Eutectic Mixtures of Luaric Acid and Palmitic Acid as Phase Change Materials in Building Application

Pornpan Tawongchai

A Report Submitted in Partial Fulfillment of the Requirements
for the Degree of Bachelor of Engineering (Petrochemical Engineering)
Department of Chemical Engineering, Faculty of Engineering,
King Mongkut's Institute of Technology Ladkrabang
Academic Year 2017

ของผสมยูเทคติกจากกรดลอริกและกรดปาล์มมิติก
เพื่อใช้เป็นวัสดุเปลี่ยนสถานะในงานด้านการก่อสร้าง

นางสาวพรพรรณ ต๊ะวงศ์ชัย

ปริญญานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตร
วิศวกรรมศาสตรบัณฑิต สาขาวิชาวิศวกรรมปิโตรเคมี
ภาควิชาวิศวกรรมเคมี คณะวิศวกรรมศาสตร์
สถาบันเทคโนโลยีพระจอมเกล้าเจ้าคุณทหารลาดกระบัง
ปีการศึกษา 2560

Title	Eutectic Mixtures of Luaric Acid and Palmitic Acid as Phase Change Materials in Building Application
By	Miss Pornpan Tawongchai
Field of Study	Petrochemical Engineering
Advisor	Asst. Prof. Dr. Apinan Namkanisorn

Accepted by the Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang in Partial Fulfillment of the Requirements for the Degree of Bachelor of Engineering (Petrochemical Engineering).

Thesis Committee

_______________________________ Chairman
(Asst. Prof. Dr. Apinan Namkanisorn)

_______________________________ Committee
(Asst. Prof. Ruenruedee Benjangkaprasert)

_______________________________ Committee
(Asst. Prof. Dr. Nuttaphol Lerkkasemsan)

Title	Eutectic Mixtures of Luaric Acid and Palmitic Acid as Phase Change Materials in Building Application
By	Miss Pornpan Tawongchai
Advisor	Asst. Prof. Dr. Apinan Namkanisorn
Field of Study	Petrochemical Engineering
Affiliation	Chemical Engineering, King Mongkut's Institute of Technology Ladkrabang

Abstract

In developing a phase change material (PCM) for low temperature latent heat thermal energy storage (LHTES) for building applications under the climate conditions in Thailand, the phase change material was created from eutectic mixture of lauric acid (LA) and palmitic acid (PA). Mixing of both acids was carried out at various molar ratios and the melting temperature of the solid mixture was determined in order to identify the eutectic composition. The eutectic mixture was found to contain the molar ratio of LA to PA at 80 - 20 mol%. Differential scanning calorimetry (DSC) thermal analysis result indicates that the melting temperature of LA-PA eutectic mixture is in the range of 36 – 46 °C with the latent heat of fusion of 166.9 J/g. The heat absorption of LA-PA mixture as a thermal energy storage was tested by placing this mixture inside the spaces in commercial concrete blocks that were placed in a direct sun light and observing melting behavior of the mixture at different times of day. The results indicate that more than 90% by mass of the PCM melts when the outside temperature is continuously above 37 °C for more than 1 hours. When the temperature decreases, the PCM solidifies again. For thermal performance study, 538.5 g of this PCM stores 9.0 kJ per 0.152 m^2, leading to 23.5 % reduction of heat transmitted through concrete wall exposed to sunlight. The temperature inside concrete wall with PCM insert is about 0.5 – 1 °C lower than the temperature of wall without PCM. This study shows the possibility of using eutectic mixture of lauric acid and palmitic acid as a phase change material for the building that requires energy saving at low cost.

Keywords: Phase change material (PCM), latent heat thermal energy storage (LHTES), Lauric acid (LA), Palmitic acid (PA), differential scanning calorimetry (DSC), eutectic mixture, concrete blocks

เรื่อง	ของผสมยูเทคติกจากกรดลอริกและกรดปาล์มมิติกเพื่อใช้เป็นวัสดุเปลี่ยนสถานะในงานด้านการก่อสร้าง
โดย	นางสาวพรพรรณ ต๊ะวงศ์ชัย
อาจารย์ที่ปรึกษา	ผศ.ดร. อภินันท์ นัมคณิสรณ์
สาขาวิชา	วิศวกรรมปิโตรเคมี
สังกัด	วิศวกรรมเคมี สถาบันเทคโนโลยีพระจอมเกล้าเจ้าคุณทหารลาดกระบัง

บทคัดย่อ

ในการพัฒนาวัสดุเปลี่ยนสถานะสำหรับเป็นตัวกักเก็บพลังงานความร้อนแฝงที่อุณหภูมิต่ำในการประยุกต์ใช้งานด้านการก่อสร้างภายใต้สภาพภูมิอากาศของประเทศไทย วัสดุเปลี่ยนสถานะนี้ทำมาจากของผสมยูเทคติกของกรดลอริกและกรดปาล์มมิติก โดยการผสมทั้งสองกรดนี้ได้กระทำที่หลายอัตราส่วนโดยโมล และอุณหภูมิหลอมละลายของของแข็งสารผสมถูกหาเพื่อระบุถึงอัตราส่วนของสารผสมยูเทคติก ซึ่งสารผสมยูเทคติกที่ได้มีอัตราส่วนโดยโมลของกรดลอริกและกรดปาล์มมิติก 80 : 20 mol % ผลการทดลองที่ได้จาก DSC พบว่าอุณหภูมิหลอมละลายอยู่ในช่วง 36 – 46 ℃ มีค่าความร้อนแฝง 166.9 J/g การดูดซึมความร้อนของสารผสมกรดลอริกและกรดปาล์มมิติกที่ใช้เป็นตัวกักเก็บพลังงานถูกทดสอบโดยวางของผสมนี้ที่ด้านในช่องว่างอิฐบล็อกคอนกรีตซึ่งสัมผัสแดดโดยตรง และจากการสังเกตพฤติกรรมการหลอมละลายของสารผสมที่เวลาในช่วงต่างๆ ของวัน พบว่ามากกว่า 90 % โดยมวลของวัสดุเปลี่ยนสถานะนี้ละลายเมื่ออุณหภูมิภายนอกมากกว่า 37 ℃ เป็นเวลาต่อเนื่องนานมากกว่า 1 ชั่วโมง และเมื่ออุณหภูมิลดลงวัสดุเปลี่ยนสถานะนี้จะแข็งตัวอีกครั้ง สำหรับการศึกษาสมรรถนะทางความร้อนปริมาณ 538.5 g ของวัสดุเปลี่ยนสถานะนี้สามารถกักเก็บความร้อนได้ 9.0 kJ ต่อพื้นที่ 0.152 m^2 ซึ่งช่วยลดความร้อนเข้าสู่ภายในบ้านได้ 23.5 % และอุณหภูมิภายในบ้านผนังคอนกรีตที่ใส่วัสดุเปลี่ยนสถานะนี้จะต่ำกว่าประมาณ 0.5 – 1 ℃ เมื่อเปรียบเทียบกับผนังที่ไม่ใส่วัสดุเปลี่ยนสถานะ จากการศึกษานี้แสดงให้เห็นว่ามีความเป็นไปได้ในการใช้ของผสมยูเทคติกของกรดลอริกและกรดปาล์มมิติกเป็นวัสดุเปลี่ยนสถานะราคาถูกสำหรับอาคารที่เน้นด้านการประหยัดพลังงาน

คำสำคัญ: วัสดุเปลี่ยนสถานะ, ตัวกักเก็บพลังงานความร้อนแฝงที่อุณหภูมิต่ำ, กรดลอริก, กรดปาล์มมิติก, DSC, ผสมยูเทคติก, อิฐบล็อกคอนกรีต

Acknowledgements

This thesis could not be completed without the direct and indirect assistance of many people to whom I would like to express my appreciation.

First, I would like to acknowledge with appreciation the numerous and valuable advices, comments, suggestions, criticisms, and praise of my advisor, Asst. Prof. Dr. Apinan Namkanisorn during the period of senior project.

Second, I would like to thank Assoc. Prof. Dr. Prakob Kitchaiya, who usually gave me the helpful advices, helped me for guidance in connection and purchasing the chemicals and provided some equipment in the experiment.

I would like to appropriate to Asst. Prof. Ruenruedee Benjangkaprasert and Asst. Prof. Dr. Nuttaphol Lerkkasemsan for the recommendations and audit committee in this completed thesis.

I would like to thank all professors and officers in chemical engineering department, faculty of engineering, King Mongkut's Institute of Technology Ladkrabang for partial financial supports, experimental equipment and laboratory.

I would like to thank officers and friends in civil engineering department, faculty of engineering, King Mongkut's Institute of Technology Ladkrabang for advices and giving me some knowledge about house structure, wall and concrete block in building application.

Moreover, I would like to thank my friends at faculty of engineering, King Mongkut's Institute of Technology Ladkrabang for helping and giving some advices during the period of senior project.

Finally, I would like to thank my family from my deep heart for their supports, love and encouragement throughout my life.

Pornpan Tawongchai

Table of Contents

Page

Abstract (English) I
Abstract (Thai) II
Acknowledgements III
Table of Contents IV
List of Figures VI
List of Tables VII
Nomenclature VIII
Technical Abbreviations IX

Chapter I. Introduction 1
1.1 Background 1
1.2 Objectives 2
1.3 Scopes of Work 2
1.4 Steps of Work 3
1.5 Expected Outputs 3
1.6 Work Plan 3

Chapter II. Literature Review 4
2.1 Thermal Energy Storage; TES 4
2.2 Phase Change Materials; PCMs 5
2.2.1 Type of Phase Change Materials (PCMs) 7
2.3 Eutectic Mixture System 8
2.3.1 Binary Phase Diagram 8
2.3.2 Binary Eutectic System 9
2.4 Fatty acid 10
2.5 Fatty Acid Eutectic Mixture 11
2.5.1 Theoretical Calculation of Ratio for Binary Fatty Acid Eutectic 12
2.6 PCMs in Building Application 12
2.6.1 The Impregnation of Building Materials 12
2.6.2 The Micro-Encapsulation 13
2.6.3 Shape-Stabilized PCM 13
2.7 Literature Reviews 13

Chapter III. Research Methodology 16
3.1 Experimental Apparatus and Equipment 16
3.2 Experimental Chemicals 16
3.3 Experimental Procedures 16
3.3.1 Determination of Eutectic Composition and Thermal Properties for Lauric Acid and Palmitic Acid Mixture 16
3.3.2 Mixing Lauric Acid and Palmitic Acid in Eutectic Mixture as Phase Change Material 17
3.3.3 PCM Containment in Concrete Block for Building Application 17
3.3.4 Measurement Performance of the Phase Change Material in Building Application 17

Table of Contents (Cont.)

Page

Chapter IV. Results and Discussion 19

4.1 Verification Melting Point of the Composition LA-PA Eutectic Mixture as Phase Change Material 19

4.2 Differential Scanning Colorimeter (DSC) Analysis of LA-PA Eutectic Mixture as Phase Change Material 20

4.3 Thailand Climate Condition and Room Air Temperature from Using the Phase Change Material in Building Application 21

4.4 Thailand Climate Condition with Melting of the Phase Change Material in Building Application 22

4.5 Thermal Performance of the Phase Change Material in Building Application 23

4.5.1 Heat Absorption from the Daylight Incidence with the Mass of the PCM 23

Chapter V. Conclusion 24

5.1 Conclusions 24

5.1.1 Verification Melting Point of the Composition LA-PA Eutectic Mixture as Phase Change Material 24

5.1.2 Differential Scanning Colorimeter (DSC) Analysis of LA-PA Eutectic Mixture as Phase Change Material 24

5.1.3 Thailand Climate Condition and Room Air Temperature from Using the Phase Change Material in Building Application 24

5.1.4 Thailand Climate Condition with Melting of the Phase Change Material in Building Application 24

5.1.5 Thermal Performance of the Phase Change Material in Building Application 24

5.2 Suggestions 25

References 26

Appendix 28

Appendix A: DSC Principle 29

A.1 Theory and Principle of DSC 30

Appendix B: Raw Data 32

B. 1 Verification Melting Point of the Composition LA-PA Eutectic Mixture as Phase Change Material 33

B. 2 Thailand Climate Condition and Room Air Temperature from Using the Phase Change Material in Building Application 34

B. 3 Thailand Climate Condition with Melting of the Phase Change Material in Building Application 35

Appendix C: Calculations 37

C.1 Calculation Molar Ratio of Lauric Acid and Palmitic Acid Mixture in the Experiment 38

