UNIVERSITI TEKNIKAL MALAYSIA MELAKA

PREPARATION AND CHARACTERIZATION OF PARAFFIN/POLY(ETHYLENE GLYCOL) COMPOSITES AS FORM-STABLE PHASE CHANGE MATERIALS FOR THERMAL ENERGY STORAGE APPLICATIONS

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Mechanical Engineering Technology (Automotive Technology) (Hons.)

by

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ABSTRAK

Bahan perubahan fasa (PCM) adalah bahan yang boleh menyerap, menyimpan dan membebaskan haba dari dan ke persekitaran semasa peleburan dan penyejukan. Parafin adalah PCM yang paling popular mempunyai banyak kelebihan seperti kapasiti penyimpanan haba yang tinggi dan kestabilan haba menjadikan PCM yang paling sesuai dalam sistem penyimpanan tenaga. Walau bagaimanapun, kekurangan parafin adalah masalah kebocoran paraffin itu sendiri semasa perubahan fasa dari pepejal ke cecair. Dalam kajian ini, komposit parafin / poli (etilena glikol) disediakan pada pelbagai komposisi dengan mencampurkan parafin dan poli(etilena glikol) dalam proses peleburan langsung. Pengimbasan pembezaan kalorimeter (DSC) memberikan data sifat haba terutamanya titik lebur dan pelakuran haba bagi komposit. Ujian kebocoran dijalankan dengan meletakan sampel komposit pada satu set kertas penapis empat lapisan dan dibiarkan pada suhu 90˚C selama 1 jam. Dengan menggabungkan PEG ke fasa parafin, peratusan kebocoran telah dikurangkan secara drastik. Sebagai contoh, peratusan kebocoran parafin 50wt% / PEG 50wt% adalah 32.2% iaitu lebih separuh rendah daripada parafin tulen (72.8%). Keputusan DSC menunjukkan bahawa suhu lebur dan haba pelakuran apabila kandungan PEG meningkat. Pemeriksaan lanjut ke atas lengkung DSC mendedahkan bahawa puncak kecil yang boleh didapati di lengkung DSC bagi parafin tulen beransur-ansur hilang sebagai kandungan PEG meningkat. Menunjukan komposit terhasil lebihh homogen. Oleh itu, penggabungan PEG dalam fasa parafin mengasilkan struktur yang lebih stabil. Matrix polimer PEG dalam komposit mungkin memerangkap molekul parafin semasa proses peleburan dengan menghalangnya daripada bocor. PCM bentuk stabil ini berpotensi menjadi bahan PCM untuk aplikasi penyimpanan tenaga haba.

ABSTRACT

Phase Change Material (PCM) are materials that can absorb, store and release the latent heat of fusion to and from the environment during the melting and freezing processes. Paraffin which is the most known PCM have many advantages such as high thermal energy storage and thermal stability to make them the most suitable PCM in thermal energy storage applications. However, the problem of the paraffin is the leakage problem of the PCM itself during the solid to liquid phase change. In this study, paraffin/poly (ethylene glycol) composites were prepared at various mass compositions by mixing paraffin and poly (ethylene glycol) via direct heating method. The differential scanning calorimeter (DSC) provides the data on the thermal properties particularly the melting points and the heat of fusion of the composites. The range of melting temperature and heat of fusion of composites were 56-67˚C and 122-148 kJ/kg respectively. The leakage tests were conducted by replacing the composite samples on a set of four layers filter papers and left at 90˚C for 1 hour. By incorporating PEG into paraffin phase, the leakage percentage was drastically reduced. For example, the leakage percentage at paraffin 50wt% / PEG 50wt% was 32.2 % which was more than half lower than of pure paraffin (72.8%). DSC results show that the melting temperature and heat of fusion of the composites increased as PEG composites increased. Further examination on the DSC curves revealed that the small peak which can be found in the DSC's curve of pure paraffin gradually disappeared as the PEG composites increased. Suggesting the composites obtained become more homogeneous. Thus, the incorporating PEG in paraffin phase result in more stable composites structures. The PEG polymer matrix in the composites may have trapped the paraffin molecules during melting process thus prevent it from leakage. These form-stable PCM would potentially become novel candidates of PCM for thermal energy storage applications.

