Free Cooling of Building Using Phase Change Material

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***Abstract*—This project will present a model representation of a free-cooling system using Phase-change material. Current trend in energy supply and use are economically, environmentally and socially unsustainable since it is free carbon dioxide emission thus reducing global warming effect. Globally, buildings are responsible for 40% of the total world annual energy consumption which is responsible for one-third of greenhouse gas emissions around the world. A significant portion of this energy is used for lighting, heating, cooling, and air conditioning purposes in buildings. Increasing awareness of the environmental impact of greenhouse effect prompt a renewed way in environmentally and friendly cooling technologies, making free cooling one of the alternative way to replace current air conditioning system used for the buildings. To overcome this, latent heat storage of Phase-change material can be used as a free-cooling system. This material acts as a storage material, cool air during night time will solidify the PCM and the accumulated cold is extracted during hot day time. In other words, PCM will absorb heat during day time, making the building cool and will release the heat back into the environment when the temperature drops during night time. The heat that being released is called the waste heat. In order to satisfy the demand towards saving energy, this project will focus on cooling the building without using electricity. The room temperature will be monitored by a monitoring system. This innovative technology can be place in hot area in which the buildings can save energy without using too much electricity on cooling system.**

***Keywords*—free cooling, phase change material, latent storage media**

I. Introduction

Universally, buildings are responsible for 40% of the total world annual energy consumption which is responsible for one-third of greenhouse gas releases around the world. In buildings, a major percentage of the energy is used by heating and cooling applications hence, leads to the energy demand increasing over the security of supplies throughout years. Therefore, it is vital for exploring deeper in finding material and system to overcome the future demand.

It can be seen the buildings are being develop progressively to live up the population necessities. Consequently, the energy consumption escalates as the development of buildings rise. To overcome this problem or to reduce this number of energy consumption, passive cooling had been a trend for the past few years. Passive cooling refers to those technologies or techniques which are used to cool building's interior with or without minimum electricity usage.

One of techniques is the free cooling technique using Phase-change material. PCM is a substance with high heat of fusion, melting and solidifying at a certain temperature. It has the capability of storing and releasing large amount of thermal energy a certain phase change temperature. Thermal energy is absorbed or released as the material changes its phase from solid to liquid or vice versa.

On the other hand, electricity generation is one of the main contributors of carbon dioxide emission in Malaysia. From the former study, the lifetime of carbon dioxide has been estimated around 200 years remains in the atmosphere before removed by chemical reaction. Based on the statistics from Asian Pacific Energy Center (APEC), the carbon dioxide emission from energy consumers is expected to grow about 4.2% annually reaching 414 million tons of carbon dioxide in 2030 in Malaysia. According to Greenhouse gas producers' world ranking published by Yale University, Malaysia was 26th country among 149 countries in Greenhouse gas production on 2008.

There is a potential in reduction of greenhouse effect such as carbon dioxide emissions due to the applicability of free cooling systems in buildings. The applicability of the PCM based free cooling capable to reduce the ventilation or cooling load of the buildings that mainly depends on the daytime temperature range or the amplitude of the ambient air temperature swing rather than average ambient temperature of the region. Hence, free cooling of buildings coupled with PCM storage unit works efficiently in the climatic condition.

This paper is to design a free cooling system using PCM by inserting the PCM in between the bricks or walls of the building. During day time, heat will be absorbed and then being released during night time when the temperature falls. This absorbed and released heat process will be monitored using Arduino IDE to measure and analyze the amount of heat stored and released in the PCM and room respectively.

II. Calculation Theory

A particular amount of heat called as latent heat is absorbed and released when a material melts or solidifies when it reaches a certain melting and boiling point respectively in the process of liquifying and solidification. To calculate the heat stored in the material, an equation

$$Q = \frac{Lm}{t} \quad [1]$$

Where L_m is the total heat capacity of PCM in S.I unit Joule and t is the total period taken for the whole volume of PCM to change its phase.

III. Design Methodology

A. Phase Change Material

Thermal energy storage (TES) is described as the temporary keeping of thermal energy in the form of hot or cold substances for later utilization. The two types of TES are sensible and latent. Sensible TES system store energy by changing the temperature of the storage medium while latent TES system store energy through phase change of the storage medium.

The idea is to use PCM for the purpose of storing thermal energy is to make use of the latent heat of a phase change usually between the solid and the liquid state. Since a phase change involves a large amount of latent energy at small temperature changes, PCMs are used for temperature stabilization and for storing heat with large energy densities in combination with rather small temperature changes.

