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INVESTIGATION ON THE EFFECTIVENESS OF USING PHASE CHANGE MATERIAL AS AN ENERGY-FREE PASSIVE COOLING SYSTEM IN BUILDINGS

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor's of Mechanical Engineering Technology (Refrigeration and Air-Conditioning System) (Hons.)

by

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BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

TAJUK: **Investigation on the Effectiveness of Using Phase Change Material as an Energy Free Passive Cooling System in Buildings**

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APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering Technology (Refrigeration and Air-Conditioning System) (Hons.). The member of the supervisory is as follow:

……………………………….

(Project Supervisor)

ABSTRACT

Most of the current air-conditioning system consumes large amount of electricity. If measures are not taken, it will give adverse impact to the environment such as global warming and climate change. This leads to the necessity of developing new energy-efficient technology for air-conditioning system. The alternative method that is presented in this study is with the usage of Phase Change Material (PCM) as an energy-free passive cooling system that is incorporated into a room model. PCM stores cool energy that are available over-night within the PCM and later the stored energy is used to absorb the internal and solar heat gains during the day-time thus, cooling the targeted space. The purpose of this study is to investigate the effectiveness of using (PCM) as energy-free passive cooling system in buildings. Paraffinic PCM with melting point of 24.0 ~ 25.0°C were selected since the melting point falls in the range of 23.5 ~ 25.5°C the ideal room temperature for human thermal comfort that is suggested by American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). A room model was fabricated in accordance to the parameter to be investigated. The parameters are the effect of with and without PCM, location of PCM in the room model, enhancement in thermal conductivity, quantity of PCM and the effect of air supplied by fan. The results show that by incorporating PCM in the room model, the air temperature maintained at about 26.0°C as compared to that of system without PCM in which the air temperature fluctuated from 28.0 ~ 29.0°C. The cooling effect can also be enhanced by increasing the thermal conductivity of the PCM packaging and by increasing the quantity of the PCM used. When six packs of PCM were used, the temperature became stable at 24.0 ~ 24.5°C which is within the comfort temperature suggested by ASHRAE. The Carnot efficiency of this system was 16.9%. This study proved that PCM can potentially be used as an alternative solution for the conventional high energy consumption of the compressor-driven refrigeration system. The main advantage of PCM are energy-free and low-maintenance required which makes it attractive and technically feasible for the cooling system in buildings.

ABSTRAK

Sebahagian besar daripada sistem penyaman udara pada masa kini menggunakan sejumlah besar tenaga elektrik. Jika langkah penyelesaian tidak diambil, ia akan memberi impak buruk terhadap alam sekitar seperti pemanasan global dan perubahan iklim. Perkara ini melahirkan keperluan terhadap pembangunan teknologi tenaga baharu bagi sistem penyaman udara. Langkah alternatif yang dibentangkan dalam projek ini adalah dengan penggunaan bahan perubah fasa (PCM) sebagai satu sistem penyejukan pasif dan tenaga percuma yang diaplikasikan ke dalam model bilik. PCM menyimpan tenaga sejuk yang didapati pada waktu malam di dalam PCM dan seterusnya, tenaga yang disimpan itu digunakan untuk menyerap haba solar dan haba dalaman pada waktu siang, lantas menyejukkan ruang yang disasarkan. Tujuan projek ini adalah untuk menyiasat keberkesanan penggunaan PCM ini sebagai sistem penyejukan pasif dan tenaga percuma di dalam bangunan. PCM jenis parafin yang mempunyai takat lebur 24.0 ~ 25.0℃ telah dipilih oleh kerana takat lebur itu berada dalam lingkungan 23.5 ~ 25.5℃ iaitu suhu bilik yang dicadangkan oleh *American Society of Heating, Refrigerating and Air-Conditioning Engineers* (ASHRAE) bagi suhu keselesaan manusia. Sebuah model bilik telah difabrikasikan mengikut parameter yang dikaji. Parameter tersebut adalah kesan PCM, kesan tanpa PCM, lokasi PCM di dalam model bilik, penambahbaikan kekonduksian haba, kuantiti PCM dan kesan pengaliran udara oleh penggunaan kipas. Hasil daripada kajian menunjukkan bahawa dengan penggunaan PCM di dalam model bilik, suhu bilik kekal pada sekitar 26.0℃ jika dibandingkan dengan sistem tanpa PCM yang suhu biliknya berubah-ubah sekitar 28.0 ~ 29.0°C. Kesan penyejukkan juga boleh ditingkatkan dengan meningkatkan kekonduksian haba pembungkusan PCM dan dengan menambah kuantiti PCM yang dipakai. Apabila enam bungkusan PCM dipakai, suhu stabil pada 24.0 ~ 24.5℃ yang berada dalam suhu keselesaan yang dicadangkan oleh ASHRAE. Kecekapan Carnot bagi sistem ini ialah 16.9%. Kajian ini membuktikan bahawa PCM berpotensi untuk diaplikasikan sebagai alternatif kepada penggunaan sistem penyejukan konvensional yang dipacu oleh kompressor yang menggunakan tenaga elektrik yang tinggi. Kelebihan utama PCM adalah tenaga percuma dan penyelenggaraan yang rendah membuatkannya menarik dan praktikal dari segi teknikal bagi sistem penyejukan di dalam bangunan.