DECLARATION

I hereby, declared this report entitled "Preparation And Characterization Paraffin/Poly(ethylene Glycol) as Form-Stable Phase Change Materials For Thermal Energy Storage Applications" is the results of my own research except as cited in references.

Signature	:	…………………………………………….
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APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering Technology (Automotive Technology) with Honours. The member of the supervisory is as follow:

………………………………

(Project Supervisor)

DEDICATION

This project work is dedicated to my beloved parents for their enthusiastic caring throughout my life, my loving siblings and also my friends for their encouragement, passion and love

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I dedicated my dissertation work to my family and all my friends. A huge gratitude to my supervisor, Mr Aludin Bin Mohd Serah for all the guidance given for me to finish this research. The supervision and supports that he gave me truly help the progression and smoothness while completing this project.

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

PEG - Polyethylene Glycol

DSC	-	Differential Scanning Calorimeter
HDPE	-	High Density Polyethylene
$CaCO_3$	-	Calcium Carbonate
TES	-	Thermal Energy Storage

CHAPTER 1
INTRODUCTION

1.0 Introduction

This chapter explains the background of this study which explains the important of the energy in daily life, the thermal energy storage (TES) and its application and the passive cooling system. Then, it continues with the problem statement which is the leakage problem of paraffin phase change material (PCM) and finally this chapter will highlight the objectives and the scope of this study.

1.1 Project Background

Energy is the primary input for almost all human activities and therefore, it is important in improving quality of our life. To ensure the continuous supply of energy for our ever increasing demands in sector such as industry, commerce, transport, telecommunications and wide range of agricultural activities, a huge step must be taken to secure the supply for these demands. Figure 1.1 shows the primary energy consumption present in our earth.

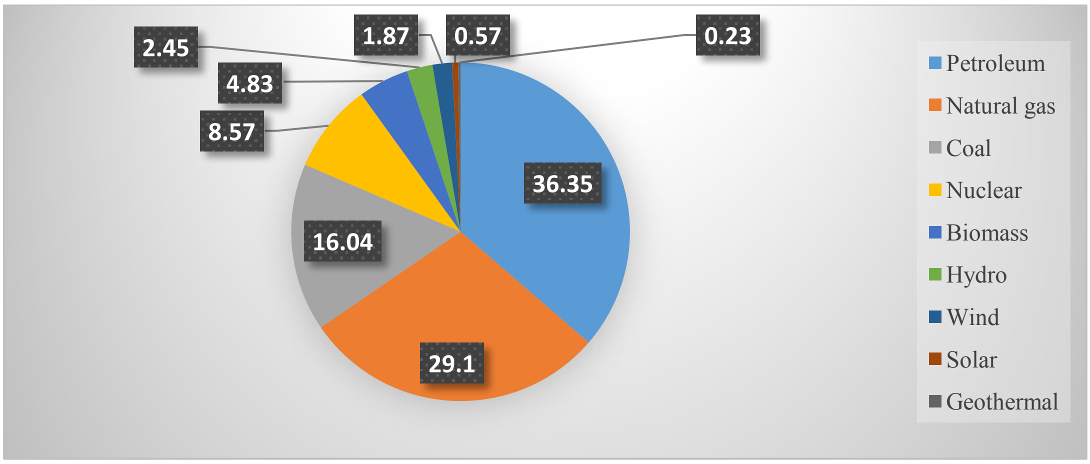

Figure 1.1: Primary energy consumption

It can be concluded that the most energy used are petroleum, natural gas and coal and all of these energies are natural resources expected to be depleted in future. Generating energy requires precious natural resources Therefore, one of the logical steps to preserve these energies and make them last longer in future is by using less energy in our daily life. Appropriate and organized actions must be done to save the energy. Saving energy means decreasing the amount of energy used while achieving a similar output of the end use. Using less energy has many benefits such as save the money and environment. Thermal energy is one of form energy that being consumed more as compared to the other form of energies. One of the way to save thermal energy is by applying thermal energy storage (TES) techniques.

