DEVELOPMENT OF PHASE CHANGE MATERIAL (PCM) WALLBOARD FOR BUILDING PASSIVE COOLING APPLICATIONS

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Faculty of Mechanical and Manufacturing Engineering Technology

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MUHAMMAD HAZIM BIN AHMAD ZULKAFLI

A thesis submitted
in fulfillment of the requirements for the degree of
Bachelor of Mechanical Engineering Technology (Refrigeration and Air-Conditioning System) with Honours

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2023

DECLARATION

I declare that this Choose an item. entitled " Developement of Phase Change Material (PCM) Wallboard for Building Passive Cooling Applications" is the result of my own research except as cited in the references. The Choose an item. has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Mechanical Engineering Technology (Refrigerantion and Air-Conditioning System) with Honours.

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DEDICATION

This research paper is dedicated to my dear father who has been nicely my supporter until my research was fully finished. Also, my beloved mother who has encouraged me attentively with her fullest and truest attention to accomplish my work with truthful self-confidence. I also dedicate this dissertation to all my friends who have supported me throughout the process. I will always appreciate all they have done.

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ABSTRACT

Air-conditioning systems are used to fulfill the demand of cooling for building spaces worldwide. However, these vapor-compression refrigerantion systems consume a large amount of electricity. The processes to produce electricity can cause a huge impact to the environment such as climate change and global warming because of the CO_2 emissions. This lead to the necessity of developing new energy-efficient technology for air conditioning systems. The alternative method that presented in this study is by integrating phase change materials (PCM) into wallboards as structural building materials with additional latent heat storage capacity that can increase the thermal mass of the building materials. During daytime, PCM absorbed the heat gain by the wallboard and during night time the heat absorbed is rejected back to the surrounding. The fabrication of the wallboard employed V-shape slot method. Plastic also used to avoid leakage of the PCM from the wallboard. Eutectics PCM were made of the combination of coconut oil and paraffin wax. The melting temperature of eutectics PCM selected was 28°C which made of 90 wt% of coconut oil and 10 wt% of paraffin wax. This passive cooling technique could maintain the indoor temperature thus provides thermal comfort for the occupants and reduce the electric energy consumption in buildings. A PCM-integrated wallboards was fabricated according to the parameters to be investigated. The parameters are the mixing ratio of the eutectics PCM and the layer components of the wallboard. The wallboards consist of eutectics PCM, thermal sheet and aluminium foil. The overall size of the wallboard was 6" x 6" x 6" with total thickness of the wall was 3cm. The study aim is to evaluate the performance of the PCM-integrated wallboards in reducing indoor building temperature by applying heat load to cubicle PCM wallboard made from the wallboards as its main structural materials. The result shows that cubicle PCM wallboard can maintain the indoor temperature effectively. Day and night temperature tests for cubicle PCM wallboard were with different surrounding temperature i.e. 25°C and 35°C respectively. The temperature of cubicle PCM wallboard maintain the indoor temperature at 29.3°C for 15 minutes and rise by 0.1°C for every 5minutes. Meanwhile, the wallboard without PCM kept indoor temperature at 29.4°C for 10 minutes and keep increase about 0.1°C for every 5 minutes. For night temperature surrounding test at temperature of 24°C, cubicle PCM wallboard can steadily maintain indoor space temperature within range of 26°C to 27°C. However, the indoor space temperature for cubicle wallboard without PCM kept decrease from 25.3°C to 23.3°C. It can be conclude that PCM can effectively reduce the temperature fluctaution of indoor space at 26°C - 28°C within the human comfort temperature. This study proved that PCM can potentially be used as alternative solution for the conventional energy consumption of the compressor-driven refrigeration systems. The advantages of PCM are low maintanance required and energy free which makes it attractive and technically feasible for passive cooling systems in buildings.