DEDICATIONS

This piece of writing is dedicated especially to my love ones who were always there by my side.

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I would like to express my sincere gratitude to the following who have never ceased in helping me throughout the whole process of completing my final year project report.

First and foremost, the completion of this report could not have been possible without the unwavering guidance from my supervisor, Mr. Aludin Bin Mohd. Serah. He has been such a great mentor who has given me endless amount of encouragement, support and positive insights in finishing this report in time.

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PCM	=	Phase Change Material
DSC	=	Differential Scanning Calorimeter
NVP	=	Night Ventilation with PCM Packed Bed Storage
ASHRAE	=	American Society of Heating, Refrigerating and Air-Conditioning Engineers
COP	=	Coefficient of Performance

CHAPTER 1
INTRODUCTION

1.0 Introduction

This chapter discusses about the background, problem statement, objectives and scope of this report. The background states the energy consumption in buildings, current air-conditioning system, and the effects to the environment. This leads to the overview of passive cooling system using Phase Change Material (PCM). This chapter then clarifies the objectives of this study.

1.1 Background

1.1.1 Energy Consumption in Malaysian Buildings

Currently, we live in an era of modern technology. It is clear that with the enhancement of various technology, it helps us to be more advanced and developed in almost anything we do. Although there are countless advantages of the rise in technology, the side effects of it should not be neglected. Modern buildings that are equipped with the latest technologies, obviously requires high energy consumption, especially in lighting and air-conditioning system. Table 1.1 shows the energy consumption in Malaysian buildings in 2003. It can be observed that air-conditioning system accounts a relatively high percentage of energy consumption. This is due to the high performance and cooling load requirements that is needed to be achieved in order to provide thermal comfort for the human’s inside the buildings.

Table 1.1: Energy Consumption in Malaysian Buildings
(Source: Pusat Tenaga Malaysia)

	Residential (%)	**Hotels (%)**	**Shopping Complexes (%)**	**Offices (%)**
Lighting	25.3	18.0	51.9	42.5
Air-Conditioning	**8.3**	**38.5**	**44.9**	**51.8**
Total	33.6	56.5	96.8	94.3

1.1.2 Current Air-Conditioning System

There are several types of air-conditioning system that is currently in used nowadays. For example, in residential areas, there are window air-conditioner, split air-conditioner and packaged air-conditioner. Although these air-conditioning system may seem different, the similarity is that all of these system comprises the main component of air-conditioning which are the compressors. Larger buildings such as hotels, shopping complexes and offices, central air-conditioning is most commonly used. A central air-conditioning system is comprised of a huge compressor that has the capacity to produce hundreds of tons of air-conditioning. In addition to central systems, it also consists of the Air Handling Unit (AHU), chiller, and cooling tower which consumes high electrical energy. Thus, it can be said that most of the current air-conditioning system that are in used nowadays uses huge amount of electricity. This leads to the awareness of the need for the conservation of energy in air-conditioning system.

1.1.3 Adverse Effects to the Environment

Basically, if non-renewable energy resources are used, adverse effects to the environment such as the increase in global warming and climate change are inevitable. This naturally leads to the exploration on passive conservation methods, including the use of renewable energy resources, which can help to reduce energy consumption.

1.1.4 Overview of Passive Cooling System using Phase Change Material (PCM)

After several measures that have been taken into consideration, this project introduces the usage of Phase Change Material (PCM) as an alternative cooling system in buildings which is passive and energy-free. It functions by storing cool energy that are available over-night within the PCM and later the stored energy is used to absorb the internal and solar heat gains during the day-time thus cooling the space. This passive cooling system is illustrated in Figure 1.1.