The thermal energy storage (TES) can be defined as the temporary storage of thermal energy in the forms of hotness and coolness. The TES is not a new concept, since it has been used for centuries. Energy storage can reduce the period or rate of mismatch between energy demand and energy supply, and it plays an important role in energy conservation.

One of the technique in thermal energy storage application is by using Phase Change Materials (PCM). TES can store energy in a form of latent heat, sensible heat and thermochemical or combination of these energy forms (Sharma et al, 2007). Sensible heat storage is relatively inexpensive, but it has disadvantages such as low energy density and variable discharging temperature. These disadvantages can be overcomed by employing PCM based on the TES system, which enables target oriented discharging temperatures and higher storage capacities. The change of phase could be either a solid/liquid or a solid/solid process. Figure 1.2 shows phase change process of PCM.

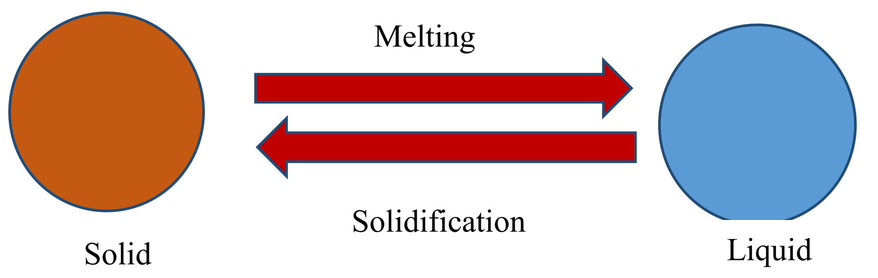

Figure 1.2: Phase change of PCM

According to (A. Sari, 2004) PCM are substances that absorb and release thermal energy during the process of melting and freezing. When such material melts, it absorbs a large amount of heat from the surrounding. Conversely, when a PCM freezes, it releases the same amount of energy in the form of latent heat at a relatively constant temperature. PCMs recharge as ambient temperatures fluctuate, making them ideal for a variety of useful applications that require temperature control.

In the PCM, sensible and latent heat were utilized and consolidated together as they have the diverse capacities that encourages the PCM to work in the correct way. Latent heat is required as it change the material from solid to liquid or liquid to solid without changing the temperature. In any case, the present of sensible heat modifies the temperature without change the phase of materials. Thus, both latent and sensible heat are needed to produce excellent PCM applications.

PCM can be divided into three categories which are organic compound, inorganic compounds and eutectics. In this study, paraffin which is an organic compound was used as it has many advantages as compared to other compounds. For example, it is non-corrosive and has high latent heat of fusion. In this study, the PCM is targeted to be applied in passive cooling system.

Passive cooling is an approach that focuses on heat gain control and heat dissipation in a building in order to improve the indoor thermal comfort with low or zero energy consumption. Passive cooling system may use two different source of energy which are renewable sources and PCM.

According to (Hannan M. Taleb, 2014) passive cooling utilizes free, renewable sources of energy, for example, the sun and wind to give cooling, ventilation and lighting requirements for a household. This will lessen the need to utilize mechanical cooling. It can likewise decrease levels of energy utilized and natural effects, for example, greenhouse gas emissions. Figure 1.3 illustrate how passive cooling with PCM works.