C.2 Calculation Heat from the Daylight Incidence with the Mass of the PCM 38

Biography 40

List of Figures

Page

Figure 2.1 Classification of energy storage materials...4
Figure 2.2 The melting/solidification process 5
Figure 2.3 Relationship between PCM's enthalpy and temperature for different types of PCMs 6
Figure 2.4 Classification of PCMs...7
Figure 2.5 Binary phase diagram – isomorphous system. 8
Figure 2.6 Binary phase diagram – azeotropic point...9
Figure 2.7 Binary phase diagram – eutectic point 9
Figure 2.8 Core and shell microencapsulation PCM 13
Figure 3.1 The illustration of the concrete block and its spaces................................18
Figure 3.2 The illustration of house model for experimental for comparison (a) without the PCM and (b) with the PCM 18
Figure 4.1 Melting temperatures LA-PA mixtures versus composition of the components 19
Figure 4.2 DSC curve for the eutectic mixture 80-20 mol% of LA-PA acid 20
Figure 4.3 Relationship between the average temperature outside and inside the home model with the PCM and without the PCM at different times of day 21
Figure 4.4 Temperature and melting percentage of PCM in concrete block at different times of day 22
Figure 4.5 Outside temperature (T out), inside temperature with the PCM (T with PCM) and inside the concrete block spaces (T b) at different times of day on 11 April 2018 at 14:30 - 21:30 PM 23
Figure A.1.1 The parts of heat flux DSC 30
Figure A.1.2 The parts of power compensation DSC...31
Figure B. 3 Average melting percentage of PCMs in concrete block with times 36

List of Tables

Page

Table 1.1 Work plan in 2 semesters 3
Table 2. 1 Phase change temperature and latent heat of fatty acids 11
Table 2. 2 Density, specific heat and thermal conductivity of fatty acids as PCMs.... 11
Table B. 1 Verification melting point of LA-PA in molar ratio from 100 – 0 %........ 33
Table B. 2 Data of temperature outside and inside the home model with PCMs and without PCMs with times.. 34
Table B. 3. 1 Data of average melting percentage of PCMs in concrete block with any temperatures and times 35
Table B. 3. 2 Data of the outside temperature (T out), inside temperature with the PCM (T with PCM) and inside the concrete block spaces (T b) with any temperatures since on 11 April 2018 during 14:30 - 21:30 PM at KMITL, Bangkok Thailand 36

NOMENCLATURE

C_p	Specific heat-capacity (J/kg K)
$C_{p,l}$	Mean specific heat capacity of liquid PCM (J/kg K)
C_{ps}	Mean specific heat capacity of solid PCM (J/kg K)
$C_{p,t}$	Specific heat capacity of test tube (J/kg K)
$C_{p,w}$	Mean specific heat capacity of water (J/kg K)
E	Radiative flux density (W/m^2)
H_m	Latent heat of fusion of PCM (J/g)
h	Enthalpy (J/kg)
Q	Total heat energy stored (J)
L	Latent heat (J/ kg)
m	Mass of PCM (g)
T	Temperature (°C or K)
T_f	Freezing temperature (°C or K)
T_m	Melting temperature (°C or K)

TECHNICAL ABBREVIATIONS

CA	Capric Acid
DSC	Differential Scanning Colorimeter
FTIR	Fourier Transformed Infrared
HDPE	High-Density Polyethylene
LA	Lauric Acid
LHTES	Latent Heat Thermal Energy Storage
MA	Myristic Acid
MEEMs	Microencapsulated Eutectic Mixtures
MPCM	Microencapsulated Phase Change Material
MTES	Methyl Triethoxysilane
PA	Palmitic Acid
PCM	Phase Change Material
PEGs	Polyethylene Glycols
PS	Polystyrene
SA	Steatric Acid
SBS	Styrene–Butadiene–Styrene
SEM	Scanning Electronic Microscope
TES	Thermal Energy Storage
TMD	Thai Meteorological Department
XRD	X–ray diffractometer

CHAPTER I
INTRODUCTION

1.1 Background

The world energy demand nowadays has been increasing because of the increase of population all around the world and the other reason is human demands has no limit but the resources has been decreased. Especially, for the non-renewable energy resources which take an important role to drive the world activities such as fossil fuels. In the term of power plant for generate electricity to the world activities, non-renewable energy has been used to generate electricity more than renewable energy, so to save world energy consumption is to reduce energy use as much as possible or to use the resources to have high efficiency. Moreover, these kind of non-renewable energy has emitted more greenhouse gases while they are combusted for uses in world activities. Then energy conservation and saving is the present concerned topic in any parts of the world likewise in Thailand and for energy efficiency, one of the most effective is use thermal energy storage (TES) technology.

Thermal energy storage (TES) which is greatly assisted by the incorporation of latent heat storage in different products, so sometimes, it is called latent heat thermal energy storage (LHTES) system. It has been observed that building components, which store heat during peak power operation, can reduce at the same time space-conditioning energy consumption. Phase change materials (PCMs) are one of the thermal control devices used today in building envelopes. PCMs in building envelopes can be used for many different purposes including reduction of space-conditioning energy consumption, thermal peak load shaving and shifting, local temperature control in building envelope components, or improvement of overall system durability. [1]

Since Thailand is located south of Tropic of Cancer, then Thailand is tropical country and hot in the most of country. Generally, the temperature at night is always lower than the temperature on day time, so using phase change materials as latent heat thermal energy storage can be the answer for energy efficiency. And according to Thailand temperature data in year 2016 of Thai Meteorological Department (TMD), the average maximum temperature all parts of Thailand is 30.50 °C and the average minimum temperature all parts of Thailand is 24.50 °C. However, some data about the overview of Thailand has remarked that the temperature in Thailand averages from 18 °C to 34 °C. These temperature can be one the important parts for phase change materials selection because environmental temperature can affect to melting temperature of them. So in this study, the range of temperature that selected for melting temperature of phase change material is 30 °C to 33 °C because when the temperature of the daytime is more than 30 °C then phase change material is melted by latent heat and at night, the temperature is usually less than 30 °C, then this temperature can solidify the phase change material.

Therefore, selection type of phase change material is the way to do to get phase change materials with melting point in range of 30 °C to 33 °C. For phase change materials, there are three kinds of them which are organic phase change material, inorganic phase change material and eutectic mixture phase change material. In the term of energy efficiency with renewable energy, organic phase change materials such as fatty acids, paraffins, PEGs are the alternative for this issue. However, Thailand is the agricultural country that has many kinds of biomass and one of the most important agricultural products of Thailand in economy aspect is palm that usually be the raw material in palm oil production and biodiesel production because palm is composed of saturated and unsaturated fatty acids. So using saturated fatty acids from palm oil to be organic phase change material are selected because of their stability more than unsaturated fatty acids. Moreover, one important advantage for this organic phase change materials are environmental friendly which is the concerned issue in this era of the green world.

Since the above melting temperature of the phase change materials that need to be develop in this study is slightly low, then using 2 types of fatty acids to be eutectic mixture phase change material is the best reason to get that melting temperature. According to the review of the study fatty acids as phase change materials, the use of capric acid, luaric acid, palmitic acid and streatric acid has been used in this application. And for the melting point in range of 30 °C to 33 °C, using eutectic mixture of luaric acid and palmitic acid in ratio 80 mol % and 20 mol % respectively which is the best way to obtain 32.7 °C of melting point of phase change material. [2]

Therefore, in this study is to develop eutectic mixture of fatty acid as phase change material for latent heat thermal energy storage in building application by using eutectic mixture of luaric acid and palmitic acid to obtain the target melting temperature, which condition is following [2]. In the term of building application, these eutectic mixture phase change materials are enveloped by concrete block and study for their efficiency in local temperature control by phase change material.

1.2 Objectives

1.2.1 To develop eutectic mixture of fatty acid as phase change material for latent heat thermal energy storage in building application

1.2.2 To evaluate heat involved in implementing the phase change material in building application under the climate in Thailand

1.3 Scopes of Work

1.3.1 To prepare fatty acid which are Lauric acid and Palmitic acid with ratio 80 and 20 percent mole respectively to be eutectic mixture phase change material

1.3.2 To analyze thermal properties of the eutectic phase change material by using differential scanning colorimeter (DSC) for the target melting temperature in Thailand building application

1.3.3 To develop the phase change material with the target melting temperature into the concrete block and study the behavior with thermal energy storage in building application

1.3.4 To study thermal performance of thermal energy storage in phase change material in building application

1.4 Steps of Work

1.4.1 Study the principle of phase change material and phase change material from biomass

1.4.2 Study phase change material in building application

1.4.3 Study and search for the recent average temperature of Thailand in any seasons by weeks, months and years for phase change material temperature selection

1.4.4 Study eutectic mixture of fatty acid as phase change material to get the target temperature

1.4.5 Analyze melting point and heat data from eutectic mixture of fatty acid as phase change material by differential scanning colorimeter (DSC)

1.4.6 Develop phase change material in building application by taking in concrete block

1.4.7 Compare the thermal energy storage performance between the wall with phase change material and without phase change material for building application

1.5 Expected Outputs

1.5.1 To obtain the high performance concrete blocks which have phase change materials inside concrete blocks that are suitable for Thailand weather in building application of latent heat thermal energy storage which can reduce heat from outside temperature of the building into inside of the building

1.5.2 To learn how to apply biomass in Thailand which are fatty acids to be more useful phase change materials in building application and using phase change material in concrete block in building application with their thermal performance

1.6 Work Plan

Table 1.1 Work plan in 2 semesters

Topic	**Semester 1/2017**					**Semester 2/2017**				
	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
Topic selection										
Theory and related research study										
Laboratory setup										
Verification molar ratio of LA-PA										
DSC Analysis										
Application the PCM in house model										
Result analysis										
Report Writing										

CHAPTER II
LITERATURE REVIEW

2.1 Thermal Energy Storage; TES

A variety of thermal energy storage (TES) techniques have developed over the time for the reason of enormous potential to make the use of thermal energy equipment more effective and for facilitating large-scale energy substitutions from an economic perspective. Energy storage through solid-liquid phase change is a transient process. The material is either absorbing or releasing energy as its melts or solidifies. Thus this type of system is not particularly well suited for applications that operate primarily in steady-state conditions.

For thermal energy storage technology has been used in various forms and applications. Some of the more common applications include the use of sensible TES (oils, molten salts) or latent TES (ice, phase change material) for refrigeration or space heating and cooling needs.

The use of TES systems often results in significant benefits, such as the following:

• reduced energy costs;
• reduced energy consumption;
• improved indoor air quality;
• increased flexibility of operation;
• decreased initial and maintenance costs;
• reduced equipment size;
• more efficient and effective utilization of equipment;
• conservation of fossil fuels (by facilitating more efficient energy use); and
• reduced pollutant emissions (e.g., CO_2). [3]

The useful classification of the substances that used for TES can be shown in Figure 2.1. [4]

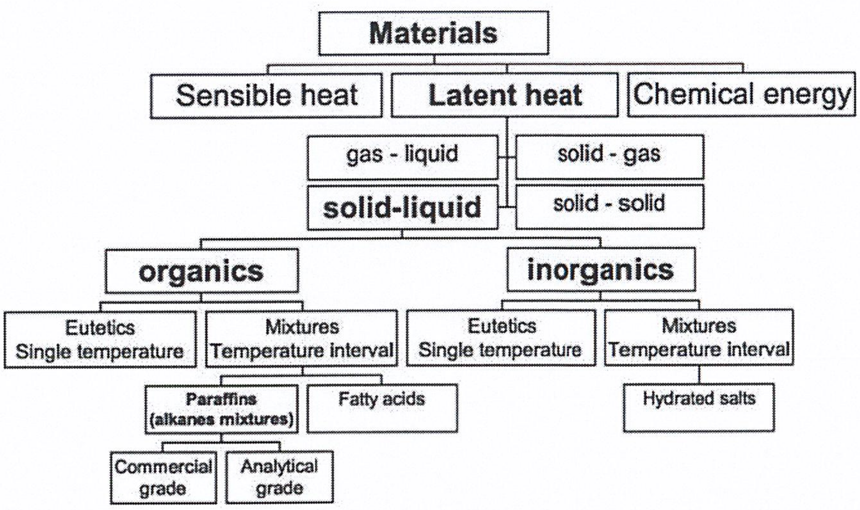

Figure 2.1 Classification of energy storage materials [4]

For the use of latent TES in the term of the material that undergo solid-liquid, systems that require storage of thermal energy for later system usage will normally use phase change materials (PCMs) for what is referred to as thermal energy storage or TES. In these applications, during times of excess energy production, some of that thermal energy can be diverted into a storage system where it is kept for utilization at a later time period. The storage system features a solid PCM which slowly transitions to a liquid at constant temperature as the thermal energy flows into the material. The energy is thus stored in within the material itself, and can easily be extracted by solidifying the material.

