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Developing Heat Mitigation Wall by Integrating PCM into Building Material

(Membangunkan Penebat Haba dengan Mengintegrasikan PCM ke dalam Bahan Binaan)

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ABSTRACT

Population growth and industrial demand are related in construction of buildings and houses which contribute to increment of energy consumption. The invention of phase change materials (PCMs) with high latent heat capacity were explored to be integrated into building materials. PCMs are substances that are capable of storing large amounts of thermal energy as latent heat during their phase transition. Development of this product can ensure a comfortable indoor temperature in buildings without depending on air conditioning system which consumes more energy and damage the environment not to mention contributing towards global climate change. This research concentrated on proposing the method of PCM incorporation and its heat resistance performance. Calcium Chloride Hexahydrate ($CaCl_2.6H_2O$) was used in this research while the incorporation method is direct mixing into gloss paint and added into zip-lock plastic then covered by conventional cement plaster. From the data obtained, we can see the PCM incorporated wall is better in heat resistance than wall without PCM resulting difference in temperature between internal and external wall 3 ˚C rather than 1 ˚C. For the conclusion , PCM incorporated wall can decrease the internal temperature of building slightly contributing to conserving nature by reducing air conditioner system consumption.

Keywords: Phase change materials; $CaCl_2.6H_2O$; salt hydrate; heat mitigation

ABSTRAK

Pertumbuhan penduduk dan permintaan industri berkaitan dengan pembinaan bangunan dan rumah yang menyumbang kepada peningkatan penggunaan tenaga. Penemuan bahan perubahan fasa (PCM) dengan kapasiti haba pendam tinggi diterokai untuk disatukan ke dalam bahan binaan. Bahan perubahan fasa (PCM) adalah bahan yang mampu menyimpan sejumlah besar tenaga haba sebagai haba pendam semasa peralihan fasa mereka. Pengembangan produk ini dapat memastikan suhu dalaman bangunan yang selesa tanpa bergantung pada sistem penyaman udara yang menggunakan lebih banyak tenaga dan merosakkan alam sekitar juga menyumbang terhadap perubahan iklim global. Penyelidikan ini tertumpu pada mencadangkan kaedah penggabungan PCM dan prestasi tahan panasnya. Kalsium Klorida Hexahidrat ($CaCl_2.6H_2O$) digunakan dalam penyelidikan ini sementara kaedah penggabungan adalah pencampuran langsung ke cat gloss dan dituangkan ke dalam plastik kunci zip kemudian ditutup oleh plaster simen konvensional. Dari data yang diperoleh, kita dapat melihat dinding gabungan PCM lebih baik dalam ketahanan haba daripada dinding tanpa PCM sehingga menyebabkan perbezaan suhu antara dinding dalaman dan luaran 3˚C dan bukannya 1 ˚C. Untuk kesimpulannya , dinding yang digabungkan dengan PCM dapat menurunkan suhu dalaman bangunan yang sedikit sebanyak menyumbang kepada pemuliharaan alam dengan mengurangkan penggunaan sistem penghawa dingin.

Kata kunci: Bahan perubahan fasa; $CaCl_2.6H_2O$; Garam hidrat; pengurangan haba

INTRODUCTION

Rapid growth in population affects the house demand. Increasing of house demand causes the need for more building construction that will pollute our Earth. According to the International Energy Agency (IEA), building is one of developing countries' main energy consumers. The building industry accounts for 31% of global total energy consumption also accounting for 31% of greenhouse gas emissions per year (Dean et al. 2016). As to maintain the indoor thermal comfort in a building, air-conditioning system plays a significant role in majority of buildings these days. Therefore, to save the enormous energy consumed by air-conditioning system, a heat resistant wall is produced and commercialized. However, it should be properly designed and tested such that the unwanted heat gain and loss within the indoor area can be minimized.

Phase change materials (PCMs) were identified as substances that are capable of storing large amounts of thermal energy as latent heat during their phase transition. Due to the large energy storage density and nearly isothermal nature of the PCM, the possible use of PCM in buildings becomes a great attention for research and discovery. The operating principle of PCMs takes advantage of the modification of their state due to changes in temperature: as the temperature increases, the PCM passes from the solid to the liquid state, thus, absorbing and storing energy. Conversely, when the temperature decreases, the material can release the previously stored energy, passing from liquid to solid state (Kun et al. 2015; Janarthanan et al. 2015) as shown in Figure 1.