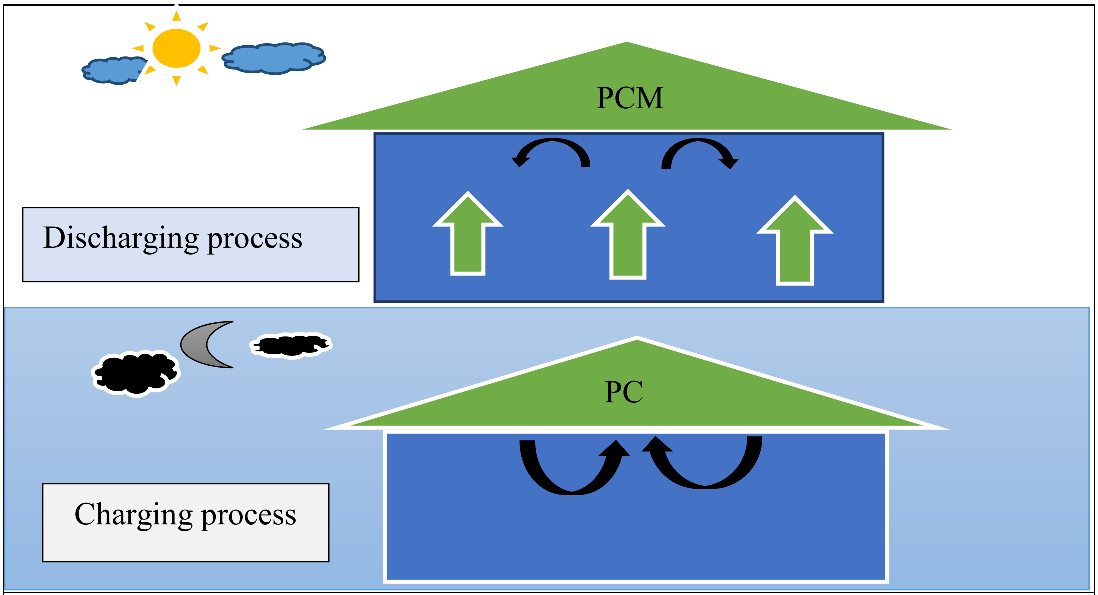

Figure 1.3: passive cooling system using PCM

PCM function by storing cool energy that is available over-night within PCM (charging-process) and later the stored energy is used to absorb the internal and solar heat gain during the day time thus cooling the space.

1.2 Problem Statement

Global warming has become a serious problem to human being. It is caused by the emission of greenhouse gasses. This phenomenon adversely affects the environment and cause the depletion of energy sources. An appropriate and organized method must be taken to save the energy. Thermal energy storage (TES) is one of the best alternative and TES using PCM is one of the best technique. Thermal storage device is able to absorb, store and release energy when needed. PCM is targeted to be applied in the passive cooling system method as it is a promising material that suits this purpose. Compare to other PCMs, paraffin is the most studied materials for thermal energy storage applications. However, the main problem of paraffin is the liquid leakage of this material during solid to liquid phase change. This will affect the original quantity of the paraffin used hence reduce its effectiveness. Figure 1.4 illustrates the leakage problem of paraffin when it is use in a building.