Thermal energy quantities differ in temperature. As the temperature of a substance increases, the energy content also increases. The energy required E to heat a volume V of a substance from a temperature T_1 to a temperature T_2 is given by

$$E = mC\,(T_2 - T_1) = \rho VC\,(T_2 - T_1) \qquad (2.1)$$

Where C is the specific heat of the substance. A given amount of energy may heat the same weight or volume of other substances, and increase the temperature to a value greater or lower than T_2. The value of C may vary from about 1 kcal/kg°C for water to 0.0001 kcal/kg°C for some materials at very low temperatures. [3]

2.2 Phase Change Materials; PCMs

Phase change materials are materials that undergo the solid-liquid phase transformation, or sometimes commonly called as the melting-solidification cycle, at a temperature within the operating range of a selected thermal application. Phase change material absorbs energy from surrounding and the energy that is absorbed by the material acts to increase the energy of the constituent atoms or molecules, increasing their vibrational state. At the melting temperature, the atomic bonds loosen and the materials transfer from a solid to a liquid. Solidification is the reverse of this process, during which the material transfers energy to its surroundings and the molecules lose energy and order themselves into their solid phase, which can be described in Figure 2.2. [1]

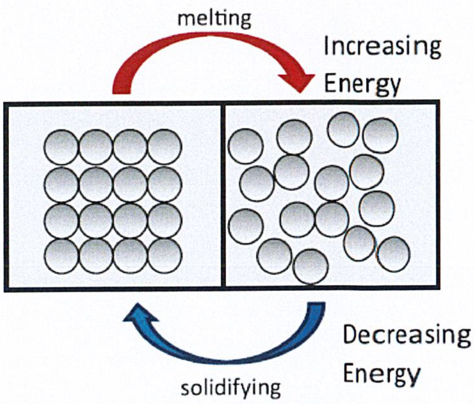

Figure 2.2 The melting/solidification process [1]

The phase change, which is usually used to store latent heat energy in buildings, is between the liquid phase of the material and its solid phase. The liquid to solid transformation is called solidification and the solid to liquid transformation is called fusion. [7]

There are several kinds of phase change materials that used nowadays, since their properties for application depend on any materials which can be investigated from various perspectives including operating temperature range, phase-transition enthalpy, chemical stability, long-term durability, and flammability. And in figure 2.3 shown that relationship between PCM's enthalpy and temperature for different types of PCMs such as paraffin, salt hydrates, water, sugar alcohol, fatty acids and so on. It seems to be that fatty acids and paraffin which are organic PCMs, usually cover in the short range of phase transition temperature and enthalpy. In the other hand, such chlorides, carbonates – inorganic PCMs cover the large phase transition temperature and enthalpy range more than organic PCMs. These characteristics are especially important for their application in building envelopes, since PCM has to be incorporated into the structural components, finish materials, or thermal insulation.

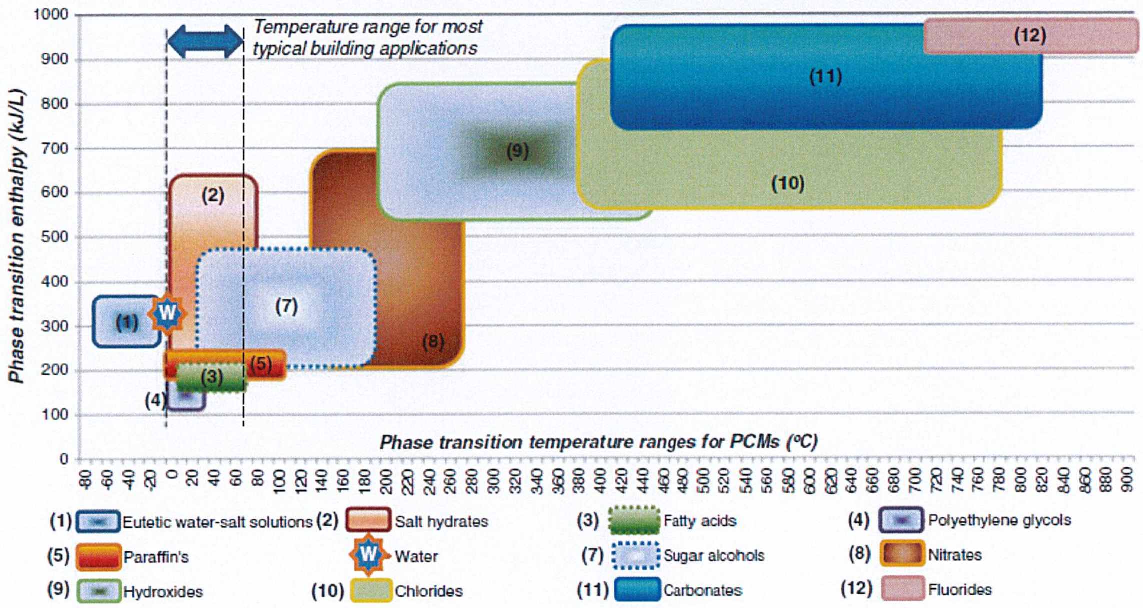

Figure 2.3 Relationship between PCM's enthalpy and temperature for different types of PCMs [5]

2.2.1 Type of Phase Change Materials (PCMs)

The main categorization of PCMs is the differentiation between inorganic PCMs and organic PCMs. The commonly used phase-change substances for technical applications are as follows: paraffins (organic), fatty acids (organic), and salt hydrates (inorganic), which shown in Figure. 2.4. [5]

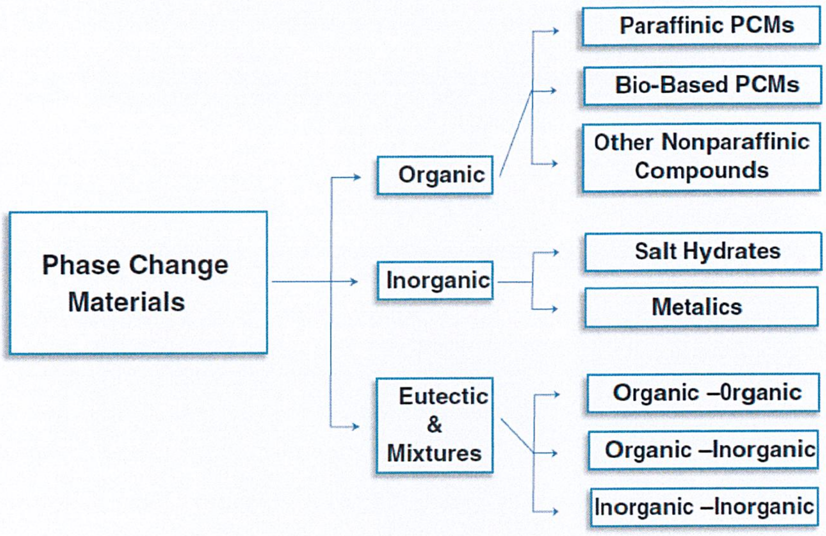

Figure 2.4 Classification of PCMs [5]

- **Organic Phase Change materials (PCMs)** [6]

Organic phase change materials are in general chemically stable, do not suffer from supercooling, non-corrosive, non-toxic and have a high latent heat of fusion. Organic PCMs can be divided into two groups: paraffins and non-paraffins.

1. Paraffins

Paraffin waxes or $CH_3(CH_2)nCH_3$ are cheap and have a reasonable thermal storage density of 120 kJ/kg up to 210 kJ/kg and have a low vapour pressure in the melting state. Paraffins are available in a wide range of melting temperatures from approximately 20 °C up to about 70 °C, they are chemically inert, and do not undergo phase segregation. However, paraffins have a low thermal conductivity of about 0.2 W/(mK) which limits their application.

2. Non-Paraffins

They include many kinds of organic materials such as fatty acids, esters, alcohols and glycols. They are expensive when compared to paraffins. And the most interest in organic PCMs are the fatty acids or palmitoleic acids with their advantages following they have melting points in a relatively low temperature range, a high latent heat of fusion, undergo small volume changes during phase transition and do not undergo supercooling during freezing. Most common useful fatty acids are divided in 6 groups: caprylic, capric, lauric, myristic, palmitic and stearic with respectively 8 up to 18 carbon atoms per molecule. Their melting points are in the range between 16 and 65 °C and freezing points between 17 and 64 °C, with a heat of fusion between 155 and 180 kJ/kg.

- **Inorganic Phase Change Materials (PCMs)**

Inorganic PCMs in general have a rather high heat of fusion, good thermal conductivity, cheap and non-flammable. However, they are some disadvantages such as corrosive to most metals, undergo supercooling and undergo phase decomposition. The inorganic PCMs are common known hydrated salts. [6]

- **Eutectics**

Eutectic mixtures or eutectics are a mixture of two or more chemical components or solids in such proportions that the melting point is as low as possible, have in general sharp melting points and its volumetric storage density is slightly higher than that of organic compounds. However, they have some limitations are available on their thermal and physical properties. Eutectics can be divided into 3 groups according to the materials of which they consist: organic–organic, inorganic–inorganic and inorganic–organic eutectics. [5]

2.3 Eutectic Mixture System [7]

2.3.1 Binary Phase Diagram

The phase change of a binary mixture is multi-components mixture, the theory is quite similar but more complicated from a representation point of view. The binary diagram is used to represent the location of the different phases of a mixture.

Figure 2. 5 shown a binary diagram of an isomorphous system. The abscissa corresponds to the proportion of the component B in the mixture A + B, and the ordinate is the temperature of the mixture. The volume and the pressure are constant.

The diagram consists of two single-phase fields separated by a two-phase field. The boundary between the liquid field and the two phase field in Figure 2. 5 is called the liquidus; that between the two phase field and the solid field is the solidus. In general, a liquidus is the locus of points in a phase diagram representing the temperatures at which mixtures of the various compositions of the system begin to freeze on cooling or finish melting on heating; a solidus is the locus of points representing the temperatures at which the various mixtures finish freezing on cooling or begin melting on heating. The phases in equilibrium across the two-phase field (the liquid and solid solutions) are called conjugate phases.

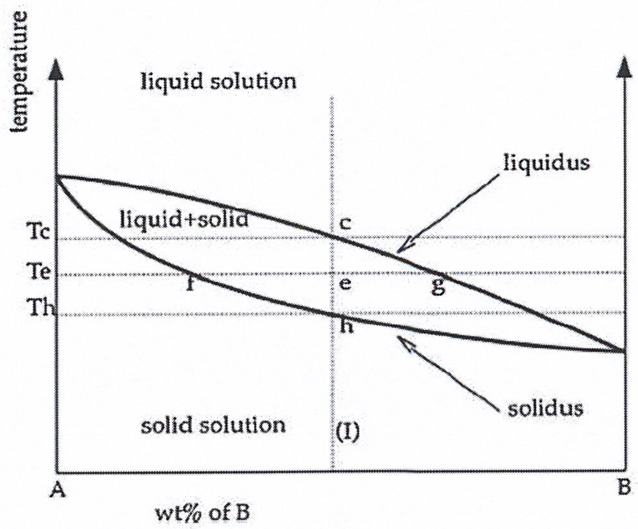

Figure 2.5 Binary phase diagram – isomorphous system [7]

Depending on the components, several phase diagrams exist depending on the phase change behavior of the mixture. Figure 2.6 shown that the phase diagram with a large solubility gap and a minima liquidus temperature, such as an azeotropic point X.

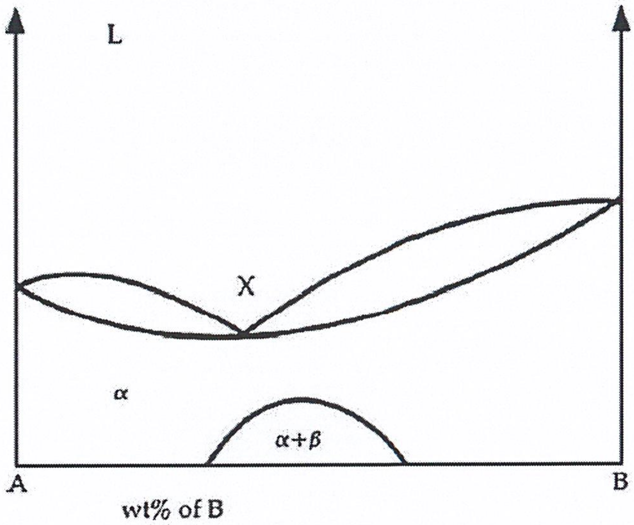

Figure 2.6 Binary phase diagram – azeotropic point [7]

2.3.2 Binary Eutectic System

The binary eutectic phase diagram explains the chemical behavior of two immiscible (unmixable) crystals from a completely miscible (mixable) melt.

The phase diagram for eutectic mixture can be shown by Figure 2. 7. It is the special case of a system with an eutectic mixture by point E; it is a mixture at such proportions that melting point is as low as possible and that all the components crystallize simultaneously.