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ABSTRAK

Sistem penyaman udara digunakan untuk memenuhi permintaan penyejukan untuk ruang bangunan di seluruh dunia. Walau bagaimanapun, sistem penyejukan mampatan wap ini menggunakan sejumlah besar elektrik. Proses untuk menghasilkan tenaga elektrik boleh menyebabkan impak yang besar kepada alam sekitar seperti perubahan iklim dan pemanasan global kerana pelepasan CO_2. Ini membawa kepada keperluan membangunkan teknologi baru yang cekap tenaga untuk sistem penyaman udara. Kaedah alternatif yang dikemukakan dalam kajian ini ialah dengan mengintegrasikan bahan perubahan fasa (PCM) ke dalam papan dinding sebagai bahan binaan struktur dengan kapasiti penyimpanan haba pendam tambahan yang boleh meningkatkan jisim haba bahan binaan. Pada waktu siang, PCM menyerap penambahan haba oleh papan dinding dan pada waktu malam haba yang diserap ditolak kembali ke persekitaran. Pembuatan papan dinding menggunakan kaedah slot bentuk-V. Plastik juga digunakan untuk mengelakkan kebocoran PCM dari papan dinding. Eutektik PCM dibuat daripada gabungan minyak kelapa dan lilin parafin. Suhu lebur PCM eutektik yang dipilih ialah 28°C yang diperbuat daripada 90% berat minyak kelapa dan 10% berat lilin parafin. Teknik penyejukan pasif ini boleh mengekalkan suhu dalaman sekali gus memberikan keselesaan terma kepada penghuni dan mengurangkan penggunaan tenaga elektrik dalam bangunan. Papan dinding bersepadu PCM telah direka mengikut parameter yang akan disiasat. Parameternya ialah nisbah pencampuran PCM eutektik dan komponen lapisan papan dinding. Papan dinding terdiri daripada PCM eutektik, kepingan haba dan kerajang aluminium. Saiz keseluruhan papan dinding ialah 6” x 6” x 6” dengan jumlah ketebalan dinding ialah 3cm. Matlamat kajian adalah untuk menilai prestasi papan dinding bersepadu PCM dalam mengurangkan suhu bangunan dalaman dengan menggunakan beban haba pada papan dinding PCM kubikel yang diperbuat daripada papan dinding sebagai bahan struktur utamanya. Hasilnya menunjukkan papan dinding PCM kubikel boleh mengekalkan suhu dalaman dengan berkesan. Ujian suhu siang dan malam untuk papan dinding PCM kubikel adalah dengan suhu sekeliling yang berbeza iaitu masing-masing 25°C dan 35°C. Suhu papan dinding PCM kubikel mengekalkan suhu dalaman pada 29.3°C selama 15 minit dan meningkat sebanyak 0.1°C untuk setiap 5minit. Sementara itu, papan dinding tanpa PCM mengekalkan suhu dalaman pada 29.4°C selama 10 minit dan terus meningkat kira-kira 0.1°C untuk setiap 5 minit. Untuk ujian sekeliling suhu malam pada suhu 24°C, papan dinding PCM kubikel boleh mengekalkan suhu ruang dalaman secara berterusan dalam julat 26°C hingga 27°C. Walau bagaimanapun, suhu ruang dalaman untuk papan dinding kubikel tanpa PCM terus menurun daripada 25.3°C kepada 23.3°C. Dapat disimpulkan bahawa PCM boleh mengurangkan turun naik suhu ruang dalaman dengan berkesan pada 26°C - 28°C dalam suhu keselesaan manusia. Kajian ini membuktikan bahawa PCM berpotensi boleh digunakan sebagai penyelesaian alternatif untuk penggunaan tenaga konvensional sistem penyejukan dipacu pemampat. Kelebihan PCM adalah memerlukan penyelenggaraan yang rendah dan bebas tenaga yang menjadikannya menarik dan boleh dilaksanakan secara teknikal untuk sistem penyejukan pasif dalam bangunan.

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LIST OF SYMBOLS AND ABBREVIATIONS

GHG	-	Greenhouse Gases
CO_2	-	Carbon Dioxide
CCPI	-	Climate Change Performance Index
HVAC	-	Heating Ventilating Air Conditioning
VRV	-	Variable Refrigerant Volume
PCM	-	Phase Change Material
CFD	-	Computational Fluid Dynamics
FEMs	-	Finite Element Methods

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CHAPTER 1

INTRODUCTION

1.1 Background

Nowadays, global warming is a severe threat to the Earth and it has a wide range of adverse environmental consequences. The root cause of this phenomena is greenhouse gas (GHG) emissions, particularly CO_2. Most of the CO_2 emission are ariginated from vehicles, power plant and buildings. Futhermore, buildings commercial and residential buildings sectors are the major contributors to the rising of fossil fuel consumption. Building sectors employ active cooling systems such as air conditioning to achieve indoor thermal comfort. These systems consume a large amount of electricity. In fact, buildings account for about 40% of total global energy consumption and CO_2 emissions. Figure 1.1 shows the percentage of world CO_2 emissions by sector.