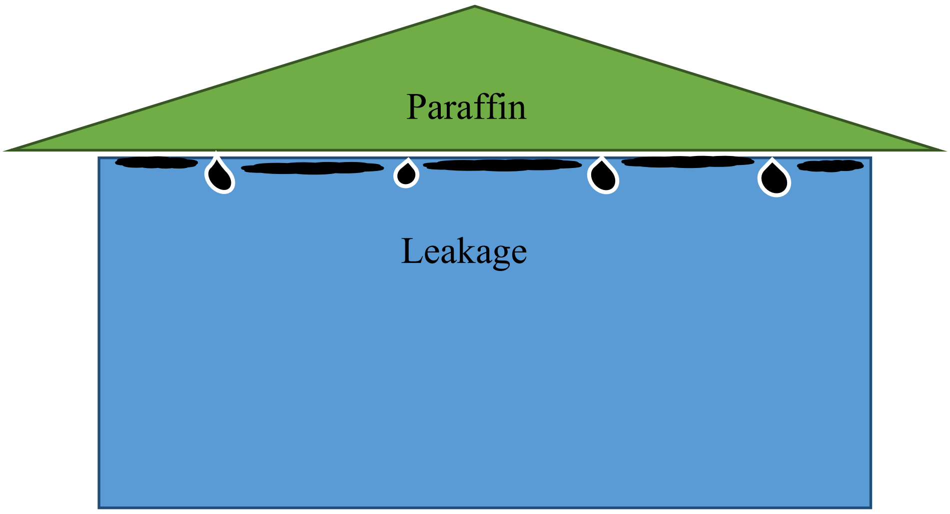

Figure 1.4: The leakage problem of paraffin

To solve this problem, the paraffin needs to be encapsulated with other supporting materials. In this study, paraffin is blended with a polyethylene glycol (PEG) at varied composition by dissolving paraffin with PEG via direct heating method. The effect of incorporating PEG into paraffin on the thermal properties of the composites obtained was investigated by using Differential Scanning Calorimeter (DSC) analysis. Furthermore, the leakage characteristic of the composites was investigated through the leakage tests. PEG was chosen because it has very similar thermal properties to paraffin. These form-stable paraffin/PEG composite are expected to become a novel of PCM candidate for thermal energy storage applications.

1.3 Objectives

In order for this study to be successfully conducted, the following objectives are set:

1.3.1 General Objective:

To prepare and characterize form stable paraffin/polyethylene glycol (PEG) composites as a novel phase change material (PCM) candidate for thermal energy storage application.

1.3.2 Specific Objectives:

1. To investigate the best method for the preparation of form stable paraffin/PEG composites.
2. To prepare paraffin/PEG composites at varied mass compositions.
3. To determine the thermal properties and leakage characteristics of the paraffin/PEG composites by Differential Scanning Calorimeter (DSC) analysis and leakage test, respectively.

1.4 Scope

The scope of this study are:

- Investigation of the best method for the preparation of form-stable paraffin/PEG composites.
- Preparation of form-stable of paraffin/PEG at varied mass compositions.
- Characterization of paraffin/PEG as a novel phase change material (PCM) by using DSC analysis and leakage test respectively.

CHAPTER 2
LITERATURE REVIEW

2.0 Introduction

This chapter first reviews the concept of thermal energy storage. Then it introduces Phase Change Material (PCM) categories and criteria of PCM in terms of physical, thermal, chemical and economic for thermal energy storage application. Several recent research on form-stable paraffin PCM are then reviewed. This chapter introduces the properties of polyethylene glycol (PEG) as PCM.

2.1 Thermal Energy Storage (TES)

Thermal energy storage (TES) is a system that store thermal energy by warming or cooling a storage medium so that the stored energy can be utilized in future for heating and cooling applications and generation of power. TES system are utilized especially as a part of structures and industrial procedures. In these applications, nearly half of the energy consumed is in the form of thermal energy, the demand for which may change vary any given day and from one day to next. Focal points of utilizing TES as a part of an energy system are the expansion of the general productivity and better overall quality. It also has many other benefits such as financial benefits, reduction in investment and running expenses, and less contamination of the earth and less CO_2 emission (A. de Gracia, L.F. Cabeza, 2015). Figure 2.1 shows different types of thermal energy storage.