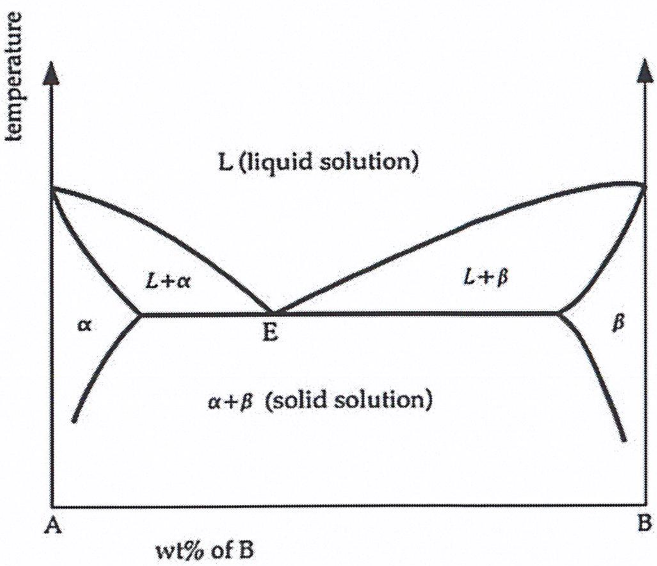

Figure 2.7 Binary phase diagram – eutectic point [7]

2.4 Fatty Acid

Fatty acid is the important component of lipids in plants, animals, and microorganisms, so this assures a continuing non-pollutant source. Generally, a fatty acid consists of a straight chain of an even number of carbon atoms, with hydrogen atoms along the length of the chain and at one end of the chain and a carboxyl group (−COOH) at the other end. It is that carboxyl group that makes it an acid (carboxylic acid). And there are 2 types of fatty acids included saturated fatty acids which the carbon-to-carbon bonds are all single, and the other is unsaturated fatty acids that if any of the bonds is double or triple, the acid is unsaturated and is more reactive. [16]

The unsaturated fatty acids have one or more double bonds between carbon atoms, for example myristoleic acid, palmitoleic acid, oleic acid and so on. And for saturated fatty acids which have no double bonds, such as capric acid, lauric acid, myristic acid, palmitic acid, steatric acid.

Since the raw materials of fatty acids are derived from renewable vegetable and animal sources. So fatty-acid based PCM can be produced in the following categories:

1. Naturally occurring triglycerides.
2. Hydrates of acids of triglycerides and their mixtures.
3. Esters of the fatty acids of naturally occurring triglycerides.
4. Refined/synthesized triglyceride products produced by a combination of fractionation and transesterification processes.
5. Synthesized triglyceride products using hydrogenation (or dehydrogenation) and fractionation.
6. Synthesized triglyceride products using cis-trans isomerization and fractionation.
7. Synthesized fatty acid derivatives that have the desired freezing point temperatures.
8. Refined fatty acid hydrates that have the desired freezing point temperatures.
9. Prepared mixtures produced by essentially any of the previous processing approaches with other chemicals (preferable cheap and nontoxic) to produce eutectic compositions with the desired freezing point temperature range [10]

The phase change materials (PCMs) have two basic parameters of phase change temperature and latent heat. Therefore, many researchers have tested the two parameters of fatty acids as PCMs. Since the phase change temperature and latent heat of PCMs tend to be influenced by individual experimental condition such as temperature, purity, and the accuracy of analytical instruments which shown in table 1 and table 2 for density, specific heat and thermal conductivity of fatty acids as PCMs. Almost research has not been done about the unsaturated acids as PCMs or the chemical structure of saturated and unsaturated acids and the influence of chemical structure on thermal properties. However, saturated fatty acids are almost interest to be phase change material more than unsaturated fatty acid in organic PCMs.

Table 2. 1 Phase change temperature and latent heat of fatty acids [9]

Fatty acid	Melting temperature (°C)	Melting latent heat (J/g)	Freezing temperature (°C)	Freezing latent heat (J/g)
Caprylic acid $CH_3(CH_2)_6COOH$	16.1	144.2	-	-
Capric acid $CH_3(CH_2)_8COOH$	29.62 - 32.14	139.77 - 168.77	25.57 - 32.53	14012 - 154.24
Lauric acid $CH_3(CH_2)_{10}COOH$	42.14 - 44.33	175.80 - 217.29	39.78 - 42.20	180.51 - 194.23
Myristic acid $CH_3(CH_2)_{12}COOH$	51.5 – 58	178.14 - 210.70	51.74 - 52.49	181.63 - 212.65
Palmitic acid $CH_3(CH_2)_{14}COOH$	58.9 - 65.5	185.40 - 233.24	58.23 - 60.38	205.39 - 237.11
Steatric acid $CH_3(CH_2)_{16}COOH$	53.8 - 70.9	159.30 - 298.98	52.12 - 66.36	177.80 - 263.32
Oleic acid $CH_3(CH_2)_7CH{=}CH(CH_2)_7COOH$	13.6	138.07	-	-

Table 2. 2 Density, specific heat and thermal conductivity of fatty acids as PCMs [9]

	Capric acid (CA)	Lauric acid (LA)	Myristic acid (MA)	Palmitic acid (PA)	Steatric acid (SA)
Density (kg/m^3) Solid Liquid	1004 878	1007 862	990 861	989 850	965 848
Specific heat (kJ/kgK) Solid Liquid	1.9 2.1	1.7 2.3	1.7 2.4	1.9 2.8	1.6 2.2
Thermal conductivity liquid (W/m K)	0.153	0.147	0.150	0.162	0.172

In this study, the saturated fatty acids is the substance that used because of their saturated that is hardly to reactive when be in building application. However, since their physical properties such as the odor of each fatty acids, capric acid, myristic acid and streatric acid are strong rancid and unpleasant that seem to be not suitable for building application. Then lauric acid and palmitic acid are more suitable and cheaper than the others.

2.5 Fatty Acid Eutectic Mixture

The eutectic temperature is the lowest melting temperature of a mixture of two or more components, and such mixture is a eutectic mixture which features the same stability of a single component. The eutectic mixtures of fatty acids as PCMs have expanded the phase change temperature range and thus the engineering application of fatty acids as PCMs. [9]

2.5.1. Theoretical Calculation of Ratio for Binary Fatty Acid Eutectic

Generally, a certain pure fatty acid has a higher melting point than the desired temperature by building energy conservation. In order to decrease phase change temperature of the eutectic mixture, two kinds of fatty acids can be mixed together in their eutectic proportion to reach the lowest eutectic temperature, namely phase change temperature, according to the lowest eutectic point theory. The eutectic ratio of the chosen fatty acids in this study can be calculated with Schrader equation which shown in equation 2.2 described as following [8].

$$T=1/(\frac{1}{T_f}-R\ln X_A/\Delta_S^l H_A) \qquad (2.2)$$

Where x_A is the mole fraction of component A in the mixture, $\Delta_S^l H_A$ and T_f are the latent heat and melting point of material A, T is the melting point of the mixture and R is the gas constant (8.315 J/k mol).

The formula for calculating the melting enthalpy of a (quasi) eutectic is shown below:

$$H_m= T_m\sum[\frac{X_iH_i}{T_i}+X_i(C_{PLi}- C_{PSi})\ln(T_m/T_i)] \qquad (2.3)$$

Where H_m is the latent heat of the mixture, $Jmol^{-}1$; C_{PLi}, the specific heat at constant pressure of the ith component in the liquid state, and C_{PSi} the specific heat at constant pressure of the ith component in the solid state. [9]

In this study, the saturated fatty acids that used are lauric acid (LA) and palmitic acid (PA) in molar ratio 80% and 20% respectively to be eutectic mixture for phase change material to get phase change temperature about 32 °C to 33 °C which is the temperature of the eutectic mixture that is lower than the pure each fatty acid that mixed, which is from literature review in reference [2].

2.6 PCMs in Building Application [1]

There are several different ways to implement PCM in a given application such that the liquid melt phase remains contained and does not contaminate the system by the use of macro scale container systems, of microencapsulated PCM beads, and of completely form stabilized PCM.

2.6.1 The Impregnation of Building Materials

The simplest method consists in the direct impregnation of the PCM into gypsum, concrete or other porous materials. The volume occupied by the PCM in the pores is small enough to prevent from the isolation of the solid PCM crust. The structure of the porous material transports the heat to the pores which could be leakage. This interaction between PCMs and its porous can deteriorate the mechanical properties of the container. The materials used for impregnation are as follows: plaster, concrete, vermiculite, wood, cement and compound. [7]

Concrete is a common construction material made of four components: cement, water, aggregates, and additives. PCM can be either introduced to concrete as an additive or during the impregnation process. Cement is the bounding concrete element that is activated by water. Frequently used portland cement usually consists of the following four major mineral ingredients: tricalciumsilicate ($3CaO{\cdot}SiO_2$), dicalciumsilicate ($2CaO{\cdot}SiO_2$), tricalciumaluminate ($3CaO{\cdot}Al_2O_3$), and tetracalcium aluminaferrate ($Al_2O_3{\cdot}Fe_2O_3$). Occasionally, blast furnace cements or fly ash cement can be used in concrete mixtures instead of, or in addition to the portland cement. Sometimes lime and clay are added to the concrete mixture as well. [5]

2.6.2 The Micro-Encapsulation

The microencapsulation consists in enclosing the PCM in a microscopic polymer capsule or shell which encapsulate a PCM core as seen in Figure 2. 8. The scale of the material is typically 1–1000 μm in diameter for microPCM beads and 10–500 nm for nanoPCM beads. The microcapsules form a powder, which is then included in the recipe of a building construction material such as concrete, a polymer or gypsum, to form the improved building phase change material. Special attention has to be taken in the choice of the capsule's material to avoid chemical reactions between the capsules and the building material. The PCM is trapped and cannot leak anymore, and the size of the capsules is small enough to prevent from a disproportionate isolation of the solid crust of the PCM. [7]

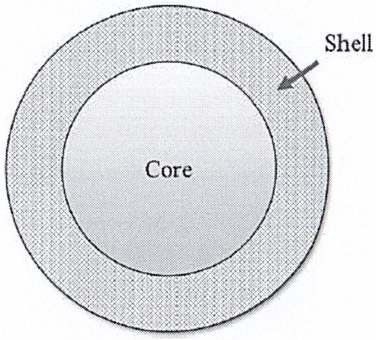

Figure 2.8 Core and shell microencapsulation PCM [1]

2.6.3 Shape-Stabilized PCM

Shape-stabilized PCM are prepared from a liquid mixture of the PCM and a supporting material. The mixture is then cooled below the glass transition temperature of the supporting material, until it becomes solid. An appropriate choice of the supporting material allows PCM mass proportions up to 80%. The most common supporting materials found in the literature are high-density polyethylene (HDPE) and styrene–butadiene–styrene (SBS). However, the thermal conductivity of a shape-stabilized PCM is not so high, which is a problem in latent heat storage systems. [7]

2.7 Literature Reviews

D. Feldman and the team [2] had studied about an analysis thermal properties of fatty acids and their binary mixtures which are attractive candidates for latent heat thermal storage in space heating applications by using method differential scanning calorimetry to determine the transition temperatures and latent heat of transition of the fatty acids and their binary mixtures. The melting range of the fatty acids (capric, lauric, palmitic and stearic) was observed to be approximately from 30 °C to 65 °C. Their heat of transition was observed to have a range from approximately 153 to 182 J/g. The melting points of the eutectics for the binary systems of capric-lauric, lauric-palmitic, lanric-stearic and palmitic-stearic acids were found to be 18 °C, 32.7 °C, 34 °C and 51 °C, respectively. And the corresponding heats of melting were 120, 145, 150 and 160 J/g, respectively.

Ahmet Sarı and Ali Karaipekli [11] had studied the preparation, thermal properties and thermal reliability of capric acid–palmitic acid (CA–PA) mixture as phase change material (PCM) for low temperature latent heat thermal energy storage (LHTES) by using the differential scanning calorimetry (DSC) to indicate that the CA-PA mixture with eutectic composition (76.5/23.5 wt.%) was suitable PCM for low temperature LHTES applications in terms of melting and freezing temperatures ($T_m = 21.85$ °C; $T_f = 22.15$ °C) and latent heats of melting and freezing ($\Delta H_m = 171.22$ J/g; $\Delta H_f = 173.16$ J/g). The thermal properties make it potential PCM for LHTES systems used in heating, ventilation, and air conditioning applications. Accelerated thermal cycling tests showed that the eutectic mixture as a PCM has good long-term thermal reliability.