Passively, the PCMs will absorb the heat from exterior environment during daytime by melting (phase transition) and releases the heat when temperatures cool down at night time. The heat is naturally dispersed through the night time air force. As a result, indoor thermal comfort is improved and the building's energy consumption is reduced (Cellat et al. 2015; Vaz Sá et al. 2015).

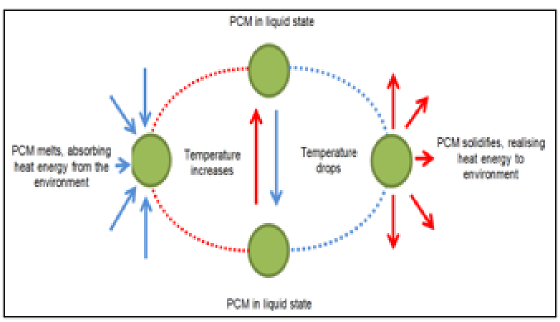

FIGURE 1. Transformation cycle of PCM operates by different temperature

Source: Kun et al. (2015)

In (Voelker et al. 2008) research paper, the PCMs were integrated into a gypsum board by microencapsulation technique. The melting point was adjusted between the ranges of 25 – 28 °C as compatible with the indoor thermal comfort in Malaysia. From the results, it is shown that a reduction of the peak temperature up to 4K in comparison to the reference room (ordinary plaster boards) could be achieved.

Castellón et al. (2009) constructed nine identical cubicles in Lleida, Spain. Two with concrete, five with conventional brick, and two with alveolar brick. The cubicles were equipped with a heat pump to maintain indoor temperature at 24 ºC. Their electricity consumption in a summer week was reduced by up to 15% and 17% by adding PCM to cubicles containing plain and alveolar brick, respectively. The authors also claimed that the performance could be further improved by optimizing the PCM melting temperature according to the climate conditions.

There are a number of studies done on different issues of PCM applications in buildings. The researchers mainly focused on using microencapsulated PCMs for energy saving in buildings. With microencapsulation, the amount of PCM that can be used is decreased and microencapsulation increases the cost. Direct incorporation and immersion techniques are more cost and time effective. However, some existing difficulties hinder the wide spread applications in buildings. Main difficulty of incorporating PCMs directly in building elements is leakage problem (Li et al. 2014; Zhou et al. 2012).

There are two types of encapsulation concept which is microencapsulation and macro-encapsulation. Microencapsulation is common and popular in building applications for sustainability and energy saving purpose. It is because of the workability during the integration process into building materials is easier than macro-encapsulation. Microencapsulation can be applied directly as in-situ process while macro-encapsulation needs to have a significant quantity of PCM as a discrete unit. It aids in holding the liquid PCM during phase change by providing a self-supporting structure, improves heat transfer rate, and preserves the material composition (Swetha 2012).

Macro-encapsulation technique contains the PCMs and commercialized in difference format such as; panels, capsule, bags, and tubes. While, microencapsulation enclosed in microencapsulate with coating such as; painting and coating (Ahmed et al. 2016).

In this research, the focus is to develop and test heat resistant wall by incorporating PCM into wall cement plaster and gloss paint. This was identified as a microencapsulation technique. Thus, extensive literature review is done to determine the most suitable PCM for its compatibility to be mixed or incorporated into wall material. Hence, the PCM will be modified by adding additives substances so that its properties such as melting point fulfil the required temperature. The base for wall material used is red clay brick. The modified PCM will be incorporated into wall cement plaster and gloss paint then will be tested for its compatibility and behavior with focusing on replacing the microencapsulation with lowest cost as possible. Finally, the prototype of the heat resistant wall will be tested for heat resistance performance by using 400 Watt Philips high-pressure sodium lamp representing sunlight's ray.

METHODOLOGY

In achieving research objectives, there are several processes and experiment will be done in sequence such as extensive literature review about PCM used for heat resistant structure, modifying PCM selected, preliminary test on material selected and finally experiment the prototype of heat resistant wall developed on its heat resistance performance. Figure 2 below shows research flowchart.

