roof and wall structure at full scale with the implementation of locally extracted new paraffin types. Earlier researches were conducted with prototype building structure, where commercially available standard paraffin is either put on the wall or on the roof. Thus, systematic study must be conducted with room structure containing local paraffin at both roof and wall to maintain the thermal comfort and reduce energy consumption

1.3 Research Hypothesis

This research aims to study the thermal performance of different compositions of wax materials to choose the material that best suits hot and dry weather conditions. Use of this locally extracted paraffin is expected to be the best

PCMs for reducing energy consumption inside buildings in hot and dry climate conditions not only in Iraq but elsewhere.

The usage of the local waxes (paraffin) extracted from crude oil, particularly from the Iraqi petroleum companies can help to regulate the energy consumption in buildings efficiently and thus provide suitable thermal conditions. Furthermore, this sort of reduction can minimise the electrical energy consumption and thermal load required to sustain and maintain the efficiency of HVAC systems.

1.4 Objectives of the Research

The research aims to achieve the following objectives:

i. To determine the thermal performance of various PCMs composition for identifying the best among them by using prototype model.
ii. To evaluate experimentally the capability of the selected best PCM in a full scale test room for reducing the temperature fluctuation and saving the energy consumption in buildings within high temperature environment.
iii. To determine the effect of PCM installed roof thickness variation on the thermal performance of full scale test room.

1.5 Scope of the Research

The proposed goal is achieved via the following stages:

i. Extraction of low cost local paraffin with new compositions to be implemented as PCM.

ii. Selection of the best PCM composition in terms of suitable thermal and physical properties.

iii. Construction of a prototype model and full-scale test rooms by implementing the best PCM to determine its thermal performance useful for hot and dry climate condition.

iv. Experimental evaluation of thermal performance in terms of comfort, heat flux and temperature fluctuation under ambient conditions with solar radiation for summer season (August).

Three compositions of paraffinic wax are derived from crude oil as storage materials for thermal energy commensurate with the ambient conditions in hot and dry climate region. Temperatures in these test rooms were recorded and their heat loads were determined.

These paraffin materials (compositions) were implemented in prototype and full-scale constructed test rooms. Experimentations on these test rooms (prototype and full scale without and with PCMs) were performed. As a case study, prototype testing is performed with all three types of materials which are implemented only on the roof structure according to the weather condition. This is to identify the best composition that can be implemented for full scale study. The best material from the prototype is now implemented for full scale investigation. Afterward, January and August are selected for full scale test room for thermal performance determination because of two main reasons. Firstly, the climate pattern in hot and dry region during past few years is found to remain unchanged without rapid fluctuations. Secondly, summer is the hottest season when the temperature is high and the consumption of electricity is the highest to maintain the room cool by air-conditioning.

For both experiments two similar test rooms are designed. The first room contained the appropriate PCM in the walls and ceiling and the second room without PCM to compare the thermal performance. The heat load of the rooms was calculated by using the commercial software Carrier v 4.6. Thermocouples were placed inside the two rooms to measure the temperature during the aforesaid period of time.

1.6 Research Significance

The significances of the present research are as follows:

i. Maintaining the thermal comfort with reduced temperature fluctuation by covering the building surfaces with PCM material.
ii. Making use of the locally extracted new type of paraffin from the remnants of crude oil.
iii. Increasing the efficiency and performance of HVAC systems and thus increase their working life, save the cost, increase the durability of expensive devices as such as DNA inside building, and reduce electricity consumption.

Careful experimental evaluations for thermal performance of this new paraffin composition as PCMs may bring important information useful for future implementation. Usage of this economical and easily available paraffin is expected to solve future crisis related to fossil fuel based electricity production. Upon successful implementation, most of the Gulf States and hot and dries countries possessing hot climate conditions may get tremendous benefits from using local paraffin for maintaining thermal comfort inside buildings to save power budget and to maintained the sensitive device as such as DNA inside building.

1.7 Thesis Outline

This thesis is organised in five chapters. Chapter 1 introduces the background of the study, problem statement, objectives, scope and significance of the study. Chapter 2 reviews the literature covering the classification of the phase change materials and their applications. Chapter 3 demonstrates the framework of research methodology to achieve the research goal. Chapter 4 discusses in detail the results on analyses, interpretation using different mechanism, validation and comparison. Chapter 5 concludes the thesis based on the research findings, contributions, and accomplishments of the proposed objectives. It also highlights the further work that can be done as recommendations.

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