Ahmet Sari [12] had studied the thermal properties and thermal reliability of the eutectic mixtures of lauric acid–myristic acid (LA–MA), lauric acid–palmitic acid (LA–PA), myristic acid–stearic acid (MA–SA) as phase change material (PCM) with determination after repeated melt/freeze cycles by the method of differential scanning calorimeter (DSC). The DSC thermal analysis results indicate that the binary systems of LA–MA in ratio of 66.0 : 34.0 wt.%, LA–PA in ratio of 69.0 : 31.0 wt.% and MA–SA in ratio of 64.0:36.0 wt.% form eutectic mixture with a melting temperature of 34.2 °C, 35.2 °C and 44.1 °C, and with a latent heat of fusion of 166.8 J g^{-1}, 166.3 J g^{-1} and 182.4 J g^{-1}, respectively. The changes in the melting temperatures and the latent heats of fusion are in the range like -0.40 °C – 0.23 °C and 1.5% – 3.0% for LA–PA during the 1460 thermal cycles. Based on the results, it can be concluded that the studied PCMs have good thermal properties and thermal reliability for a four-year energy storage period, which corresponds to 1460 thermal cycles, in terms of the change in their melting temperatures and latent heats of fusion.

T. Lee and the team [13] presents the results of macro scale tests that compare the thermal storage performance of ordinary concrete blocks with those that have been impregnated with two phase change materials (PCM). One is a commercial Butyl Stearate, and the other is a commercial Paraffin. The comparative characteristics of these PCM - concrete combinations were examined. Also, the effect of air velocity was studied in respect to the control of the rates of heat storage and discharge. This research is an extension of the laboratory scale work. And this capability renders feasible the use of low-cost heat such as that derived from solar energy, and waste heat whose supply may be asynchronous with the demand.

Derya Kahraman Dö˘güs¸ cü and the team [14] had studied, palmitic acid (PA) and capric acid (CA) eutectic mixture was encapsulated in polystyrene (PS) capsules as new latent heat thermal energy storage (LHTES) material for building applications. Microencapsulated eutectic mixtures (MEEMs) were prepared in homogenized emulsions in 3 different PS/(PA-CA) weight ratios. The synthesis reaction was found complete according to Fourier Transformed Infrared (FTIR) Spectroscopy. The physical and physicochemical characteristics, thermal endurance limits and operating stability of MEEMs were investigated through differential scanning calorimetry, thermal gravimetry and thermal conductivity, particle size distribution analysis, scanning electron microscopy, and polarized optical microscopy techniques. The onsets of melting of MEEMs were measured between 13.5 and 17.1 °C as those of crystallization were between 16.9 and 17.9 °C. The latent heats of melting of MEEMs were measured between 46.3 and 77.3 J/g as those of crystallization were between −45.0 and −73.6 J/g. As a result, a eutectic mixture of PA and CA was depicted for building heating cooling applications and successfully encapsulated in PS shell at different weight ratios.

Guruprasad Alva and the team [15] had studied microencapsulation of myristic acid–palmitic acid (MA–PA) eutectic mixture with silica shell using sol-gel method. The core phase change material (PCM) for thermal energy storage was myristic acid-palmitic acid eutectic mixture and the shell material to prevent the PCM core from leakage was silica prepared from methyl triethoxysilane (MTES). Thermal properties of the microcapsules were measured by differential scanning calorimeter (DSC). The morphology and particle size of the microcapsules were examined by scanning electronic microscope (SEM). Fourier transformation infrared spectrophotometer (FT–IR) and X–ray diffractometer (XRD) were used to investigate the chemical structure and crystalloid phase of the microcapsules, respectively. The DSC results indicated that microencapsulated phase change material (MPCM) melts at 46.08 °C with a latent heat of 169.69 kJ kg^{-1} and solidifies at 44.35 °C with a latent heat of 159.59 kJ kg^{-1}. The thermal stability of the microcapsules was analyzed by a thermogravimeter (TGA). The results indicated that the MPCM has good thermal stability and is suitable for thermal energy storage application.

CHAPTER III
RESEARCH METHODOLOGY

According to literature reviews, this study of fatty acid as phase change materials for building application is done with the experiment in laboratory scale, pilot scale and especially for uses of phase change material in building application.

3.1 Experimental Apparatus and Equipment

1. Aluminum pan
2. Beaker 250 ml
3. Thermometers
4. DSC
5. Heater
6. Stirring rod
7. Lab glass kit
8. Weighing apparatus
9. Cylinder
10. Zip lock plastic bag (12 cm x 16 cm)
11. Capillary tubes

3.2 Experimental Chemicals

1. Lauric acid
2. Palmitic acid
3. Concrete block (40 cm x 19 cm x 6 cm)

3.3 Experimental Procedures

3.3.1 Determination of Eutectic Composition and Thermal Properties for Lauric Acid and Palmitic Acid Mixture

1. Lauric acid is prepared into the molten phase by using temperature at 45 °C for heater.

2. Palmitic acid is prepared into the molten phase by using temperature at 70 °C for heater.

3. Lauric acid and palmitic acid in molten phase are mixed in molar ratio 0 – 100 % into the beaker for 10 minutes and pour it into aluminum pan and to cool the mixture down by room temperature.

4. When all the samples are solidification, they are grinded into the powder for verification the eutectic mixture ratio of lauric acid and palmitic acid by using capillary tube with lab kit.

5. After eutectic mixture of fatty acids verification is done, some of the eutectic mixture sample are taken to test the thermal properties of phase change material by differential scanning colorimeter (DSC) for thermal properties of the phase change material.

3.3.2 Mixing Lauric Acid and Palmitic Acid in Eutectic Mixture as Phase Change Material

1. Lauric acid is prepared into the molten phase by using temperature at 45 °C for heater.

2. Palmitic acid is prepared into the molten phase by using temperature at 70 °C for heater.

3. Lauric acid and palmitic acid in molten phase are mixed in molar ratio 80 % and 20 %, respectively into the beaker for 10 minutes and pour it into aluminum pan and to cool the mixture down by room temperature.

4. When all the samples are solidification, they are cut and grinded into the small pieces or powder in order to increase surface area of phase change material in building application.

5. The phase change material powder is put into 12 cm x 16 cm plastic zip lock bag for implement into the spaces of concrete block with 90 g for 6 bags.

3.3.3 PCM Containment in Concrete Block for Building Application

- **For comparison the concrete block with phase change material and without phase change material**

1. A house model is built by 12 concrete blocks to be the wall of the house and asbestos – cement shingles to be the roof, which shown following figure 3.2.

2. The bags with the phase change material in 90 g are enveloped into the spaces of right hand side of 2 concrete blocks in the side that receive direct sunlight. And the other left hand side, there is nothing inside the spaces of the concrete blocks.

3. One thermometer is taken outside the house to measure the outside or environmental temperature. For another 2 thermometers are taken into a middle space of concrete block in the side with PCM and without PCM. For another 2 thermometers are taken inside the house model by one is in the side with PCM and the other is in the side without PCM.

3.3.4 Measurement of the Phase Change Material Performance in Building Application

1. The concrete block with the phase change materials inside is put on the outdoor with the sunny weather and observation the behavior of phase change material inside the concrete block with the weather at day and night time by observation from melting volume to be percentage in melting at any times.

2. Concrete blocks with the phase change materials inside are lined to be the house wall model in building application for measuring the efficiency of them with thermal energy storage at the wall in keeping heat conduction from outside temperature into phase change material by observation from temperature of the thermometers and record the data at any times.

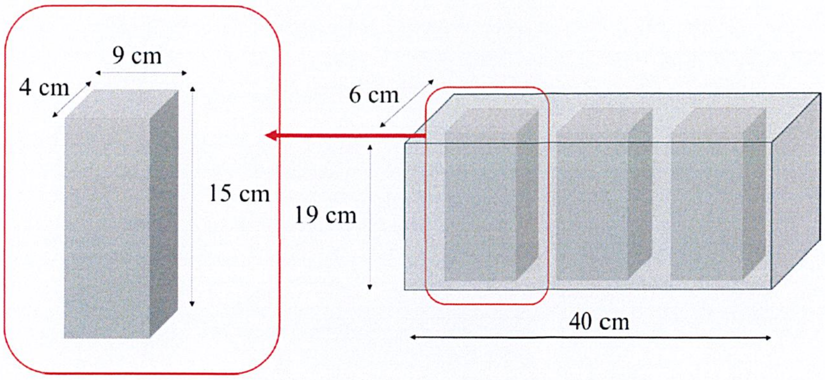

Figure 3.1 The illustration of the concrete block and its spaces

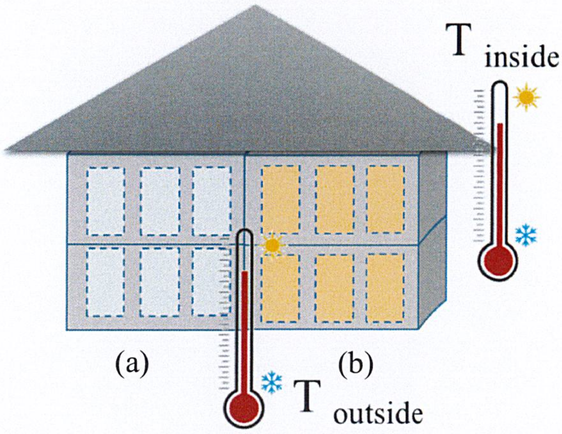

Figure 3.2 The illustration of house model in experiment for comparison (a) without the PCM and (b) with the PCM

CHAPTER IV
RESULTS AND DISCUSSION

4.1 Verification Melting Point of the Composition LA-PA Eutectic Mixture as Phase Change Material

In this part of experiment is preliminary verification to obtain the lowest melting temperature from the mixture of two fatty acids which are luaric acid (LA) and palmitic acid (PA) by mixing in eutectic mixture ratio of LA-PA as the phase change material in building application. The verification of LA-PA eutectic mixture had done by mixing LA-PA in molar ratio 0 – 100 % and the results of the variations in melting temperature of LA-PA mixture with composition of the components (mol %) are shown in figure 4.1. According to figure 4.1, the melting temperature at the molar ratio 80 % – 20 % of LA-PA is lower than another components. And in this ratio of LA-PA is the eutectic mixture that provide the lowest melting temperature, in the range of 37 °C – 44 °C for this composition. So this molar ratio is selected to use for mixing more PCM in the application in the house model. However, when compared the eutectic combination ratio and melting temperature with the given literature [2], it can be observed that in the aspect of eutectic combination ratio, in the molar ratio 80 % – 20 % of LA-PA in this experiment is generally good agreement with the literature, but in the aspect of melting temperature, there has the discrepancy between the results. Following the given literature, the eutectic composition ratio and melting temperature of LA-PA eutectic mixture were found to be 80 – 20 mol % with 32.7 °C [2]. The melting temperature difference between the results is higher about 4 °C because of the factor of the used commercial grade materials (LA and PA) in this experiment but for the literature, they used reagent grade of the materials which are generally less impurity than the commercial grade as the result to increase the melting temperature of 80 – 20 mol % of LA-PA eutectic mixture to be 37 °C.

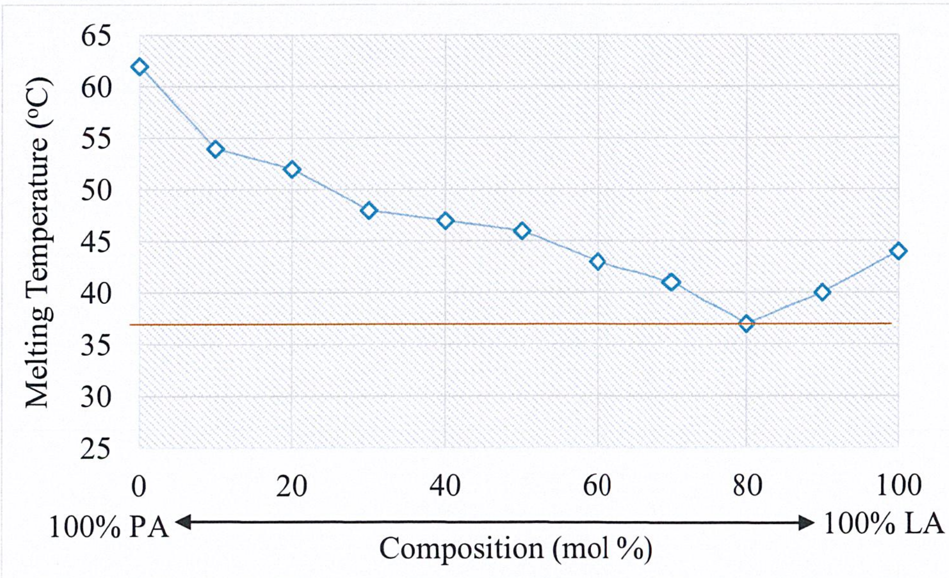

Figure 4.1 Melting temperatures LA-PA mixtures versus composition of the components

4.2 Differential Scanning Colorimeter (DSC) Analysis of LA-PA Eutectic Mixture as Phase Change Material

When the preliminary verification was done, then some sample of 80 – 20 mol % of LA-PA eutectic mixture was taken to characterize the thermal properties by DSC. The DSC measurement was performed using DSC 204 F1 series provided by NETZSCH, Germany and the analysis was carried out between the temperatures of 25 and 100 °C at 10 °C/min heating rate under a constant stream of nitrogen. Figure 4.2 shown the DSC curve result for heating processes of 80 – 20 mol % LA-PA eutectic mixture which has the melting temperature in the range of 36.7 °C to 46.9 °C with its the latent heat of fusion 166.9 J/g. These properties make them to be one of the potential PCMs from LA-PA eutectic mixture with suitable phase change temperature for low temperature LHTES applications for the climate condition in daytime summer of Thailand. However, when compared to the given literature and in this experiment, the used heating rate is different because the literature used 2 °C/min and heated in the range of 0 – 100 °C [2]. So they can obtain the little shifted curve or some discrepancy from literature in the range of melting temperature that in this experiment obtain increased melting temperature than the literature about 4 °C because using 2 °C /min heating and cooling rate, were optimal for all the experiments taking into account the relatively broad peaks in melting and freezing characteristics of the fatty acids as well as the much broadest peak of their mixtures [2]. However, using difference heating rate of 2 and 10 °C/min provided the difference in melting point 0.2 °C from the experiment of the literature review [2].