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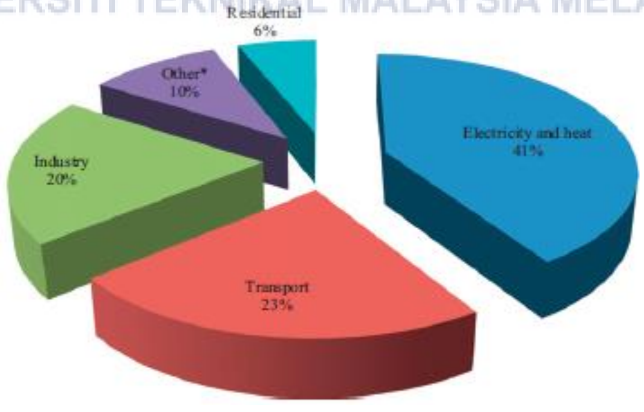

Figure 1.1 World CO_2 emissions by sectors

Electricity and heat sectors produce a higher CO_2 emissions with 41% meanwhile residential sectors produce 6% of CO_2 emissions. Next, transportation sectors produce 23%

and industry sectors produce 20% of CO_2 emissions. While, the other sectors produce 10% of CO_2 emissions.

Malaysia are also one of the world's greatest CO_2 emissions country. In the climate change performance index (CCPI), Malaysia is categorised as "in trouble" in terms of its ability to regulate carbon dioxide emissions. Malaysia is ranked 51 out of 61 countries, with a very low rating, as shown in Figure 1.2.

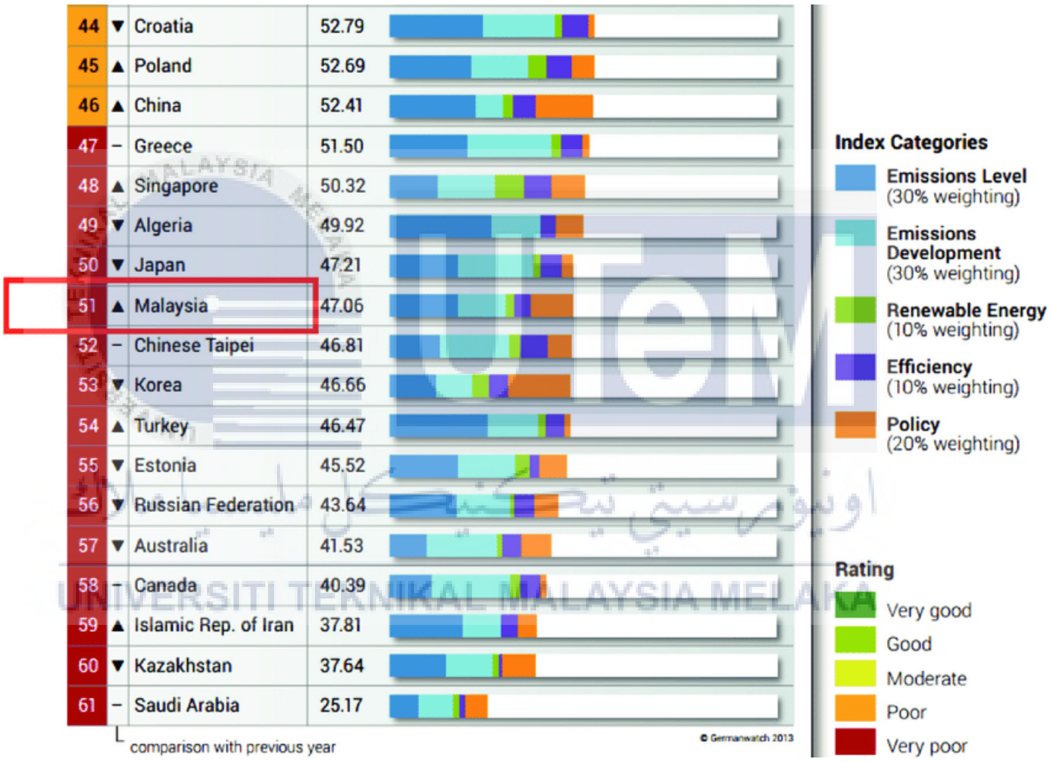

Figure 1.2 World CCPI ranking

Malaysia ranking is 51 over 61 countries above Chinese Taipei and below Japan. The performance index is based on 30% of emissions level, 30% of emissions developement, 10% renewable energy, 10% efficiency and 20% policy. Malaysia rating in world CCPI is very poor. As a result, Malaysia is one of the worst countries in terms of CO_2 emission control. Therefore, more environmentaly friendly approaches are paramount in reducing CO_2 emission due to fuel burning for transportation, industrial and air conditioning systems.

In addition, Malaysia is one of a country that is located in high environment temperature zone because of its geological location. People in hot countries use air conditioning devices as a cooling strategy to cool and attain thermal comfort in buildings. Air conditioning system is a popular techniques used to cool building spaces worldwide. Unfortunately, air conditioning devices consume high energy to drive and maintain its operation.

