A Review on The Application of Phase Change Material for Indoor Temperature Management in Tropical Area

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Abstract. Phase change material (PCM) is widely use on any products such as electronic product, airplane industry, agricultural and medical container, etc. However in building sectors the usage of PCM is quite uncommon. Since the potential of PCM as thermal energy storage (TES) is very promising, the usage of PCM in cooling system of buildings should be pursued. The cooling strategy of PCM is based on thermal balance concept that it absorb heat energy at charging period and release back at discharging period. In this study, the strenght and challenge on the usage of PCM in building is discussed in several factors. The results of this research shown the potential advantages of PCM in retrofitting the thermal performance of buildings in tropical area.

1. Introduction
The research of Phase Change Material (PCM) has been increased in recent decades. Published papers in the Web of Science database related to PCM has been significantly increased from 154 papers in 2000 to 10752 papers in 2014 \[1\]. These number are spread for lots of field study. Furthermore, PCMs are also beneficial for lots of industry such as electronic manufacturing, solar power plants, agricultural, photovoltaic electricity, pharmaceutical products, domestic hot water and space industry \[1\]. The trends of PCMs will continue to increase in the further.

For building performance, Phase Change Material (PCM) could be useful for passive cooling strategy through thermal energy storage. This strategy could manage energy use in the building and also capable for reducing dependency on the fossil fuels which is the major cause of carbon dioxide (CO\textsubscript{2}) production \[2\]. Few temperate countries have been conducted extensively studies about PCM including China, European countries and the US \[3\]. However, the study of PCM for building application in tropical climate is quite uncommon, especially for cooling strategy \[1, 3\].

This study will review the past studies about PCM application for the indoor environment in the tropical area. This climate is facing the sunshine for an entire year, thus make the people adapt with the high temperature. Moreover, the aim of this study is to create a map of recent studies about PCM application in tropical climate.

2. Previous Study of PCM Application For Indoor Temperature In Tropical Climate
As mention above, lots of study about PCMs in various field, especially for the building performance. The main benefit of the study is to balance the temperature between indoor temperature and the human...
physiological temperature. Few studies about this topic have been found from digital journals (See Table 1.). Moreover, the findings have various approaches in particular part of the study. However, these materials will be comprehensively discussed in this review.

Relevant studies about PCM for tropical climate were collected (See Table 1.). Table 1 figured out the information of the studies such as the location, the PCM type, the melting temperature, the method, the PCM location on the building and the factors. The first study has been conducted in 2008 and the latter study is in 2016. However, the PCM studies in tropical area are still uncommon if compared to another climate.

### Table 1. The study of PCM on the tropical area

| No. | Author(s) | Location | PCM Name and Type | Melting Point (°C) | Method of study | PCM Location |
|-----|-----------|----------|-------------------|-------------------|----------------|--------------|
| 1   | Pasupathy & Velraj, 2008 [11] | Chennai, India | Eutectic PCM (48% CaCl₂ + 4.3% NaCl + 0.4% KCl + 47.3% H₂O) | 26-28 | Full Scale Experiment | Roof |
| 2   | Mettawee & Ead, 2013 [10] | Cairo, Egypt | Coconut Oil | 22-24 | Full scale experiment | Ceiling |
| 3   | Biswas & Abhari, 2014 [3] | Charleston, South Carolina, US | Fatty acids/glycerides | 21 | Full scale experiment and numerical study | Wall |
| 4   | Guichard, Miranville, Bigot, & Boyer, 2014 [7] | Reunion Island | DupontTM Energain® (paraffin wax) | 23.4 | Full scale experiment | Wall |
| 5   | Biswas et al., 2014 [4] | Charleston, South Carolina, US | Paraffin | 21.1 | Full scale experiment and numerical simulation | Wallboard |
| 6   | (Chaiyat, 2015 [5] | Thailand | Paraffin | 22 | Full scale experiment | Wall |
| 7   | Lei et al., 2016 [9] | Singapore | - The idealized PCMs (temp. range 0.1°C) | 24 (outdoor) | Experimental and numerical | Wall |

### 3. Recent Condition of Tropical Climate

Climatic condition has a huge influence for the building performance in the building. The climates were divided by the latitude. One of the most popular climate classification systems is Köppen-Geiger. The climate is splitted to five zones namely, A: equatorial, B: arid, C: warm temperate, D: snow and E: polar. Furthermore, it determines the level of precipitation W: desert, S: steppe, f: fully humid, s:
summers dry, w: winter dry, m: monsoonal. Lastly, it gives details about temperature as h: hot arid, k: cold arid, a: hot summer, b: warm summer, c: cool summer, d: extremely continental, F: polar frost.