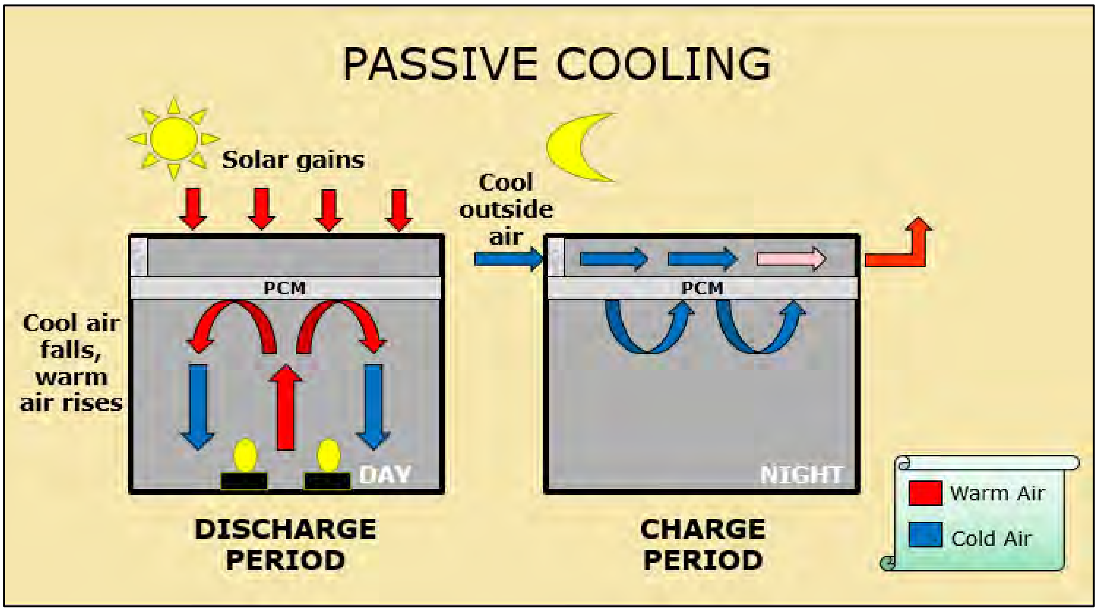

Figure 1.1: Passive Cooling System using PCM

There are several applications of PCM such as for thermal energy storage, heat pump systems, solar power plants and medical applications. In this study, PCM can be applied to the air conditioning of buildings where it is used as some sort of ice-storage cooled by night ventilation. Room model was used as a prototype to simulate the use of PCM in a real condition. It is quite similar to thermal energy storage system. The main difference is, however, it is energy free. PCM, such as paraffin wax and hydrated salts, is a substance with high heat of fusion which, melting and solidifying at a certain temperature, is able to store and release a large amount of energy. Figure 1.2 shows the photo of PCM used in this study.

Figure 1.2: PCM (Nippon Blower)

When a PCM melts, it absorbs heat, whereas when it changes to a solid (crystallize), it releases this heat. Therefore, when PCM melts during the day-time, it absorbs the heat gains and use the stored energy thus cooling a particular space. The phase change process between solid and liquid PCM is illustrated as in Figure 1.3.

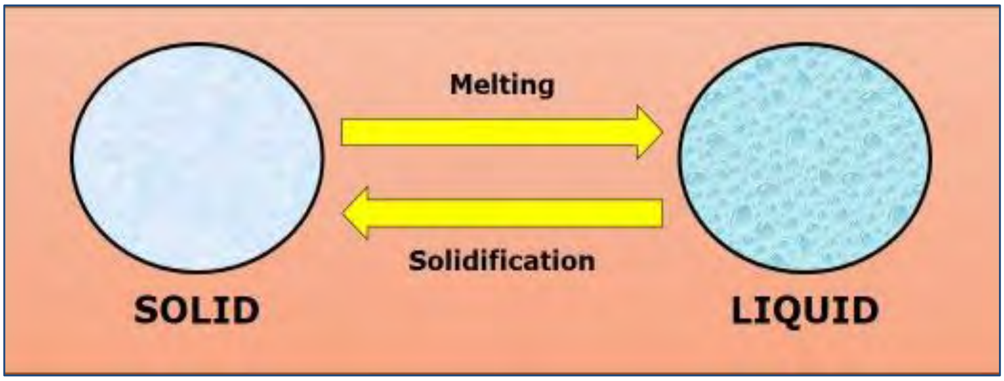

Figure 1.3: Phase Change between Solid and Liquid

It is referred to as a passive cooling system due to the fact that it does not require any form of electricity to run the system. It also does not require energy consuming components such as compressor. This system promotes energy saving potential.