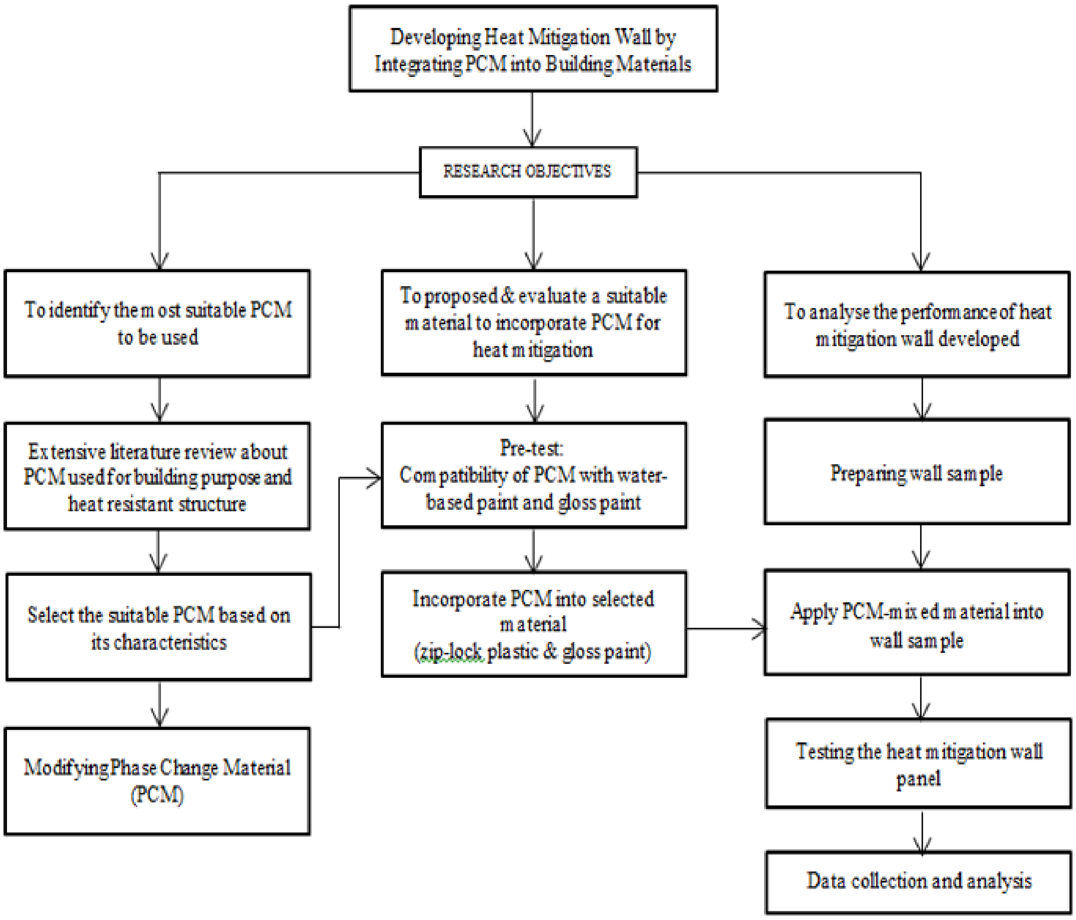

FIGURE 2. Research flowchart

SELECTION AND MODIFICATION OF PCM

Based on reviewed article, further examples of previously researched PCM used are salt hydrates, for example made up of calcium chloride hexahydrate ($CaCl_2.6H_2O$). These materials possess a high heat capacity due to a comparatively high density. However, crucial disadvantages that have been identified are super cooling effects and phase instability (Voelker 2008). The supercooling effects can be countered, therefore an added nucleator agent is needed to produce an applicable PCM. As for nucleator agent, it is possible to use oxide metal such as strontium chloride hexahydrate ($SrCl_2.6H_2O$).

Meanwhile, some additives such as potassium chloride (KCl) and sodium chloride (NaCl) were added as to decrease the melting point temperature. As known, calcium chloride hexahydrate melting point is 30-31 °C. The additives and nucleator agent can be added by mix stirring process. Thus, the melting points changes depending the variability of percentage of the additives. Table 1 shows the modifying works done with two attempts, A and B, each attempt has different chemical weight ratio.

TABLE 1. Phase change materials proportion

Chemical	Weight ratio (%)	
	A	B
$CaCl_2.6H_2O$	96.5	95.5
NaCl	1.0	1.0
KCl	2.5	2.5
$SrCl_2.6H_2O$	0	1.0

After modifying the PCM, the modified PCM then is analysed by Differential Scanning Calorimetry (DSC) machine at Universiti Kebangsaan Malaysia (UKM). The sample is analysed for identified their thermal properties.