The working principle of PCM based free cooling for building consists of following two modes of operation which are solidification and liquidation of PCM. Solidification process is carried out during nighttime when ambient temperature is lower compared to room temperature. The cool ambient air flows through storage unit and takes away heat from liquid PCM which starts solidifying at certain constant temperature. This process continues until the ambient temperature is lower enough than the melting/solidification temperature of PCM.

Liquidation process occurs when cold stored in PCM is released when room temperature rises above the comfort limit. Hot air which is to be cooled passes through the PCM storage unit and PCM which is in solid state absorbs heat from the air. The air thus cooled to comfort temperature from the storage is delivered to the living space. The expected room temperature will be at below 30°C which is the normal comforting temperature. PCM absorbing heat from air, starts converting from solid to liquid phase at certain constant temperature.

The materials that were experimented in this project is the most popular groups of PCM with a phase change solid-liquid which are salt hydrate and paraffin gel. The reason behind it is because they have a very high heat storage density and they store and release a significant amount of heat at a constant temperature. Thus, these properties make salt hydrate and paraffin are alternatives to other heat storage medium.

Generally, salt hydrate is clinically stable and not flammable such that it can be the fire shield to the walls of building. Although salt hydrate is corrosive to the metal, the packaging of the salt hydrate product has been coated with anti-corrosive material to avoid any harm. Commonly, the heat storage capacity for salt hydrate is 200 kJ/kg which is has higher fusion energy than paraffin. However, salt hydrate has major drawback that reduces the reversibility of the phase change process that leads the degradation of heat storage capacity.

Complementary to salt hydrate, paraffin is non-corrosive, its volume does not change considerably when changing phase and cheaper. Even though paraffin has a lower heat storage capacity which is 190 kJ/kg yet the phenomenon of incongruent melting which is reduces the reversibility of the phase change process does not occur in paraffin. Visibly, from both PCMs in this experiment, paraffin has an advantageable properties than salt hydrate.

In the first stage is to cool the building by inserting PCM in between the bricks or walls of the building as shown in Fig. 1 and Fig. 2. During day time, heat will be absorbed and then being released during night time when the temperature falls. This temperature during absorbed and released heat process will be monitored using heat sensing system and analyze the amount of heat stored and released in the PCM. The heat sensing system will be made of several temperature sensors and Arduino. The Arduino will be the microprocessor that monitor and collect the data to be analyze. Hence, the energy consumption is likely to be decrease as this system is fully manipulating the natural source to cool the building's living space.

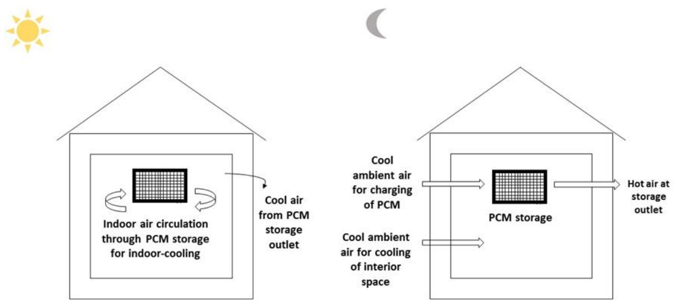

Figure 1. PCM Circulation.

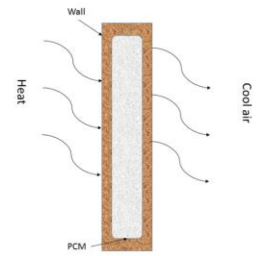

Figure 2. PCM Installed Between the Walls.

For heat measurement, several temperature sensors will be attached to the PCM and living space. The temperature sensors will be powered by Arduino to get the real-time heat reading. The operation of free cooling system is simplified in flowchart diagram below.

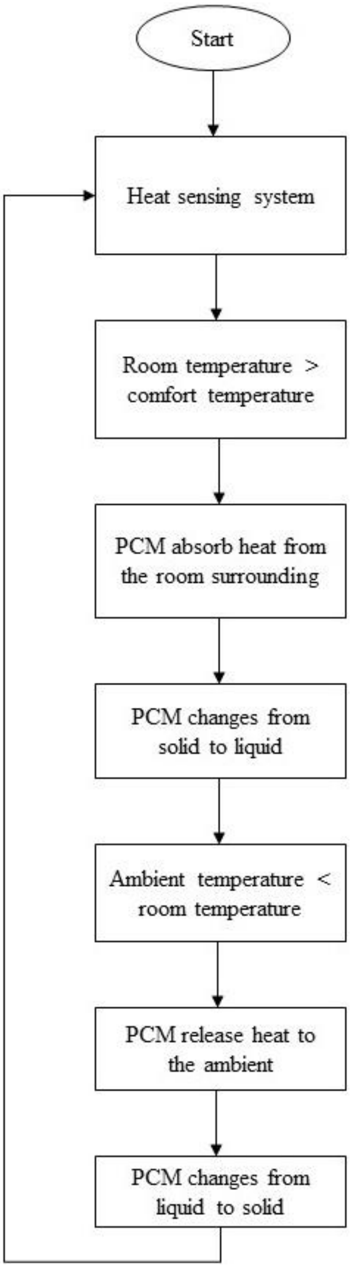

Figure 3. Flowchart of System Process.