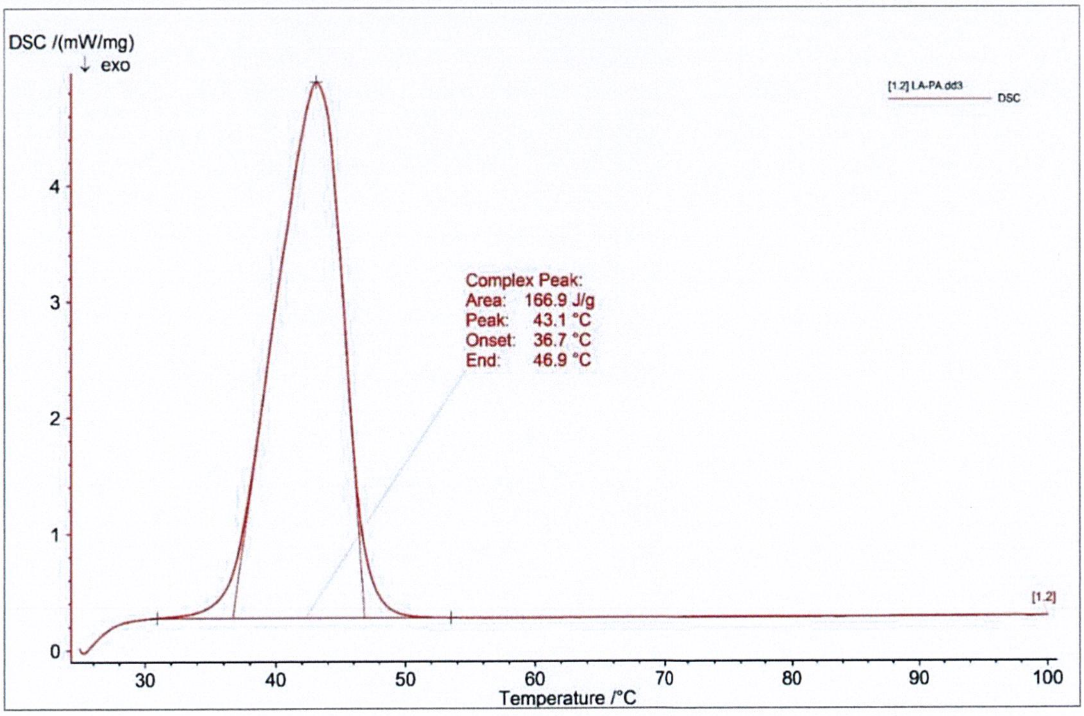

Figure 4.2 DSC curve for the eutectic mixture 80-20 mol% of LA-PA acid

4.3 Thailand Climate Condition and Room Air Temperature from Using the Phase Change Material in Building Application

The prepared 80 – 20 mol % of LA-PA eutectic mixture as PCM was applied to use in the space of hollow concrete blocks in the side that received direct daylight and observed the temperature inside the house model by comparison with the inside temperature of the house without PCM. The datum were collected in the sunny day since 30 March 2018 to 14 April 2018. The results of average temperature outside and inside the home model with the PCM and without the PCM in any times was shown in figure 4.3. The results were found that when the outside temperature (blue line) was continuously above 37 °C more than 1 hours, then the PCM was melted and the inside temperatures of the house model with PCM (orange line) are decreased about 0.5 – 1 °C from the inside temperatures of the house model without PCM (gray line) in the case of comparison to the concrete block with air spaces.

The reason for reduction of inside temperature when applied PCM in the building is phase change process; (a) the light incident onto the wall then (b) the heat from the daylight is used to absorb by the mediate inside the concrete block which is PCM to change the PCM in to the molten form and (c) storage thermal energy in the PCM to be LHTES when the outside temperature is more than melting temperature of the PCM, after that (d) if the outside temperature is decreased in the evening, the heat releases to the environment. However, in the evening, the heat from PCM released gradually to the environment and didn't increase the heat to the house which can observe from orange line that has the same inside temperature.

Then using the PCM depends on the weather on that day which can observe from the same tendency of three lines in figure 4.3 and it is suitable for summer in Thailand because they are effective in temperature more than 37 °C. So they can refer that using PCM in building application can potential reduce inside temperature of the house when the outside or environmental weather is mostly sunny, clearly sky and low relative humidity.

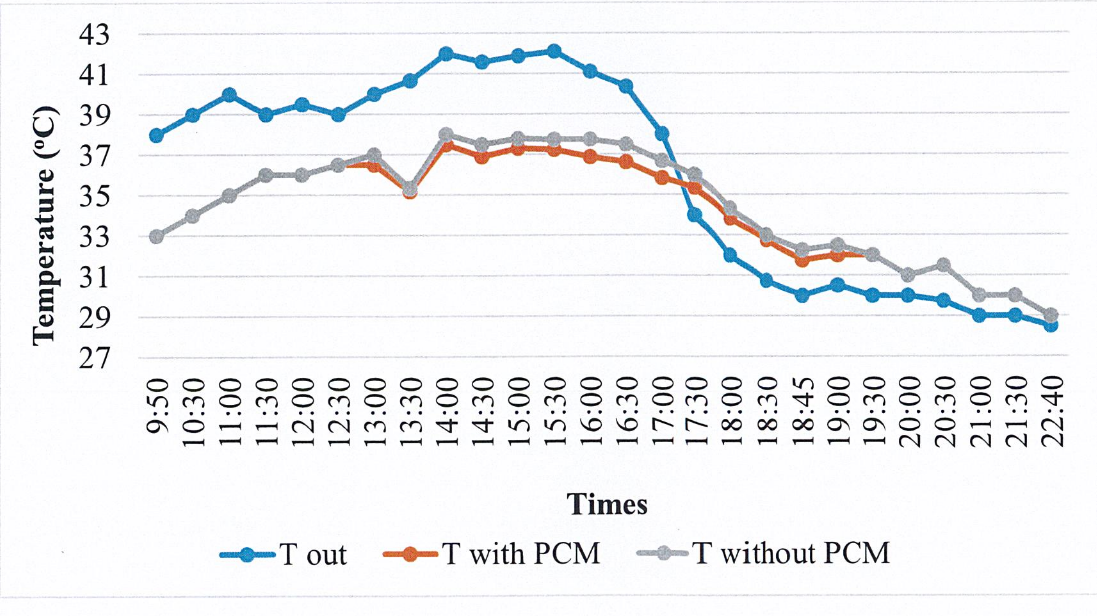

Figure 4.3 Relationship between the average temperature outside and inside the home model with the PCM and without the PCM at different times of day

4.4 Thailand Climate Condition with Melting of the Phase Change Material in Building Application

When 80 – 20 mol % of LA-PA eutectic mixture as PCM receive the incident daylight, then it is melted by the heat from the light. So in this section is study about melting percentage of the PCM depended on environmental temperature or Thailand climate condition which the result shown in figure 4.4. The results are shown that when the outside temperature was continuously increased to be above 37 °C more than 1 hours, then the PCM started to melt because the PCM need temperature to preheat itself in the first region, while inside the spaces concrete blocks also absorbed and kept the heat from light incidence to the wall as a results the temperature in the spaces was higher than the outside temperature, so in this case they can help PCM melting effectively. After they started to melt then they would gradually melt more and more following the outside temperature on that day. When the outside temperature reached more than 39 °C as a result for inside temperature of the concrete block spaces was increased about 2 – 3 °C following figure 4.5, so the PCM almost melted more than 90 % that can observe from figure 4.4 since 16:30 PM because the highest temperature in daytime was normally being 14:00 – 15:30 PM and the heat was absorbed and almost steady kept in the concrete block spaces, whatever after that the temperature was dropt less than 36 °C in the evening but the PCM still melted more to reach 100 %. When the outside temperature was less than 30 °C then the PCM started to melt gradually until solidification was 100 % occurred after 100 % melting for more than 3 hours.

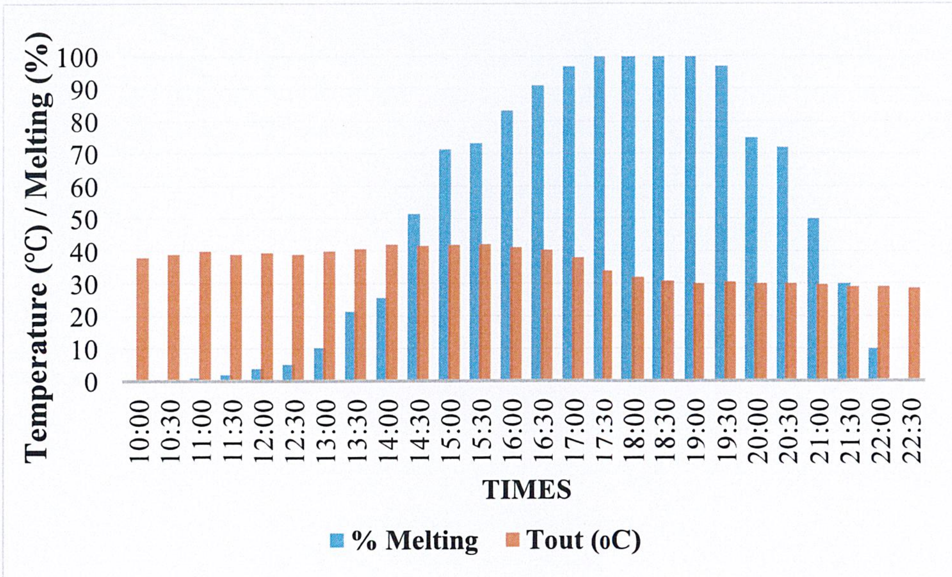

Figure 4.4 Temperature and melting percentages of PCM in concrete block at different times of day

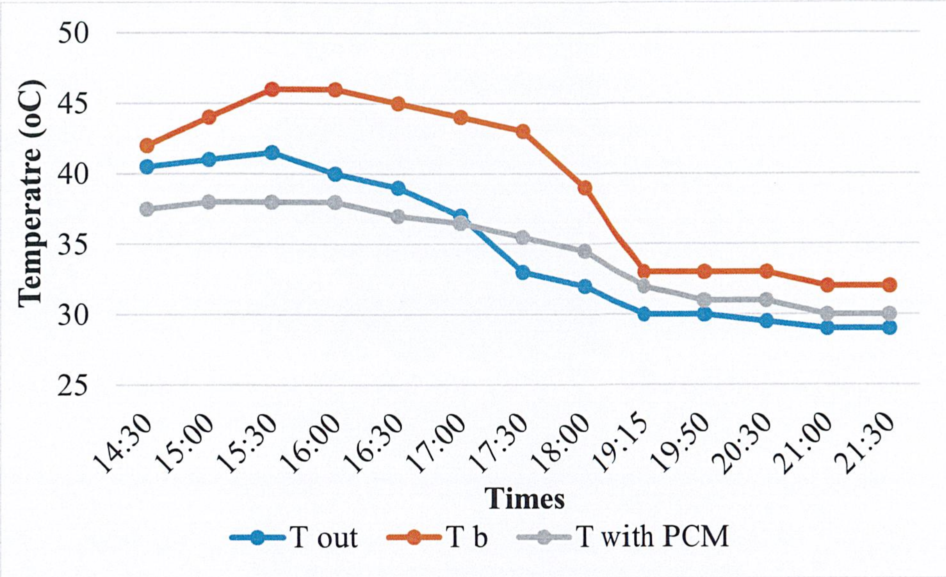

Figure 4.5 Outside temperature (T out), inside temperature with the PCM (T with PCM) and inside the concrete block spaces (T b) at different times of day on 11 April 2018 at 14:30 - 21:30 PM

4.5 Thermal Performance of Phase Change Material in Building Application

According to the application for the building, it had tested in the outdoor yard which could receive direct daylight and the results was found that the average light incidence was about 700 W/m^2 or 2,520,000 $J/h{\cdot}m^2$ in the afternoon. Then the efficiency in the aspect of heat capacity from the daylight incidence is following;

4.5.1 Heat absorption from the daylight incidence with the mass of the PCM

The objective is to reduce the heat from the sunlight before passing through the wall of the house by 50 % but from the calculation in Appendix C.2 show that if using the PCM to reduce 50 % of the overall incident heat, 1.15 kg of the PCM will be applied to the concrete block which area is 0.152 m^2. In the reality, it cannot use because of the space of concrete block and the weight of them that is not suitable for the application in building. So to reduce 30 % of the heat is more suitable in the case of heat absorption of the PCM and the weight of the wall, and the required mass of LA-PA eutectic mixture PCM for the application to reduce the heat is about 688 g. By the way, for the use of 538.5 g in the real application could store 89,875 J per the 0.152 m^2 which reduced the heat to pass through the wall of house model about 23.46 % of the heat from daylight and reduced the inside temperature of the house model with the PCM about 0.5 – 1 °C when compared to the wall without the PCM.