DIFFERENTIATING BETWEEN WATER BASED AND GLOSS PAINT

As a simple pre-test, the modified PCM is grinded into fine salt crystal and directly mixed into both water-based paint and gloss paint. Then, both PCM-mixed paints will be applied into two different sides of concrete block separately. Both samples were placed under sunlight to observe the ability to capture heat and to determine the reaction when samples reach their melting point temperature. Is there any leakage of PCM? As my expectation, highlighted that concrete block applied with gloss paint will not occur any leakage due to its glossy surface which is water resistant.

EXPERIMENT SET-UP FOR EVALUATION

For the experimental works, three sets of wall with dimension 450x450 mm will be constructed behind the UPNM structure lab. The entire wall is made of same material which is red clay brick as shown in Figure 3. The clay brick is chosen because it is the most commonly used in building constructions. Considering the dimension of the brick (220 x 100 x 65 mm), a total of 36 bricks are needed to construct three sets of wall with dimension 450x450 mm considering the gap for mortar between bricks during the brick laying. Then, each wall is denoted as wall A, wall B and wall C can be referred to Table 2 and Figure 3.

TABLE 2. Type of wall panel

Type	Component
Wall A	Wall + conventional plaster
Wall B	Wall + conventional plaster + zip-lock PCM
Wall C	Wall + conventional plaster + PCM modified gloss paint

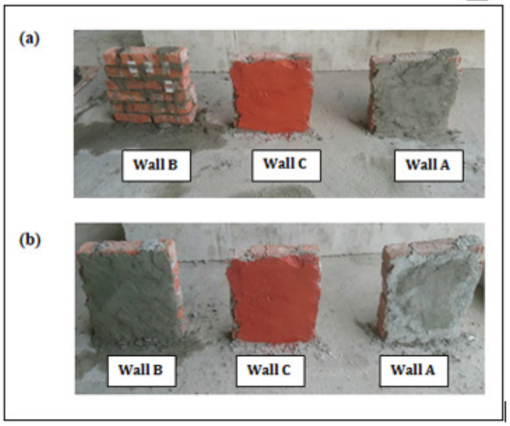

FIGURE 3. (a) Wall panel Type B before plastering, (b) Plastering completed for all wall panel type

HEAT MITIGATION PERFORMANCE TEST

The heat mitigation performance of the sample wall A, B, and C is experimented using 400-Watt high-pressure sodium outdoor lamp towards the walls representing sunlight's ray. It is because the sunlight's ray is not consistent in one place due to cloud's shadow also the probability of raining is unexpected. The constructed wall cannot be easily transferred due to its weight so the use of lamp is more efficient. Each wall sample will be exposed to heat from the lamp for six hours. For every one hour, temperature of internal and external surface of the wall will be recorded using digital thermometer while the ambient temperature and humidity is also recorded. The setup is shown in Figure 4.

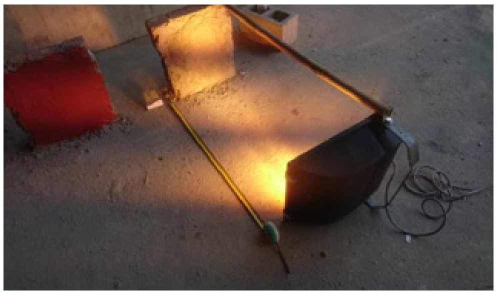

FIGURE 4. Experiment set-up

RESULTS AND DISCUSSION

MODIFYING PCM RESULTS

TABLE 3. End result after modifications

Attempt	Result
A	PCM in semi-solid state
B	PCM in solid state, little damp

From Table 3, we can see that each attempt resulting in different conditions of the modified PCM. For attempt A, we can see the PCM is in semi-solid state because it failed to return to its fully solid state due to supercooling. Supercooling, a state where liquids unsolidified even below their normal freezing point still puzzles scientists today. An example of this phenomenon is found every day in meteorology where clouds in high altitude are an accumulation of supercooled droplets of water below their freezing point (European Synchrotron Radiation Facility, 2010). It is also stated by Voelker et al. (2008) that the calcium chloride hexahydrate ($CaCl_2.6H_2O$) needs nucleator agent to prevent the supercooling as occurred in attempt as shown in Figure 5 below.