Mostly, the tropical climate is defined as ‘A’ (equatorial). This area is inclined to have less variance in temperature throughout the year. Equatorial region has significantly to large amount of incoming solar radiation. This solar radiation becomes the main factor for microclimate in a tropical area, which potentially induces the heat.

The differences of the climate create an adaptation process for the living. People on the northern and southern part deal with the cold condition and people living in the tropical climate must be adapted with the sunshine for an entire year. The use of PCM for the temperate climate is to reduce the peak of coldest temperature with some heat energy that saved on the materials. However, it is similar while PCM would be used for cooling strategy likely for the tropical climate. The PCM will absorb the heat along the day and release the heat on the night when the temperature is lower down.

![Köppen Climate Classification](image)

**Figure 1.** Köppen–Geiger’s climate classification [4]

Geographic location determines the building design and building adaptation. The annual hours between 9 am and 5 pm is about 95% and make the temperature is quite high. This condition affects the building performance as well depending on the climate area. For tropical climate, it is usually utilized the air flow through the indoor environment to reduce heat. This strategy could be obtained with active cooling and passive cooling system. For active cooling system, occupant use air conditioner to lower the temperature inside the house. Passive cooling strategy could manage the indoor air temperature with utilize the building envelope.

Research for PCMs are mainly conducted the study in subtropical and humid continental. However, very few studies reported the applications of PCMs to building envelopes in tropical climates [9]. The study shows that the main problem of PCM application in tropical area is the effectiveness of PCM melting-solidifying cycle cannot reach the maximum performance because of variation temperature.

4. Results and Discussion

In this section, the findings of each study will be separated by its motive or background, the methods and the results.
4.1. Study Background

The prone background of all research listed in the Table 1 is building energy consumption. This is due to the fact that building consume 30-40% of total energy use. Moreover, 60% energy for the building is used by the heating, ventilating and air conditioning system (HVAC).

Unsuitable condition of the indoor thermal comfort force the occupants to use a strategy such as air conditioner or heater to create a balance condition between occupants’ body and environment. Common condition in tropical area is the high temperature and induce people to utilize air conditioner to reduce its temperature. This is causing the highly used for the energy consumption with approximately 48% [5]. The topic for reducing energy consumption in the building, therefore, becomes a main concern owing to diminish fossil fuel reserves and the impact of greenhouse emission [3]. However, the passive cooling strategy in the tropical climate is a good choice due to the minimum impact to the environment. This strategy is mainly affected by the building envelope which is play a role as an adjacent between indoor and outdoor environment. Moreover, building envelope is a key factor for indoor comfort that influences the heating and cooling loads and therefore presents an opportunity to reduce the energy demands [3]. The performance of these enclosure must take an act to control and manage the indoor environment.

Phase change material (PCM) for the building application was studied in many literatures by applying for cooling and heating strategies. For the cooling process, PCM could replace the air conditioner system with electrical power to high performance of building envelope and its material [6]. To conclude, the PCM has many opportunity to generate the passive cooling strategy for the building and lessen the energy consumption produced by the building.

4.2. Study Methods

The listed studies (Table 1) have been conducted to explore the PCM performance by using experimental method. This method sets few factors to be measured in the real condition. Apart from this, there is also numerical method to describe the set up condition by mathematical models. However, experimental method is more popular than numerical method.

Few PCM have been selected to combine with the object study. In tropical area, all the related research (Table 1) use organic and eutectic PCM. The organic PCM that have been used in tropical area are coconut oil [7], fatty acids/glycerides [8] and paraffin [6, 8, 9]. Apart from this, Pasupathy & Velraj used eutectic PCM (48% CaCl$_2$ + 4.3% NaCl + 0.4% KCl + 47.3% H$_2$O) on their study [11].

![Figure 2: The use of coconut oil for PCM (left) and schematic prototype (right) with (1) auxiliary cooling system, (2) PCM capsule and (3) chamber [10]](image)

The study from Metawee [7] used organic coconut fatty acid as PCM because the suitable performance for tropical climate with its melting and freezing temperature and also has low price.
PCM is encapsulated in few cans as capsules and placed on the ceiling of experimental chamber. During the night, as the first process, the ambient air enters the ceiling chamber for cooling the capsules. Next, the air continues to spread over the indoor chamber before it exhausts to be cycled again through the first process.