1.2 Problem Statement

The demand for high performance buildings is on the rise, due to the factors such as rising energy cost, diminishing resources, and climate change. In this case, the energy usage for air-conditioning systems in buildings. The energy consumption in current air-conditioning system can be clearly seen to be on the rise with the increase in building developments today, let it be in hotels, shopping complexes or in office buildings. Measures need to be taken into considerations concerning this predicament because over-usage of energy causes negative impact to the environment. Consumption of non-renewable energy resources such as fossil fuels can lead to global warming and climate change. Therefore, alternative energy sources should be explored and made in order to reduce the impact to the environment. In this study, the alternative solution for cooling system in buildings is with the usage of phase change material (PCM) which incorporates free cooling principle. This alternative is to counterweight to energy wasting conventional compressor-driven air-conditioning system. However, several parameters involved in the application of PCM into the system have to be investigated. The parameters that affect the system are, the placement of the PCM, the quantity of PCM to be used, the effect of air fan supply, and etc. Therefore, these effects of the parameters must be identified and analysed to investigate the maximum potential efficiency of this free cooling system.

1.3 Project Objective

This section describes the general objective as well as its specific objective.

1.3.1 General Objective

The purpose of this study is to investigate the effectiveness of using Phase Change Material (PCM) as energy-free passive cooling system in buildings in order to promote energy savings and reduce energy consumption.

1.3.2 Specific Objectives

- To select a suitable phase change material (PCM) to be used as passive cooling system according to climate in Malaysia and the desired operating temperature.
- To investigate the parameters for the PCM instalment in a room model such as the effect of with or without PCM, quantity of PCM, placement of PCM, supply air fan and thermal conductivity of PCM.
- To calculate the efficiency of this system.

1.4 Work Scope

- This project targets on the selection of the PCM because the type of PCM used affects the result and data collection. The thermal properties of the PCM used were determined.
- The parameters of the PCM installation in the room model is important to be considered especially on its placement, quantity and other parameters. The ambient temperature was set to a constant temperature of 24°C so that the effects of the parameter focused on the internal heat gain.
- The investigation on the effectiveness of this cooling system was conducted based on the calculation of the efficiency from the temperature difference produced from the data collection by the usage of PCM.
- Other aspects such as humidity level, air flow rate, external heat gain and air filtration were not be focused in this project.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

This chapter mainly discuss on the basic properties and classifications of Phase Change Material (PCM) which was reviewed by several researchers. The building application of PCM and impregnation of PCM into construction material are also discussed. The chapter then introduces some reviews on how to calculate the efficiency of the system.

2.1 Phase Change Material (PCM)

Sharma *et al.* (2009) states that Phase Change Materials (PCM) are latent heat storage materials. Thermal energy transfer occurs when a material changes from a solid to liquid, or liquid to solid which is called a change in state, or phase. These solid-liquid PCMs perform like conventional storage materials, rising the temperature as it absorbs more heat. There are a large number of PCMs that melts with a heat of fusion in any required range. However, these materials must possess certain desirable thermodynamic, kinetic and chemical criteria or properties. The economic considerations and ease of availability of these materials should not be neglected as well.

Unlike conventional (sensible) storage materials, PCM absorbs and release heat at a nearly constant temperature. The content of the stored heat is from 5 to 14 times greater compared to sensible storage materials such as water and stones (Butala and Stritih, 2011).

According to Lauck (2013), similar to physical mass, PCM has the potential to reduce fluctuations in air temperature and shift cooling loads to off-peak periods. In comparison to physical mass, where energy storage capabilities are restricted to sensible heat, the ability of a PCM to store energy is largely characterized by its latent heat of fusion. When latent heat of fusion increases, the material's capacity to store heat also increases. Energy is stored as sensible heat when heat is added to a solid below its melting point or a liquid above its melting point. This sensible heat increases the temperature of the solid or liquid but does not change its phase. On the other hand, when heat is added to a solid at its melting point, the material changes phase to a liquid while maintaining at a constant temperature, effectively storing the heat as latent heat. Meanwhile, when liquid freezes and returns to solid state, the stored heat is released to surrounding environment. This characteristics is suitable to building applications when the melting temperature of the PCM is approximately equal to the desired room air temperature.

2.1.1 Classification of PCMs

Sharma *et al.* (2009) classifies phase change materials to organic, inorganic and eutectic. There are a large number of organic and inorganic chemical materials, which can be identified as PCM from the properties of its melting temperature and latent heat of fusion. However, most PCMs does not have the required criteria for a sufficient storage media. This is because no single material can have all the required properties for an ideal thermal-storage system, the usage of the available materials is needed to make up for the poor physical property. For example, metallic fins can be used to increase the thermal conductivity of PCMs. Besides that, supercooling can be eliminated by introducing a nucleating agent in the storage material or container. Figure 2.1 shows the general classification of phase change materials (PCMs).