Passive wall cooling panel with phase change material as a cooling agent

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Abstract. The study was carried out to determine performance of passive wall cooling panels by using Phase Change Materials as a cooling agent. This passive cooling system used cooling agent as natural energy storage without using any HVAC system. Eight full scale passive wall cooling panels were developed with the size 1500 mm (L) x 500 mm (W) x 100 mm (T). The cooling agent such as glycerine were filled in the tube with horizontal and vertical arrangement. The passive wall cooling panels were casting by using foamed concrete with density between 1200 kg/m³ – 1500 kg/m³. The passive wall cooling panels were tested in a small house and the differences of indoor and outdoor temperature was recorded. Passive wall cooling panels with glycerine as cooling agent in vertical arrangement showed the best performance with dropped of indoor air temperature within 3°C compared to outdoor air temperature. The lowest indoor air temperature recorded was 25°C from passive wall cooling panels with glycerine in vertical arrangement. From this study, the passive wall cooling system could be applied as it was environmental friendly and less maintenance.

1. Introduction
Nowadays, we were facing the global warming problem. Global warming was a serious threat to our planet and would result in a wide variety of harsh environmental impacts. Greenhouse gas (GHG) emissions (especially CO₂ emission) were the underlying cause of this warning. Due to this problem, the people in world feel uncomfortable. For providing comfortable environment, they would find the alternative way such as using air conditioner and using fan. All of this needed to consume the electrical energy [1].

Energy used and supplied current trends were clearly unsustainable from social, economic and environmental perspective. The increase in energy demand results in increasing level of greenhouse gas emission that contributes to the increased global warming and cost of energy. Without decisive steps, carbon dioxide (CO₂) emission associated with energy consumption expected double in 2050 which leads to growing demand of fossil energy and intensity concerns over the supplies security [1].

One of the major challenges for administration and government is energy demand to satisfy thermal comfort in building. In energy systems where temporal differences exist between the supply of energy and its utilization, thermal storage is necessary to ensure the continuity of a thermal process [2].

Consuming to much electrical energy gave the big problem for future generation. This was because for the future development, most of their life would use all the technology which was needed electrical energy. Besides, consuming more electrical energy and air conditioner was high in cost. Most of people could not afford for it especially for rural population. So that, they would not find the
comfortable environment for their life. Figure 1 showed the breakdown of energy consumption in Malaysia. This research was carried out to find the best way and solution to solve the thermal problem without using electrical energy and environmental friendly by using passive cooling system in order to save the future generation’s life.

![Figure 1. Breakdown of energy consumption](source: Malaysia Energy Commission)

2. Literature Review

2.1. Phase Change Materials

Phase change materials (PCMs) could be defined as unique materials that store and release heat by means of latent heat. PCMs were used as thermal energy storage (TES) for building to control temperature over a cycle period of 24 hours to change and discharged the heat. PCMs were one of the best management methods used to control building temperature within the daily cycle.

A first classification of substances used for thermal energy storage materials stating those utilized as PCM which was useful and widely used. The basic mechanism of phase change materials (PCMs) application in free cooling was for reduction of overheating inside buildings, as PCMs had enormous thermal capacity to absorb large amounts of heat and large ranges of melting temperatures [3]. As such, the used of PCMs helped to reduce the need for regular heating and cooling and worked as an alternative to air-conditioning to control the temperature inside the space [4]. For the selection of PCM certain specifications must be taken into account [5], melting point of PCM must be very close to the application temperature, high specific heat must be considered for the PCM, and high thermal conductivity in solid and liquid phases must be taken to support charging and discharging process in storage system used.

Changing of material phase had been classified into four states, solid-solid, solid-liquid, gas-solid and gas-liquid. For practical purposes, only the solid-liquid variety had been used for building cooling or heating because the other varieties had technical limitations [6]. There was a wide variety of PCMs on the market with different melting point ranges. The most common classification of PCMs are organic, in organic and eutectic as presented in figure 2 [7].

![Figure 2. Different types of PCMs](source: [7])
3. Methodology

3.1. Preparation of materials
The materials were used in this research were foam agent, Ordinary Portland Cement, aggregate, water, cooling agent (glycerine & tap water), tube and formwork. The volume of foaming agent used for panel with the size 1500 mm x 500 mm x 100 mm was 500 ml. with the mixing of water ten times the volume of foam agent. The Ordinary Portland Cement used was 27.72 kg for each panels. The aggregate used was fine aggregate with the size of 5 mm, quantity used was 50 kg and the aggregate was in saturated and dry surface condition. The quantity of water and glycerine used were 12.73 kg and 1000 ml. The type of tube used was reinforcement tube because of its high durability and could withstand the glycerine. Size of formwork was used same as the size of wall cooling panels, 1500 mm (L) x 500 mm (W) x 100 mm (T) and the formwork was made up of high quality of plywood and waterproofing.