There are two major categories of cooling techniques i.e. active and passive. Active cooling techniques cover all HVAC systems such as split unit air conditioning, variable refrigerant volume (VRV) and chiller. Active cooling utilize electric energy to operate. On the other hands, the utilization of energy available from the natural environment rather than consuming conventional energy resources is referred as passive cooling. Figure 1.3 shows the categories of cooling techniques.

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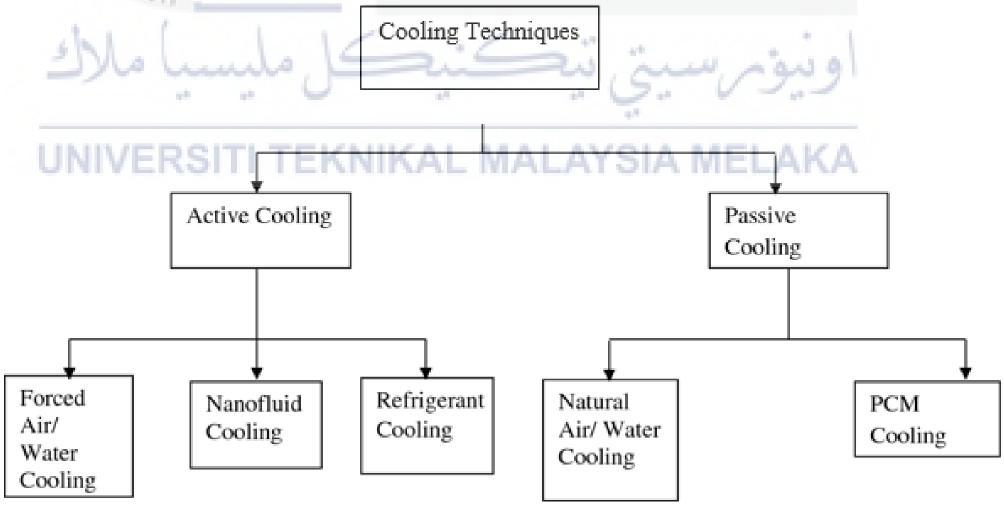

Figure 1.3 Categories of cooling techniques

Active cooling consist of three types of cooling which are forced air and water cooling, nanofluid cooling and refrigerant cooling. Passive cooling consists only two types of cooling medium which are natural air or water cooling and Phase Change Material (PCM) cooling.

Utilization of PCM is a promising option for a passive cooling technique to create a comfort temperature range in a building. PCM is a material that releases, absorbs and stores latent heat energy to generate useful heat and cooling. PCMs use latent heat during the processess of changing phases to control temperatures within a specific range. Therefore, PCMs are also called latent heat storage materials. There are four general types of PCM, they are liquid-gas, solid-solid, solid-liquid, solid and gas PCMs. Among of all the types of PCM, the most technically suitable for building cooling and heating application is solid PCM.

PCM for building applications have melting point within the human comfort temperature range. When the surrounding temperature rises and the PCM reaches its melting point, the secondary chemical bonds begin to break off and allowing the PCM to absorb energy while the material melts. This phase change of the PCM from solid to liquid is called charging process. Oppositely, when the surrounding temperature drops below the freezing point of PCM, the secondary bonds begin to reform and heat is released exothermally. This discharging process restores the solid state of the PCM. Therefore, PCM also can be assumed as a thermal reservoir. The entire charging and discharging process results in a minor volume change which is less than 10% of the original volume. Daily temperature swing during day and night conveniently fasilitate the repeated cycle of charging and discharging of PCM as illustrate in Figure 1.4.

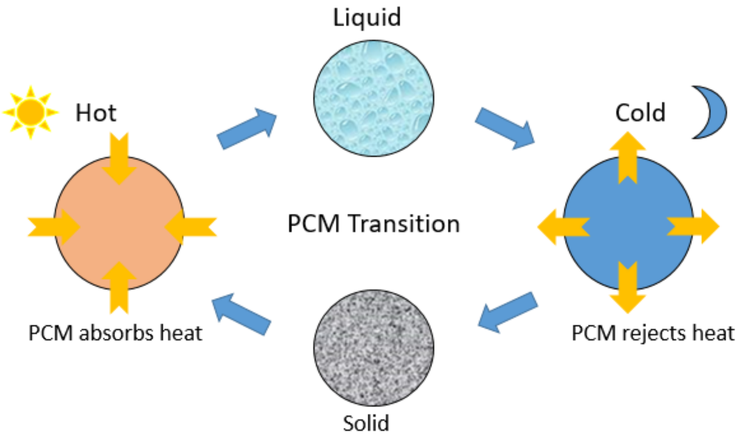

Figure 1.4 Phase change of PCM in response to surrounding temperatures

During daytime, PCM absorb and store energy and changes its phase from solid to liquid. The melting of the PCM occurs when the temperature of surrounding is higher than the PCM melting point. Meanwhile, PCM release heat and change its phase from liquid to solid during night time when the surrounding temperature drops below its freezing point.