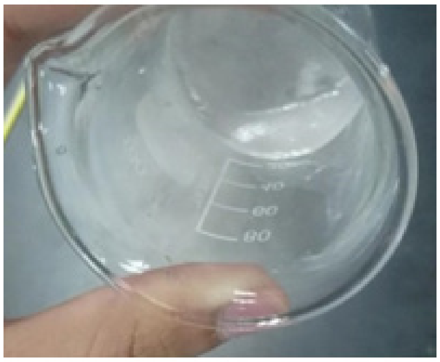

FIGURE 5. Modified PCM in semi-solid state

For attempt B, the modified PCM is in solid state with little damp as shown in Figure 6. It is considered successful because when the PCM is in solid state, it is easily inserted into the zip-lock plastic bags. During the attempt B, nucleator agent, strontium chloride hexahydrate is added in weight ratio by 1.0% to prevent the supercooling (Voelker et al. 2008). However, the properties of the modified PCM such as its melting point, latent heat capacity and freezing point, is not yet known because the sample is still not analysed using DSC machine at UKM. It is because due to Perintah Kawalan Pergerakan (PKP) ordered by the government in preventing the spread of Covid-19 virus, the appointment to use the machine was cancelled leaving the sample unanalysed. In shortage of time, it is decided to carry on the research by incorporating the wall with modified PCM attempt B.

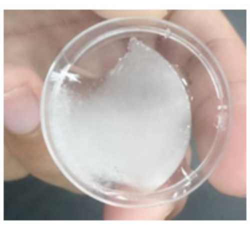

FIGURE 6. Modified PCM attempt B in semi-solid state

HEAT MITIGATION PERFORMANCE RESULTS

All the data obtained from the experiment will be presented in tabulated and graphical so that we can see the difference in performance of the three walls on their heat resistance. All graphical data are presented below as in Figures 7, 8, and 9.

Wall A – Control wall (Plaster)						
Time	Weather	Temperature				Humidity (%)
		External surface	Internal surface	Difference	Ambient	
11:30 AM	Sunny	28	28	0	30.8	66
12:30 PM	Sunny	30	29	1	32.7	57
1:30 PM	Sunny	31	30	1	33	54

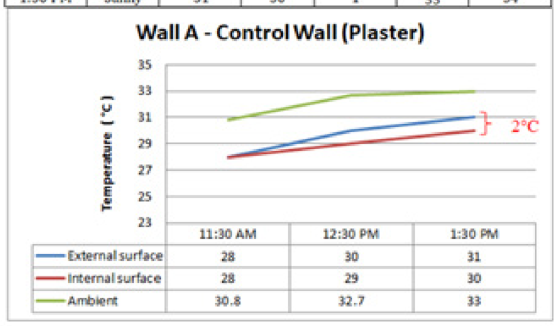

FIGURE 7. Wall type A plotted graph

Wall B – PCM Zip lock + Plaster						
Time	Weather	Temperature				Humidity (%)
		External surface	Internal surface	Difference	Ambient	
11:00 AM	Sunny	28	26	2	31.7	59
12:00 PM	Sunny	31	28	3	32.7	56
1:00 PM	Sunny	32	29	3	33.4	51

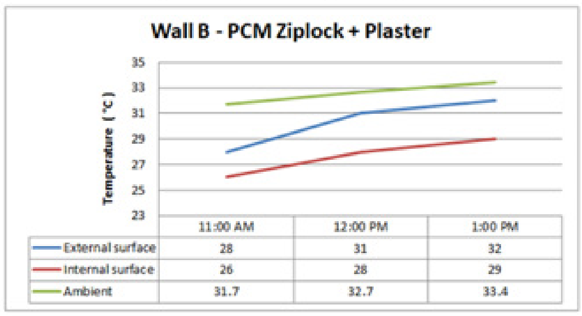

FIGURE 8. Wall type B plotted graph

Wall C – PCM mixed gloss paint + Plaster						
Time	Weather	Temperature				Humidity (%)
		External surface	Internal surface	Difference	Ambient	
10:30 AM	Sunny	27	26	1	30.5	71
11:30 PM	Cloudy	30	27	3	31.6	65
12:30 PM	Cloudy	32	29	3	32.5	61
1:30 PM	Sunny	32	30	2	32.8	59

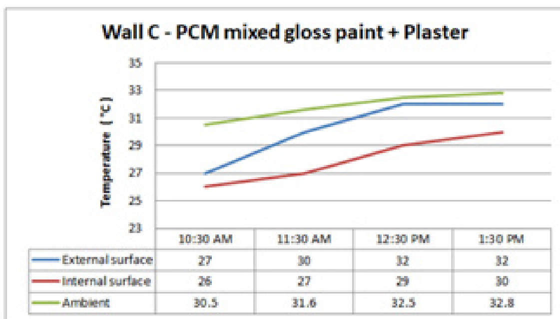

FIGURE 9. Wall type C plotted graph

From the results obtained for wall A, in Figure 7, we can see that maximum temperature difference between external surface and internal surface is 2 °C while the minimum is 0°C. It is because wall A does not have any heat resistant material, which is incorporated PCM. From Figure 8, we can see the temperature is declining due to the heavy raining. The temperature should not be decreasing because the high-pressure lamp always radiates heat onto the wall surface. However, the heavy rain affects the surrounding temperature because the experiment is done in open area.