![Material Images]

**Figure 3.** (a) – (f) : Materials of passive wall cooling panels

3.2. Casting of wall cooling panels
The wall cooling panel with dimension 1500 mm x 500 mm x 100 mm had been cast. The preparation of foamed concrete with foaming agent and installation of reinforcement tube and cooling agent in wall cooling panel had been done before using them to the field measurement. The targeted wet density for foam concrete was 1300-1400 kg/m³. Table 1 showed, list of sample, cooling panel with horizontal arrangement (CPWH) with water, cooling panel with vertical arrangement (CPWV) with water, cooling panel with horizontal arrangement (CPWH) with glycerine, cooling panel with vertical arrangement (CPWV) with glycerine, and brick panel (BP). Table 2 showed the mix design for each of the panels.

| Type of wall panel | Cooling agent | No of samples |
|--------------------|---------------|--------------|
| CPWH               | Water         | 2            |
| CPWV               | Water         | 2            |
| CPWH               | Glycerine     | 2            |
| CPWV               | Glycerine     | 2            |
| BP                 | -             | 2            |
| **Total**          |               | **10**       |
Table 2. Mix Design

| Material         | Sand | OPC  | Water | Foam Agent | Glycerine |
|------------------|------|------|-------|------------|-----------|
| Mix design (kg/m³) | 666.67 | 369.60 | 169.73 | 6.67       | 13.33     |

Eight wall cooling panel was developed to further the next phase, which was field measurement. The wall cooling panel with 1500 mm x 500 mm x 100 mm was developed. The wall cooling panels were the different arrangement of tube which are in horizontal and vertical.

![Figure 4. The tube with horizontal arrangement](image1)

![Figure 5. The tube with vertical arrangement](image2)

![Figure 6. Casting of wall cooling panel](image3)

![Figure 7. Aluminium foil as thermal conductivity](image4)

![Figure 8. Casting of wall cooling panel with vertical arrangement](image5)

3.3. Testing on foamed concrete

For fresh properties, the slump flow test was carried out according to ASTM C1611/C1611 to accesses the properties of the fresh foam concrete. The primary characteristics of fresh foamed concrete was evaluated by this two tests and was carried out directly after concrete mixing.

The flowability of self-compacting concrete was evaluated by slump flow test without any obstruction. The diameter require was shown in figure below was the measurement required for all self-compacting lightweight concrete. The self-compacting concrete should had the value between 500 mm to 850 mm for a slump value, while T₅₀ time are the time spend for the concrete to reach the 500 mm spread circle [8]. Foamed concrete workability performance was visually evaluated, which aims to be achieved an appropriate viscosity of the mix. The workability by using spreadability method. This test was done on a fresh mix of low-strength materials by measuring the spread in two directions of a
sample placed in a 75 mm diameter and 150 mm long open-ended cylinder, after cylinder was raised vertically. The average of two measured diameters was calculated and reported to the nearest 5 mm.

For hardened concrete properties, compression test was carried out. The test was conducted according to BS 1881: Part 116: 1983 [9]. According to ASTM C 796, at least three days before proceeding the testing, foamed concrete cube that will be conducted the compression test should be cured in a moist room with 100% relative humidity. The sample need to take out from the curing room and be oven-dried for 72 hours at 60° [10]. The desired compressive strength will be obtained when the sample have been cured in a normal moist air for one day and the temperature must increase at 20°C/h for steam state to preserve at 65°C for 4 hours and then cooled in air [11].

3.4. Field Measurement Test
For field measurement test, a small house had been developed for the testing of the wall cooling panel. The size of the small house was 2 m x 2 m x 2 m. The area of the floor was 4.0 m². The test for temperature performances of passive wall cooling panels were tested in the small house for 3 days. The air temperature reading were taken inside and outside of the small house. Due on Ibrahim and M. Hazrin, the thermal comfort parameter should be measure at least one meter from the floor to represent the height of occupant at seated level. The point of sampling was selected at 8 point according to the Industry Code of Practice On Indoor Air Quality 2010. However, it will change based on the condition of the nature of the building. Since the area of small house 4m² only 1 point had consider when doing field measurement. The parameter such as air velocity, air temperature and relative humidity was used as thermal comfort parameter. The measurement tool used for this test was an anemometer.