By altering the effective thermal mass, PCM can improve the building's thermal responsiveness to temperature fluctuation inside the building space. Normally, paraffin and fatty acid are PCM employed in building applications. Figure 1.5 shows the photo of a paraffin wax.

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Figure 1.5 Paraffin wax

Paraffin wax and fatty acid such as coconut oil can be combined together to create eutectics PCM. Eutectics PCM can be mixture between organic and organic, organic and inorganic or inorganic and inorganic PCM. The main purpose of creating eutetics PCM is to get suitable value of freezing point and melting point based on the operation temperature where these materials are applied.

These materials act as energy storage medium, absorbing and discharging heat to keep a constant temperature. PCM provides reduction of daily temperature changes, shifts peak demands, temporarily storage for renewable energies such as solar and geothermal energy, and offer free cooling alternative for buildings. Figure 1.6 shows the working principle of PCM in a building during day and night.

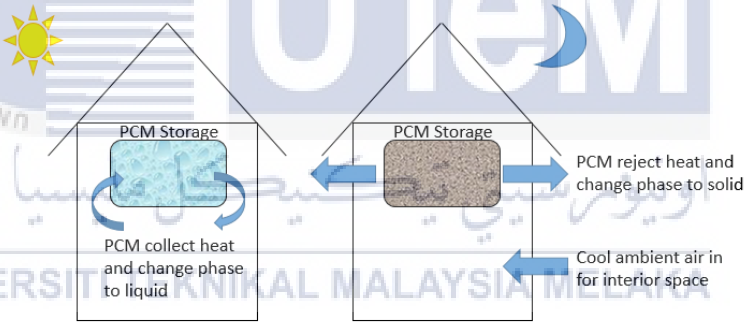

Figure 1.6 The illustration of PCM work in building

PCM absorb and store heat in the building during day time to give comfort temperature to the indoor space. This process changes the state of PCM from solid to liquid. Then, PCM reject heat to the outside surrounding of the building during night time. This process allow the cool ambient temperature from the outside to enter to the interior space. The state change of PCM during night time is from liquid to solid. These melting-solidifying cycles of PCM are then repeated and the comfort temperature in the building is maintained.

PCM can be incorporated into building structural components such as roof, ceiling, floor and wall. The example of layering PCM in the building wall is shown in Figure 1.7. PCM are placed between the capillaries and the wall.

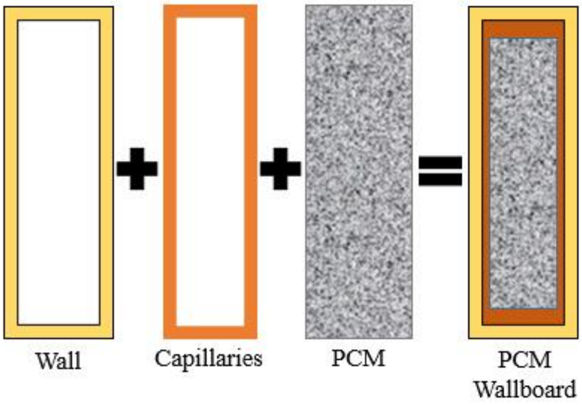

Figure 1.7 The example of layering PCM in a building wall

The main layer of the building wall above are capillaries, PCM and wall. Capilaries are use to cover the PCM for air space and avoid leakage of the PCM. The combination of the capilaries and PCM is placed inside the wall. The complete combination of the three materials is called PCM wall. These kind of PCM walls are used in buildings to provide passive cooling to create comfort temperature inside building.

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PCM-incorporated wallboards are fabricated and developed to replace conventional wallboard. Adding PCM into a building's structure increases thermal mass of the building envelope and keeps heat out of the occupied space. Thermal masses of conventional wallboards are associated solely to sensible heat. The energy absorbed by latent heat is substantially higher than the energy absorbed by sensible heat. In other words, heat interactions in PCM building materials involve both sensible and latent heat. Therefore, the increase of thermal mass of wallboard that incorporated with PCM is substantial. For example, a wallboard with PCM has a higher heat capacity compared to a normal one of the same size. Figure 1.8 shows an example of PCM integrated wallboard in a reduce scale test room.