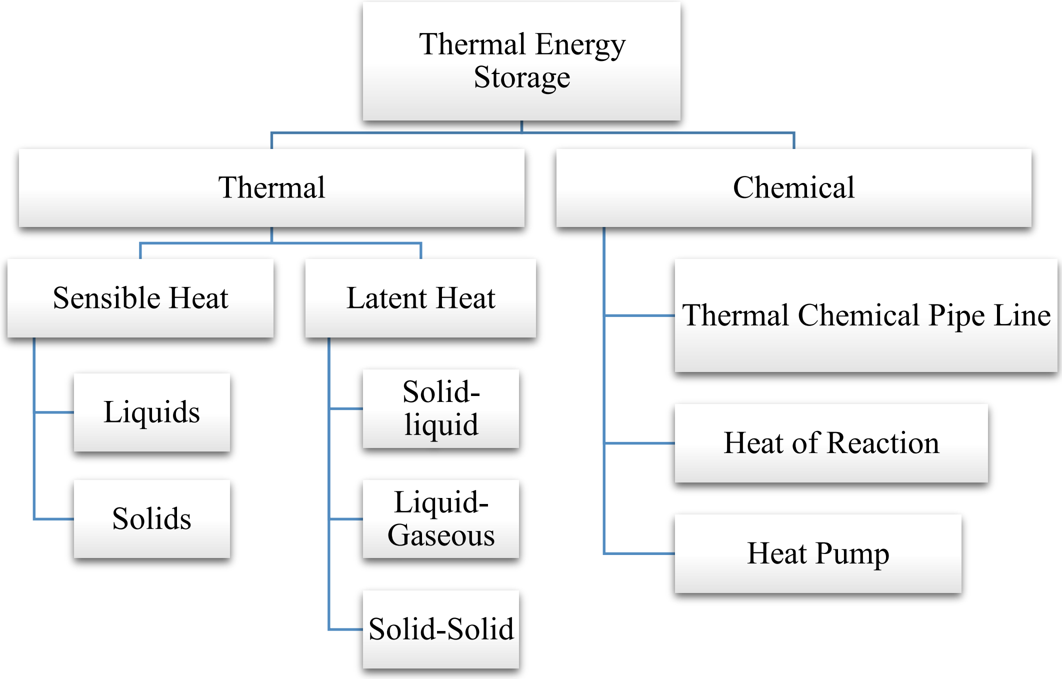

Figure 2.1: Types of thermal energy storage

TES can be divided into two categories which are thermal and chemical. Thermal storage can be divided further into sensible heat storage and latent heat storage. TES systems can be either centralised or distributed systems. Centralised applications can be utilized as a part of area heating or cooling systems, large industrial plants, combined heat and power plants, or in renewable power plants. Distributed systems are generally connected in domestic or buildings to catch sunlight energy for water and space heating or cooling. In both cases, TES systems may lessen energy request at peak times. TES normally utilize passive cooling system that helps to save energy.

TES is equipped for storing and discharging large amount of energy. The system relies on the phase change of the material for charging and discharging the latent heat. For example, processes such as melting, solidifying or evaporation require energy. Heat is consumed or discharged when the material changes from solid to liquid and vice versa. PCM typically change their phase with a specific input of energy and discharge this energy later. Figure 2.2 shows the latent heat during solid-liquid phase change.