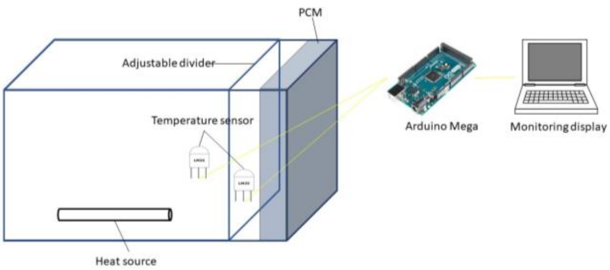

Figure 4. Side View of Setup Prototype.

Fig. 4 shows the setup of this experiment consists of a wooden box with a thickness of 12mm for it to confine the heat. Inside the box, there are two compartments with an adjustable barrier where one side is for heating process and the other side where the PCM was installed. Before the PCM absorbs the heat, the room will be heated up for 3 hours then the barrier will be lifted up for another 3 hours to expose the heat to PCM. The intention of doing this process is to measure the maximum heat absorbed by the PCM.

IV. Result & Discussion

A. Phase Change Material

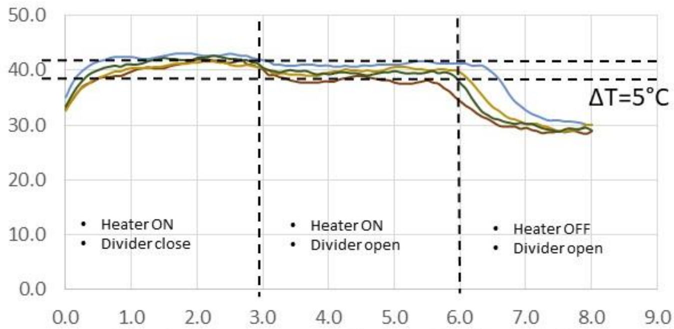

Figure 5. Graph of Room Temperature for Salt Hydrate I.

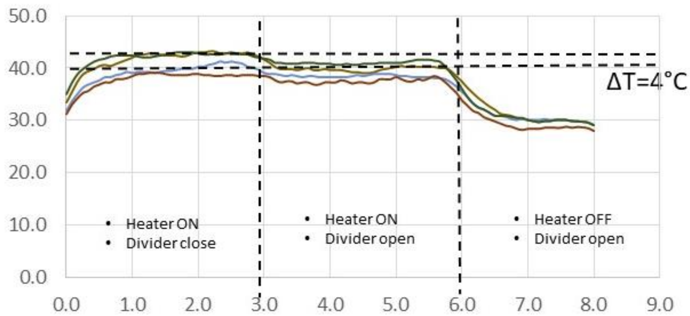

Figure 6. Graph of Room Temperature for Salt Hydrate II.

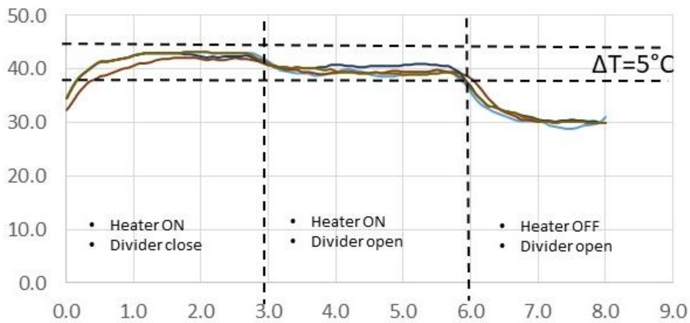

Figure 7. Graph of Room Temperature for Paraffin Gel.

	Room temperature(%)			
	1	2	3	4
salt hydrate 1	11	7	9	9
salt hydrate 2	9	9	9	9
paraffin gel	11	9	7	7

Table 1. Percentage of Temperature Difference in Room Temperature for Each Materials.