4. Results and Discussion

4.1. Slump Flow Test
According to the ASTM C1611/C1611M, all of the result showed the pass result for slump flow test and it was acceptable. From the testing, the spreadability of fresh foamed concrete was shown in the table 3 below. This result was acceptable because the spreadability of fresh concrete mixes was in arranged of the limited, between 40% and 60% of 20 seconds for 500 mm.
Table 3. Result of Slump Flow Test

| Panels | Cooling Agent | Time (s) | Result |
|--------|---------------|----------|--------|
| CPWH   | Water         | 10       | Pass   |
| CPWV   | Water         | 12       | Pass   |
| CPWH   | Glycerine     | 11       | Pass   |
| CPWH   | Glycerine     | 10       | Pass   |

Figure 13. Spreadability of fresh concrete

4.2. Space considerations

Compressive test was conducted to test the strength of harden concrete. It was the capacity of a concrete sample to withstand axially the direct force until the limit of failure load was achieved, the sample crushed. Six sample of cubes were tested to get the value of compressive strength. Figure 14 shown the compressive strength result. Based on the result below, the strength of foamed concrete increase with the day. The result of compressive strength according to BS 1881: Part 116: 1983 passed because of correct technique of rate of foam agent, w/c ratio, sand particle type, the curing method and cement-sand ratio.

Figure 14. Compressive strength result

4.3. Space considerations

The results were analysed for difference arrangement of tube and different type of cooling agent. For difference arrangement, the results were analysed for glycerin and water. According to figure 15, the result showed the differences of the temperature between horizontal and vertical arrangement of tube by using glycerine as cooling agent. The result showed 8 out of 12 times, the vertical arrangement had biggest value of difference temperature and the biggest difference was on time 10 which vertical was 5.5°C and horizontal was 1.1°C. This differences happened due to wall cooling panels with vertical arrangement had a large surface area of the exposed tube with the cooling agent compared to horizontal arrangement. Then, the cooling agent reacted quickly and decreased more temperature in the small house.

As conclusion, the wall cooling panels with vertical arrangement had better performance in decreasing air temperature in the small house compared to horizontal arrangement.
According to figure 16, the result showed the differences of the temperature between horizontal and vertical arrangement of tube by using glycerine as cooling agent. The result showed 8 out of 12 times, the vertical arrangement had biggest value of difference temperature and the biggest difference was on time 8 which vertical was 2.2°C and horizontal was 0°C. This differences happened due to wall cooling panels with vertical arrangement had a big surface area of the exposed tube with the cooling agent compared to horizontal arrangement. Then, the cooling agent reacted quickly and can decrease more temperature in the small house. As conclusion, the wall cooling panels with vertical arrangement had good performance in decreasing temperature in the small house compared to horizontal arrangement.

For different cooling agent, indoor temperature was analysed. Based on figure 17, the temperature performance was analysed with different cooling agent. The graph showed wall cooling panels in vertical with glycerine had the best performance compared to others wall cooling panels. The cooling agent of glycerine could reduce the temperature up to 25°C. The reason because, glycerine could accelerate the process of cooling because of it properties. Besides, the higher temperature was 36.3°C for wall cooling panel in vertical with glycerine because the climate changing. For others panels, the result showed the changes but wall cooling panel in vertical arrangement with glycerine was more effective to use as wall cooling panel.
5. Conclusion
Based on the study that had been carried out, the result obtained was to determine the temperature performance of wall cooling panel by using difference arrangement of the tube and to analyse temperature performance of wall cooling panel by using difference type of cooling agent. Comparison between the brick panel as control and all the wall cooling panel had been analysed. Hence, the conclusions were concluded, the wall cooling panel with vertical arrangement had better temperature performance because they had big area exposed to tube contained glycerine. The wall cooling panel with PCMs which was glycerine as passive cooling agent have the lowest temperature such as 25°C compared to others panel with more than 25°C. The Phase Change Materials, glycerine was one of the suitable cooling agent that showed lowest air temperature compared to other panels. Based on the comparison between all the cooling agent and medium with the brick panel as control, it was proved that vertical arrangement with glycerine were the suitable medium for passive cooling.

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