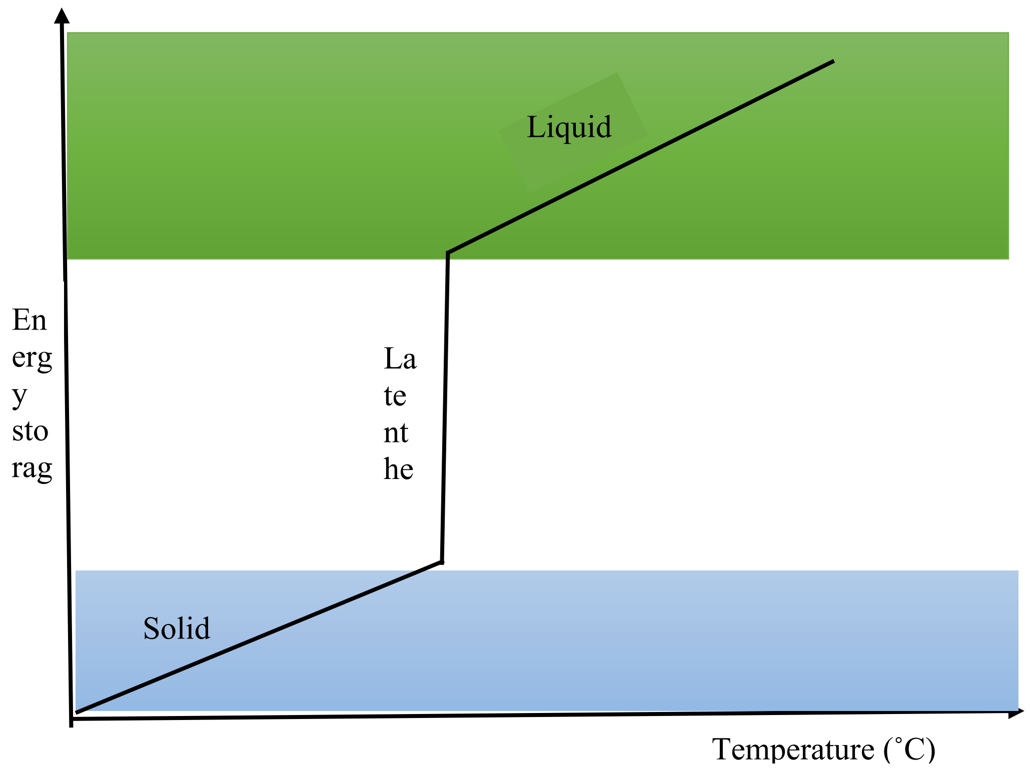

Figure 2.2: Latent heat during solid-liquid phase change

TES depends on latent heat storage. Compared to the storage of sensible heat, there is no temperature change in the storage. In a sense every material is a phase change material, because at certain combinations of pressure and temperature every material can change its aggregate state (solid, liquid, gaseous). In a change of total state, a lot of energy, the so called latent heat can be stored or discharged at a relatively constant temperature. Hence a little temperature swing can be utilized for storing energy and discharging the stored energy. Passive cooling system technique is applied in the TES system makes them turn out to be more efficient in saving the energy.

Passive cooling is an approach that emphasis on heat gain control and heat dissipation in a building to enhance the indoor thermal comfort with low or zero energy utilization. Passive cooling covers every single natural processes and techniques of heat dispersal and modulation without the utilization of energy. Active cooling system on the other hand, includes the utilization of energy to cool something, which contradicts to passive cooling that uses no energy. Figure 2.3 illustrates the difference in terms of economical benefits between active and passive cooling systems.

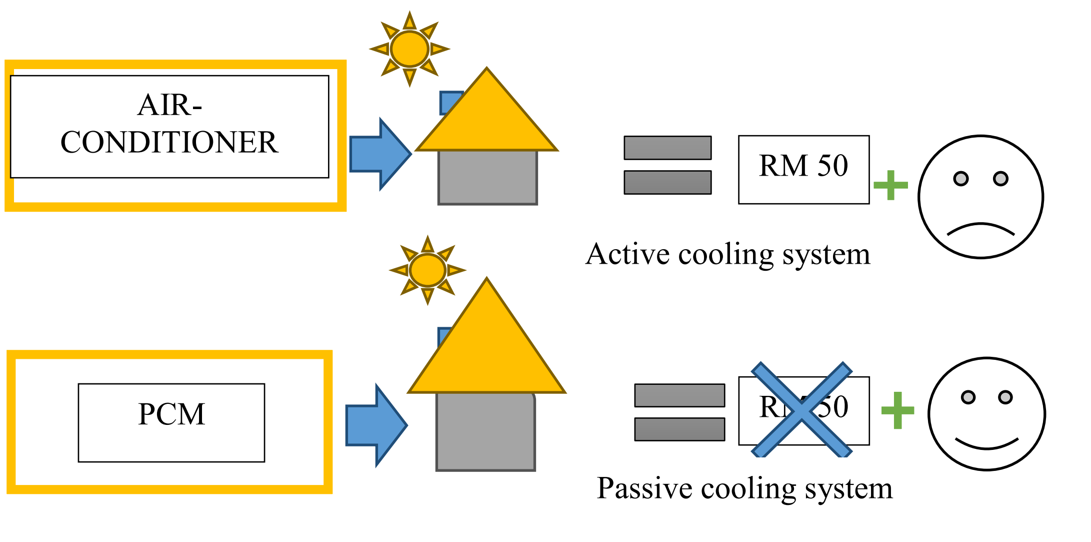

Figure 2.3: Economical benefit of passive cooling system

According to Hannan M. Taleb (2014) applying passive cooling implies decreasing contrasts between outdoor and indoor temperatures, enhancing indoor air quality and improving the building and making the environment comfort to live or work in. The utilization of TES gives a high level of control of the indoor conditions and enhances the method for storing heat energy. These systems are generally incorporated in structures to give free cooling or to move the thermal load from on-peak to off-peak conditions in a few applications such as heating, ventilating, and air conditioning (HVAC) system.