Fig. 5 until Fig.7 show the graph of room temperature for salt hydrate I, salt hydrate II and paraffin gel respectively. The readings are taken 4 times to determine its stability. For each material, the highest temperature difference is indicated on the graph. Salt hydrate I and paraffin gel have the highest temperature decrement with 5 ^oC compared to salt hydrate II with 4 ^oC. As for the percentage value in the table, the same result shown where salt hydrate I and paraffin gel have the highest average percentage with 11% for both. This is due to the different thickness exposed to the heat. In other word, the more surface area of PCM exposed to the heat, the more heat absorbed by the PCM.

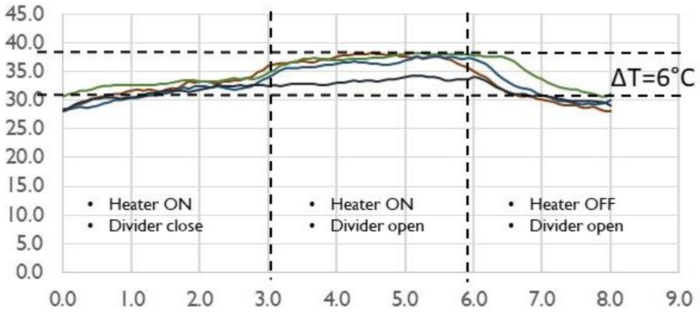

Figure 8. Graph of PCM Temperature for Salt Hydrate I.

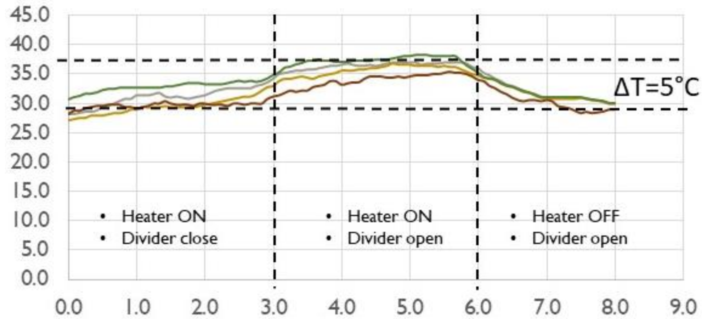

Figure 9. Graph of PCM Temperature for Salt Hydrate II.

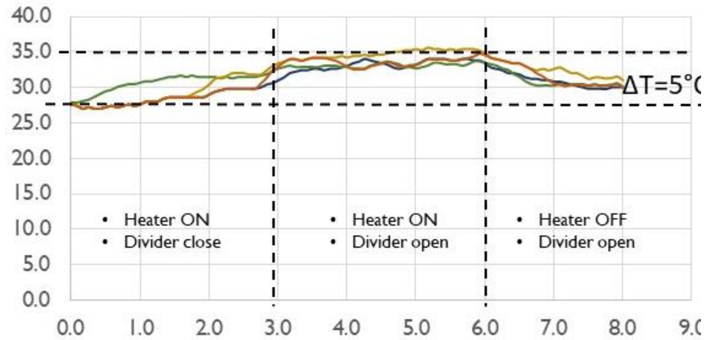

Figure 10. Graph of PCM Temperature for Paraffin Gel.

	PCM temperature(%)			
	1	2	3	4
salt hydrate 1	13	15	16	12
salt hydrate 2	13	13	13	13
paraffin gel	14	6	5	8

Table 2. Percentage of Temperature Difference in PCM Temperature for Each Materials.

Subsequently, Fig. 8 until Fig. 10 show the graphs of PCM temperature for salt hydrate I, salt hydrate II and paraffin gel respectively. The same indicator displayed on each graph shows that salt hydrate I has the highest temperature increment with 6 ^oC but paraffin gel has the highest average percentage in temperature increment with 14%. Thus, this shows that paraffin gel absorbs most heat and stored the heat longest hours compared to others. Hence, the material of paraffin gel can be the alternative for an economical choice of PCM.

V. Conclusion

The assimilation of phase change material into the building industries takes the benefit of TES for additional energy saving. In terms of thermal comfort, it is possible that the indoor environment of a building which uses PCM construction materials will have extensively lesser indoor temperature and more thermal constancy, having less likelihood of overheating and fewer temperature instabilities. Thus, the continuous search for energy conservation can be solved by the improvement of energy-storing building and the ventilation system of indoor space can be enhanced. Nonetheless, the next generation can enjoy a healthy air circulation due to carbon dioxide emission reduction.

PCM storage is the key component in the free cooling system and specification should be taken while selecting PCM and appropriate chemical properties to gain maximum heat capacity. From the experiment that has been done, paraffin shows a most promising result with temperature changes 11% for room temperature decrement and 14% of PCM temperature increment. Therefore, the electricity consumption will be reduced which will directly reduce the building generated CO2 emissions.

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