CHAPTER V
CONCLUSION

5.1 Conclusions

5.1.1 Verification Melting Point of the Composition LA-PA Eutectic Mixture as Phase Change Material

The preliminary verification to obtain the lowest melting temperature from the mixture of luaric acid (LA) and palmitic acid (PA) by mixing in eutectic mixture ratio from 100 – 0 mol %. The results show that LA-PA at a molar ratio 80-20 has the lowest melting temperature.

5.1.2 Differential Scanning Colorimeter (DSC) Analysis of LA-PA Eutectic Mixture as Phase Change Material

The eutectic mixture of LA-PA at a molar ratio 80-20 was characterized with DSC for its melting temperature and it was found that the melting temperature was in the range of 36.7 °C – 46.9 °C and the latent heat of fusion was 166.9 J/g. The difference of melting temperature obtained in this work and the value from another work [2] is around 4 °C because different grade of materials was used as well as different heating rate and the range of testing temperatures.

5.1.3 Thailand Climate Condition and Room Air Temperature from Using the Phase Change Material in Building Application

The results from a model placing in sunlight show that when the outside temperature was continuously above 37 °C more than 1 hours especially on 14:00 – 15:30 PM, then the PCM was melted and the inside temperatures of the house model with PCM decreased about 0.5 – 1 °C from the inside temperatures of the house model without PCM in the case of comparison to the concrete block with air spaces. And using the PCM depends on the weather on that day and it is suitable for summer in Thailand because they are effective in temperature higher than 37 °C.

5.1.4 Thailand Climate Condition with Melting of the Phase Change Material in Building Application

The PCM melting results show that when the outside temperature was continuously increased to be above 37 °C more than 1 hours, then the PCM started to melt effectively. After they started to melt then they would gradually melt more and more following the outside temperature on that day. When the outside temperature reached more than 39 °C as a result for inside temperature of the concrete block spaces was increased about 2 – 3 °C, so the PCM almost melted more than 90 %. And when the outside temperature was less than 30 °C then the PCM started to solidify gradually until solidification was 100 % occurred after 100 % melting for more than 3 hours.

5.1.5 Thermal Performance of the Phase Change Material in Building Application

For thermal performance study, 538.5 g of this PCM stores 9.0 kJ per 0.152 m^2, leading to 23.5 % reduction of heat transmitted through concrete wall exposed to sunlight. The temperature inside concrete wall with PCM insert is about 0.5 – 1 °C lower than the temperature of wall without PCM

Finally, Concrete block with the PCM can be LHTES by observation from temperature reduction on day time inside concrete block home model. So it is possibility of using it for the building that requires energy saving at low cost.

5.2 Suggestions

Further study should be conducted to investigate the following points:

- Another parameters for study in application PCM to building are amount of PCM and life cycle for this PCM.
- The house model wall that uses concrete block with the PCM can give the heavy weight of the wall material than another wall material, so the suggestion in this case is built another hollow block wall by using light weight material.
- Using other fatty acids that has lower melting point than this can be the great candidate under the climate in Thailand such as capric acid.
- To increase thermal conductivity of the LA-PA eutectic mixture, try to mix graphite with the mixture of their own components.
- The implementing of the PCM should be in the thin plate shape with covered plastic to increase the surface area and protect leakage of PCM, respectively.
- The other properties of the 80 – 20 mol% of LA-PA eutectic mixture such as thermal conductivity of the PCM should be measured by using laser flash apparatus or guarded hot-plate apparatus for determination heat transfer rate of the wall with PCM and without PCM.

REFERENCES

[1] Amy S. Fleischer. *Thermal energy storage using phase change materials fundamentals and applications*; Springer Briefs in Applied Sciences and Technology; Springer International Publishing, Switzerland, 2015; 1-71.

[2] D. Feldman, M.M. Shapiro, D. Banu, C.J. Fuks. "Fatty acids and their mixtures as phase change materials for thermal storage". *Solar Energy Materials*. **1989**, 18, 201-216.

[3] Ibrahim Dinc¸er, Marc A. Rosen. *Thermal energy storage systems and application*, 2nd ed; Wiley: New York, 2002, 51-80.

[4] Bellen Zalba, Jos'e M Marı'n, Luisa F. Cabeza, Harald Mehling. "Review on thermal energy storage with phase change: materials, heat transfer analysis and applications". *Applied Thermal Engineering*. **2003**, 23, 251–283.

[5] Brian Derby. Engineering Materials and Processes. *PCM-enhanced building components, an application of phase change materials in building envelopes and internal structures*; Jan Kośny Ed.; Springer International Publishing, Switzerland, 2015; pp 21-86.

[6] Ruben Baetens, BjØrn Petter Jelle, Arild Gustavsen. "Phase change materials for building applications: A state-of-the-art review". *Energy and Buildings*. **2010**, 42, 1361–1368.

[7] Frédé' ric Kuznik, Damien David, Kevyn Johannes, Jean-Jacques Roux. "A review on phase change materials integrated in building walls". *Renewable and Sustainable Energy Reviews*. **2011**, 15, 379–391.

[8] Lijiu Wang, Duo Meng. "Fatty acid eutectic/polymethyl methacrylate composite as form-stable phase change material for thermal energy storage". *Applied Energy*. **2010**, 87, 2660–2665.

[9] Yanping Yuan, Nan Zhang, Wenquan Tao, Xiaoling Caoa, Yaling He. "Fatty acids as phase change materials: A review". *Renewable and Sustainable Energy Reviews*. **2013**, 29, 482-498.

[10] D. Rozanna , T. G. Chuah , A. Salmiah , Thomas S. Y. Choong & M. Sa'ari. "Fatty acids as phase change materials (PCMs) for thermal energy storage: A review". *International Journal of Green Energy*. **2005**, 1:4, 495-513.

[11] Ahmet Sarı, Ali Karaipekli. "Preparation and thermal properties of capric acid/palmitic acid eutectic mixture as a phase change energy storage material". *Materials Letters*. **2008**, 62, 903–906.

[12] Ahmet Sarı. "Eutectic mixtures of some fatty acids for low temperature solar heating applications: Thermal properties and thermal reliability". *Applied Thermal Engineering*. **2005**, 25, 2100–2107.

[13] T. Lee, D.W. Hawes, D. Banu, D. Feldman. "Control aspects of latent heat storage and recovery in concrete". *Solar Energy Materials & Solar Cells*. **2000**, 62, 217-237.

[14] Derya Kahraman Dö˘güs¸ cü, Ays¸ e Altıntas, Ahmet Sarı, Cemil Alkan. "Polystyrene microcapsules with palmitic-capric acid eutectic mixtureas building thermal energy storage materials". *Energy and Buildings*. **2017**, 150, 376–382.

[15] Guruprasad Alva, Xiang Huang, Lingkun Liu, Guiyin Fang. "Synthesis and characterization of microencapsulated myristic acid–palmitic acid eutectic mixture as phase change material for thermal energy storage". *Applied Energy*. **2017**, 203, 677–685.

[16] Encyclopædia Britannica. Fatty Acid. https://www.britannica.com/science /fatty-acid (accessed Dec 3, 2017).

[17] G. W. H. Hahne, w. Hemminger, H.-J. Flammersheim, Marc A. Rosen. *Differential scanning calorimetry, an introduction for practitioners*, 1st ed; Springer-Verlag Berlin Heidelberg: New York, 1996, 7-38.

[18] Alibakhsh Kasaeian, Leyli bahrami, Fathollah Pourfayaz, Erfan Khodabandeh, Wei-Mon Yan. "Experimental studies on the applications of PCMs and nano-PCMs in buildings: A critical review". *Energy and Buildings*. **2017**, 154, 96 - 112.

[19] Fre´de´ric Kuznik, Joseph Virgone, Jean-Jacques Roux. "Energetic efficiency of room wall containing PCM wallboard: A full-scale experimental investigation". *Energy and Buildings*. **2008**. 40. 148–156.

[20] Lv Shilei, Feng Guohui, Zhu Neng, Dongyan Li. "Experimental study and evaluation of latent heat storage in phase change materials wallboards". *Energy and Buildings*. **2007**. 39. 1088–1091.

[21] Shamseldin A. Mohamed, Fahad A. Al-Sulaiman, Nasiru I. Ibrahim, Md. Hasan Zahir, Amir Al-Ahmed, R. Saidur, B.S. Yılbaş, A.Z. Sahin. "A review on current status and challenges of inorganic phase change materials for thermal energy storage systems". *Renewable and Sustainable Energy Reviews*. **2017**. 70. 1072–1089.

[22] Yaxue Lin, Yuting Jia, Guruprasad Alva, Guiyin Fang. "Review on thermal conductivity enhancement, thermal properties and applications of phase change materials in thermal energy storage". *Renewable and Sustainable Energy Reviews*. **2018.** 82. 2730 – 2742.

[23] Lv Shilei, Feng Guohui, Zhu Neng, Dongyan Li. "Experimental study and evaluation of latent heat storage in phase change materials wallboards". *Energy and Buildings*. **2007**. 39. 1088–1091.

[24] Yunus A. Çengel. *Heat transfer, a practical approach*, 2nd ed; McGraw-Hill: United States, 2003, 61 – 169.

[25] Bruce E. Poling, John M. Prausnitz, John P. O'Connell. *The properties of gases and liquids*, 5th ed; McGraw-Hill: United States, 2001, 10.1 – 10.56.

APPENDIX

APPENDIX A

DSC Principle

A.1 Theory and Principle of DSC [5]

DSC is one of the most widely used PCM measurement methods, because of the ease with which it can provide large amounts of thermodynamic data. DSC measures the amount of heat that is needed to increase the temperatures of the test sample and the reference material across a temperature interval.

Differential scanning calorimetry is a technique determining the variation in the heat flow given out or taken in by a sample when it undergoes temperature scanning in a controlled atmosphere. With heating or cooling any transformation taking place in a material is accompanied by a exchange of heat; DSC enables the temperature of this transformation to be determined and the heat from it to be quantified.

Two types of Differential Scanning Calorimeters (DSCs) must be distinguished:

- the power compensation DSC,
- the heat flux DSC.

- **Heat flux DSC**

Temperatures are measured in thin plates in contact with those, there by measuring the difference in heat flow from crucible. This gives a signal proportional to the difference in heat capacities between the sample and reference and thus the instrument will work as DSC.

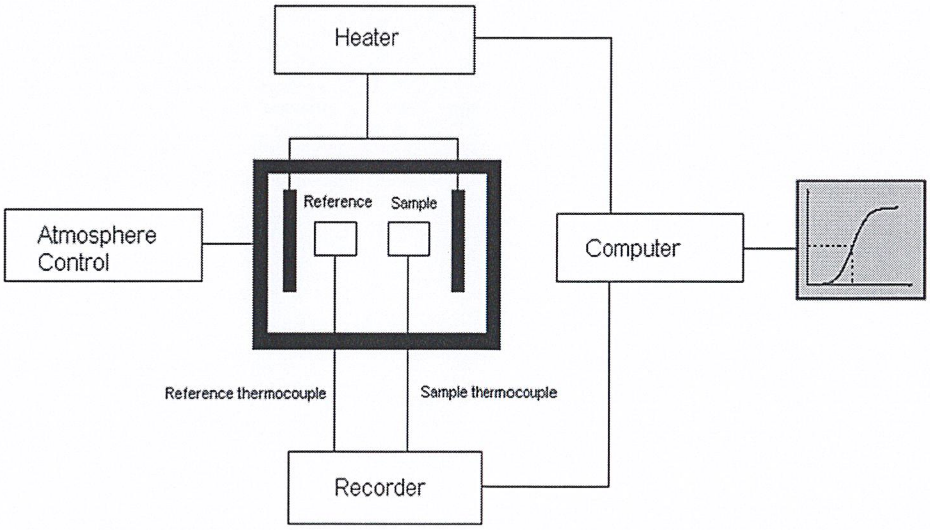

Figure A.1.1 The parts of heat flux DSC [5]

- **Power compensated DSC**

The difference in heat flow to or from as ample and to or from a reference is monitored as a function of temperature or time, while the sample is subjected to a controlled temperature program.