In this study, PCM was used in the passive cooling system. PCM high energy storage density. In free cooling using PCM the cool air at night is used to solidify back the PCM and then the stored cold energy will be discharging during the PCM melts at day-time.

2.2 Phase Change Material

Phase change materials (PCM) are substances that absorb and release thermal energy during melting and freezing. When a PCM freezes, it releases a large amount of energy in the form of latent heat at a relatively constant temperature. Conversely, when such material melts, it absorbs a large amount of heat from the environment. PCMs recharge as ambient temperatures fluctuate, making them ideal for a variety of everyday applications that require temperature control. Figure 2.4 shows the phase change of PCM in response to temperature change.

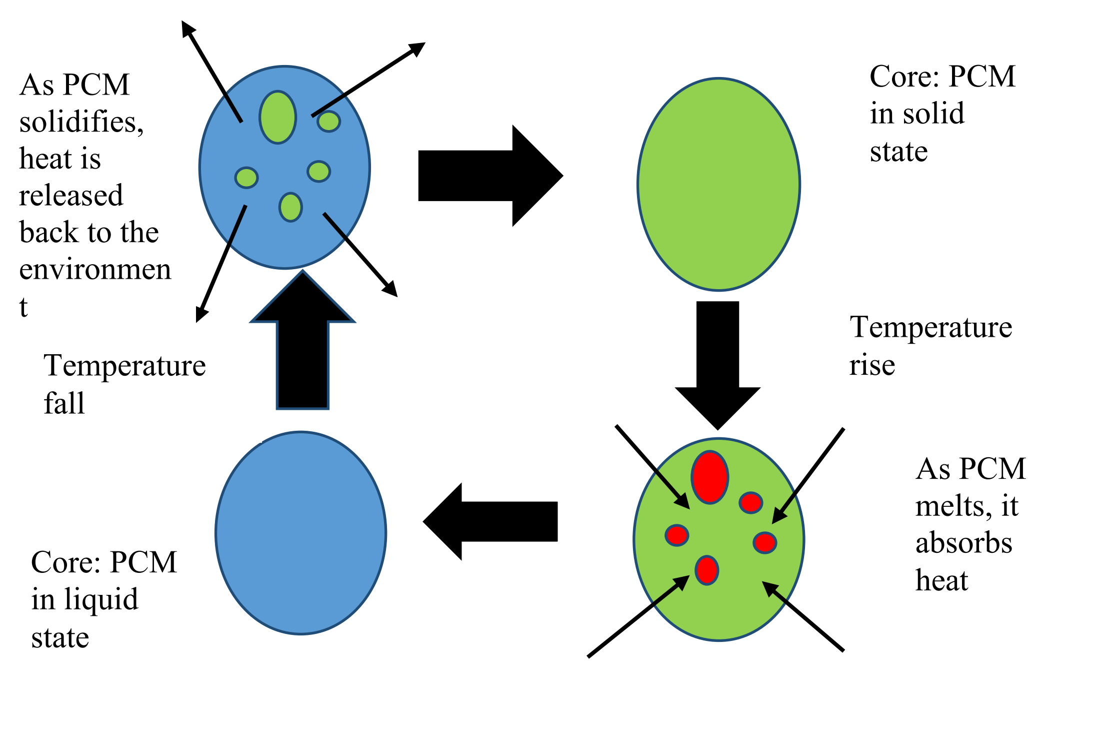

Figure 2.4: Phase change of PCM in response to temperature change.

According to M. M Farid et al (2004) PCM must have a large latent heat and high thermal conductivity. Besides, the selection of PCM also must based on their melting temperature.

To address that limitation, PCMs have been developed for use across a broad range of temperatures, from -40°C to more than 150°C. They typically store 5 to 14 times more heat per unit volume than materials such as water, masonry or rock. Among various heat storage options, PCMs are particularly attractive because they offer high-density energy storage and store heat within a narrow temperature range.