![Figure 3 Test wall construction](image)

Figure 3 Test wall construction (left) – (A) regular cellulose insulation, (B) PCM–cellulose insulation, (C) cellulose HDPE mix, and (D) cellulose–PCM–cellulose sandwich structure. Finished interior (center). Finished exterior with vinyl siding (right) [8]

Biswa and Abhari [8] conducted a research by using both experimental study and numerical study. Some parts of building envelope combined with the PCM and exposed to the natural wathering. Figure 3 shows the detailed information about the setup. Next, few sensors and instruments were placed in the test wall and the building (Figure 4). The sensors and other instruments measure the condition of temperature, weather condition, humidity, solar irradiance and wind velocity.

![Figure 4 Sensors placement in the test wall](image)

Figure 4 Sensors placement in the test wall [8]

Pasupathy & Velraj use two constructed rooms to study the effect of having PCM panel on the roof (see Figure 6)[7]. The first room is used PCM panel located between the bottom of concrete slab and the rooftop slab, another has no placed PCM panel. Next, the condition of each room is measured to find the thermal performance for both rooms. Figure 5 illustrates the section of the roof inserted with PCM and without PCM. Plywood is used for the inner walls except ceiling with 6 mm thickness on all the sides to study the effect of PCM panel placed on the roof. The material of PCM panel is made up of stainless steel with 2 m x 2 m and the thickness is 2.5 cm which contains inorganic salt hydrate \((\text{CaCl}_2 + 4.3\% \text{NaCl} + 0.4\% \text{KCl} + 47.3\% \text{H}_2\text{O})\) as PCM.
Table 1 also figured out the influenced factors for the study. There are many factors immersed on the study of PCM. The parameters involved to create sharply analyst. There are three main factors on the research of the PCM, i.e. the environmental temperature, the developed model and the PCM properties. The environmental temperature has many parameters, such as weather condition [3], ambient temperature [7, 8], heat transfer coefficients [7], sky temperature [7], temperature distribution [7], heat flux [8, 11] and relative humidity heat [11].

Developed PCM models are the physically equipment that its function to influence the environmental condition. Pasupathy & Velraj described the parameters are radiation properties of the surface, geometrical parameters and physical properties of the roof material (Roof top slab, PCM and concrete slab).

The PCM properties are the set factor to reveal the explanation of PCM performance. The properties are has been conducted a study of PCM with three parameters such as the temperature range of phase change [9], the shape of enthalpy–temperature curve [3] and the amount of PCMs [3, 7].

4.3. Study Results

The results of the studies are varies depend on the goal and influenced factors. Study from Pasupathy & Velraj [12] shows that the environment has little effect on the inner surface of the concrete slab as all the heat energy is absorbed by the PCM placed in the roof.

In the research from Metawee and Ead conducted the study in Cairo, Egypt. The study used PCM capsules in a ceiling space to manage peak load of heating energy in a chamber. From these results, it can be concluded that the PCM ceiling system becomes effective strategy to reduce the peak load of heating. Large amounts of latent heat can be stored in the PCM, which enables to make more compatible, clean, durable, and cheaper systems for air-conditioning.
Interesting finding was that PCM with inner portion of the wall cavity has no difference results for cooling electricity as adding PCM to the entire cavity [8]. Exterior wall with PCM inside has a better performance at lower cost than the wall with PCM inserted in all cavities. Moreover, the application of PCM has a good energy-savings potential depends on the wall orientation. This factor has a highly influenced for passive cooling strategy rather than other factors.

Guichard et al. have been conducted a research to study most influent parameters for PCM performance [9]. According the study, the parameters are convective exchange coefficients and a specific parameter of PCM model. It has been proved that this coefficient plays an important role in the predictions and should be chosen precisely.

5. Conclusion
The previous studies about PCM for building application in tropical climate is still uncommon. Most of these studies have a research background on energy consumption. In tropical climate, passive cooling system becomes suitable to manage peak load of heating with minimum impact for the environment.

It is shows that convective exchange coefficient has an important role to reach the maximum performance of PCM. The specific parameters for PCM application should be chosen and measured precisely. This case is related to the fact that PCM cannot reach the maximum performance in tropical climate because the diurnal of ambient temperature is narrow. Further research may develop the PCM performance with described parameters to find the best strategy to manage the peak energy load period.

6. References
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