The power compensated DSC belongs to the heat-compensating calorimeter family of measurements methods. The power compensated DSC consists of two identical micro-furnaces, one for the test sample and the other for the reference with individual heaters. The sample furnace is heated following a programed temperature–time schedule, while the reference furnace follows this temperature schedule. It results in increase and decrease of the temperature in the reference furnace following a reaction. In this case, the compensating heating power is measured, which is actually the heat flow difference.

Power compensation DSC measures the power difference (ΔW) needed to maintain the reference material and the PCM test sample at the same temperature. This can be described by the following equation:

$$\Delta W = \frac{dQ_S}{dt} - \frac{dQ_R}{dt} = \frac{dH}{dt} \qquad (A.\ 1.1)$$

Where Q_S and Q_R represent heat absorbed by the sample of the tested material and a reference, respectively.

Measured enthalpy change per unit time dH/dt can be described as a product of the total current I_T and voltage difference ΔV across the resistance heater as follows:

$$\frac{dH}{dt} = I_T \Delta V \qquad (A.\ 1.2)$$

Measured heat is compensated during the Power compensation DSC testing with electric energy, by increasing or decreasing an adjustable Joule's heat.

This type of DSC is used in this experiment to measure the thermal properties of LA-PA eutectic mixture in molar ratio 80 – 20 mol %.

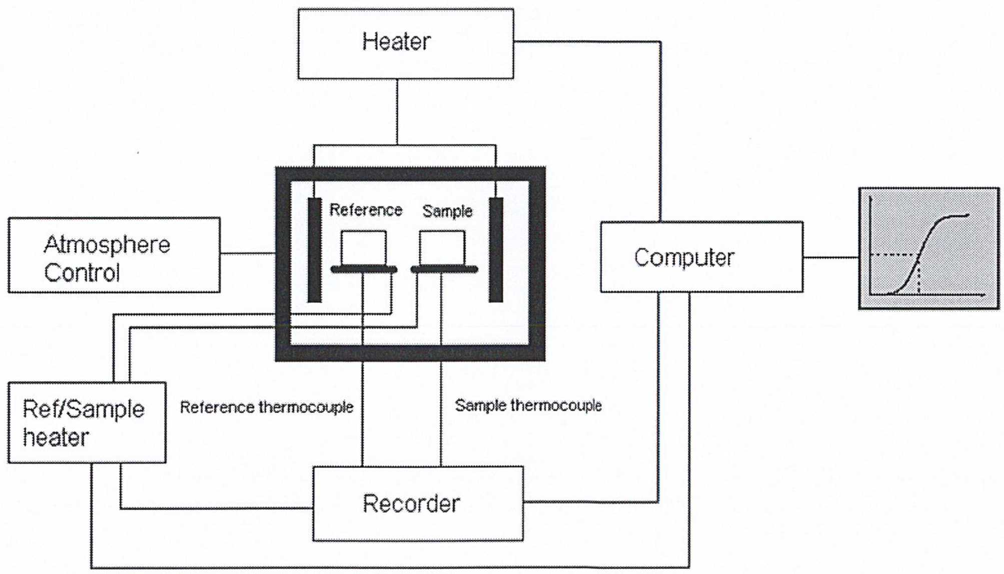

Figure A.1.2 The parts of power compensation DSC [5]

APPENDIX B

Raw Data

B. 1 Verification Melting Point of the Composition LA-PA Eutectic Mixture as Phase Change Material

Table B. 1 Verification melting point of LA-PA in molar ratio from 100 – 0 %

Luaric Acid (mol%)	Palmitic Acid (mol%)	$T_{melting}$ (°C)
100	0	44 - 45
90	10	40 - 45
80	20	37 - 46
70	30	41 - 45
60	40	43 - 46
50	50	46 - 50
40	60	47 - 50
30	70	48 - 52
20	80	52 - 60
10	90	54 - 60
0	100	62 - 68

B. 2 Thailand Climate Condition and Room Air Temperature from Using the Phase Change Material in Building Application

Table B. 2 Data of temperature outside and inside the home model with PCMs and without PCMs with times

Time	T_{out}	$T_{with\ PCM}$	$T_{without\ PCM}$
9:50	38.0	33.0	33.0
10:30	39.0	34.0	34.0
11:00	40.0	35.0	35.0
11:30	39.0	36.0	36.0
12:00	39.5	36.0	36.0
12:30	39.0	36.5	36.5
13:00	40.0	36.5	37.0
13:30	40.7	35.2	35.3
14:00	42.0	37.5	38.0
14:30	41.6	36.9	37.5
15:00	41.9	37.3	37.8
15:30	42.2	37.3	37.8
16:00	41.2	36.9	37.8
16:30	40.4	36.6	37.5
17:00	38.0	35.8	36.7
17:30	34.0	35.4	36.0
18:00	32.0	33.8	34.3
18:30	30.8	32.8	33.0
18:45	30.0	31.8	32.3
19:00	30.5	32.0	32.5
19:30	30.0	32.0	32.0
20:00	30.0	31.0	31.0
20:30	29.8	31.5	31.5
21:00	29.0	30.0	30.0
21:30	29.0	30.0	30.0
22:40	28.5	29.0	29.0

B. 3 Thailand Climate Condition with Melting of the Phase Change Material in Building Application

Table B. 3.1 Data of average melting percentage of PCMs in concrete block with any temperatures and times

Time	% Melting	T_{out} (°C)
10:00	0.00	38.0
10:30	0.00	39.0
11:00	1.00	40.0
11:30	2.00	39.0
12:00	3.85	39.5
12:30	5.13	39.0
13:00	10.26	40.0
13:30	21.41	40.7
14:00	25.64	42.0
14:30	51.53	41.6
15:00	71.43	41.9
15:30	73.31	42.2
16:00	83.36	41.2
16:30	91.09	40.4
17:00	96.95	38.0
17:30	100.00	34.0
18:00	100.00	32.0
18:30	100.00	30.8
19:00	100.00	30.0
19:30	97.00	30.5
20:00	75.00	30.0
20:30	72.00	30.0
21:00	50.00	29.8
21:30	30.00	29.0
22:00	10.00	29.0
22:30	0.00	28.5

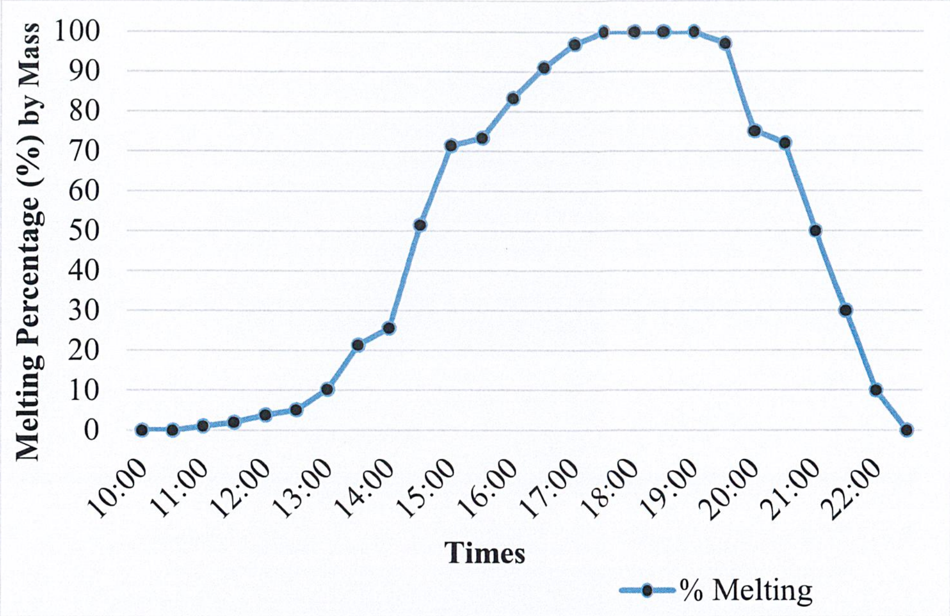

Figure B. 3 Average melting percentage of PCMs in concrete block with times

Table B. 3.2 Data of the outside temperature (T out), inside temperature with the PCM (T with PCM) and inside the concrete block spaces (T b) with time on 11 April 2018 during 14:30 - 21:30 PM at KMITL, Bangkok, Thailand

Time	T out (°C)	T b (°C)	T with PCM (°C)
14:30	40.5	42.0	37.5
15:00	41.0	44.0	38.0
15:30	41.5	46.0	38.0
16:00	40.0	46.0	38.0
16:30	39.0	45.0	37.0
17:00	37.0	44.0	36.5
17:30	33.0	43.0	35.5
18:00	32.0	39.0	34.5
19:15	30.0	33.0	32.0
19:50	30.0	33.0	31.0
20:30	29.5	33.0	31.0
21:00	29.0	32.0	30.0
21:30	29.0	32.0	30.0

APPENDIX C

Calculations

C.1 Calculation Molar Ratio of Lauric Acid and Palmitic Acid Mixture as any Component

- **80 – 20 mol % of LA-PA**

$$g = n \times Mw \quad \text{(C.1)}$$

Molecular weight of LA = 200.32 g/mol
Molecular weight of PA = 256.43 g/mol

Mass of LA (g) = 0.8 mol x 200.32 g/mol = 160.256 g
Mass of PA (g) = 0.2 mol x 256.43 g/mol = 51.286 g

C.2 Calculation heat from the Daylight Incidence with the Mass of the PCM

- **Calculation Mass Prediction of PCM with the Heat from Light Incidence**

Light incidence in the afternoon = 700 W/ m^2 = 700 J/s/m^2
= 2,520,000 J/hr/ m^2
Heat of fusion of the PCM is 166.9 J/g

If want to reduce heat 50 % = 0.5 x 2,520,000 J/hr/ m^2 = 1,260,000 J/hr/ m^2

Since $$Q_L = mL \quad \text{(C.2)}$$

m = 1,260,000 J / 166.9 J/g
m = 7,549.43 g
If 1 m^2 use PCM = 7,549.43 g
If 0.19 x 0.40 m^2 use PCM = 573.76 g
For the house model area for using PCM = 0.19 x 0.40 m^2 x 2 = 0.152 m^2
Then mass of PCM that use for reduce 50 % of maximum heat is 1,147.52 g

If want to reduce heat 30 % = 0.3 x 2,520,000 J/hr/ m^2 = 756,000 J/hr/ m^2

m = 756,000 J / 166.9 J/g
m = 4,529.66 g
If 1 m^2 use PCM = 4,529.66 g
If 0.19 x 0.40 m^2 x 2 use PCM = 688.51 g

So the mass of PCM that use for reduce 30 % of maximum heat is 688.51 g

- **Calculation Latent Heat from the Used Mass of PCM in Real Application**

Mass of PCM that used = 538.5 g
$$Q_L = mL \quad \text{(C.2)}$$
Q_L = 538.5 g x 166.9 J/g
Then Q_L = 89,875.65 J

- **Calculation Heat from Light Incidence with Latent Heat from the Used Mass**

Light incidence in the afternoon = 2,520,000 J
If 1 m^2 = 2,520,000 J
If 0.19 x 0.40 m^2 = 191,520 J
For the house model is 0.19 x 0.40 m^2 x 2 = 383,040 J

Then the heat can pass through the wall = 383,040.00 J – 89,875.65 J
= 293,164.35 J

So this used PCM can absorb heat before go to inside the wall = $\frac{89,875.65\ J}{383,040.00\ J}$

= 0.2346 x 100 %
= 23.46 %

BIOGRAHPY

Name:	Pornpan Tawongchai
Date of Birth:	05/10/1995
Address:	89 M.3 Mealoi, Thoeng, Chiang Rai 57230
E-mail:	pornpantawongchai@gmail.com
Academic Background:	
2018 – 2014	Bachelor of Engineering (Petrochemical Engineering), King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand
2014 - 2011	Science – Maths Program, Thoengwittayakhom School, Chiang Rai, Thailand
Working Experience:	
July – June 2017	Trainee student at Northern Petroleum Development Center: Mud engineer assistant: Fang, Chiang Mai, Thailand