While from the Figure 8 and Figure 9, we can see that wall B and C has similar pattern of temperature difference between external surface and internal surface. The maximum temperature difference between external surface and internal surface for both of the walls are 3 °C. Both of the walls has better heat resistance performance than the control wall, wall A.

Wall B is incorporated with zip-lock plastic PCM so that it will increase the heat resistance of the wall because the PCM undergoes its phase change cycle as it absorbs the heat energy to become liquid state. However, there is no observation that can be made to confirm the cycle of PCM returning to solid state as it release heat. This reasoning also can be applied to wall C which consists PCM-mixed gloss paint.

CONCLUSION AND RECOMMENDATION

CONCLUSION

As for the conclusion, the objectives of this research are achieved. The first objective to identify the most suitable PCM to be used for this research is achieved by working on extensive literature review to find out that calcium chloride hexahydrate ($CaCl_2.6H_2O$) is the most suitable PCM to be used in this research . Then , the second objective which is to propose and evaluate a suitable material to incorporate PCM for heat resistant purpose was also accomplished as we were able to propose and see the result of using zip-lock plastic bags and gloss paint as an alternative encapsulation for incorporating PCM . Finally , the third objective is to analyse the performance of heat resistant wall developed is achieved by conducting the high-pressure lamp experiment and recording the external and internal surface of the wall samples.

RECOMMENDATION

There are several recommendations that can be made so that the heat resistant wall can be improved in the terms of performance and economical. The zip-lock plastic bags containing PCM should be vacuumed so that there is no air trapped in the plastic. Trapped air will cause the plastic to inflate causing difficulty to plaster the wall. Moreover, the experiment is suggested to be executed in a closed indoor area so that surrounding weather/condition does not affect the temperature of the wall surface. Other than that, deeper research PCMs can be explored for future work to give better performance and quality of heat resistant wall.

ACKNOWLEDGEMENT

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DECLARATION OF COMPETING INTEREST

None

REFERENCES

Ahmed, H., Shakeel, M., Laghari & Rashid, Y. 2016. Micro-encapsulated phase change materials: A review of encapsulation, safety and thermal characteristics. *Sustainability* 1-32.

Castellón, C., Castell, A., Medrano, M., Martorell, I. & Cabeza, L.F. 2009. Experimental study of PCM inclusion in different building envelopes. *Journal of Solar Energy Engineering* 131(4).

Cellat, K., Beyhan, B., Kazanci, B., Konuklu, Y. & Paksoy, H. 2017. Direct incorporation of butyl stearate as phase change material into concrete for energy saving in buildings. *Journal of Clean Energy Technologies* 5(1).

Dean, B., Dulac, J., Petrichenko, K. & Graham, P. 2016. Towards Zero-Emission E_cient and Resilient Buildings; Global Status Report. Global Alliance for Buildings and Construction (GABC): Kongens Lyngby, Denmark.

Janarthanan, B. & Sagadevan, S. 2015. Thermal energy storage using phase change materials and their applications: A review. *Int. J. ChemTech Res*. 8: 205–256.

Kun, D., Calautit, J., Wang, Z., Wu, Y. & Liu, H. 2018. Review of the applications of phase change materials in cooling, heating and power generation in different temperature ranges. *Applied Energy* 220.

Li, H., Chen, H., Li, X. & Sanjayan, J.G. 2014. Development of thermal energy storage composites and prevention of PCM leakage. *Applied Energy* 135: 225-233.

Swetha, P. 2012. Macro encapsulation of phase change materials for thermal energy storage. University of South Florida Scholar Commons.

Vaz Sá, A., Azenha, M., De Sousa, H. & Samagaio, A. 2012. Review thermal enhancement of plastering mortars with phase change materials: Experimental and numerical approach. Energy Build 49: 16–27.

Voelker, C., Kornadt, O. & Ostry, M. 2008. Temperature reduction due to the application of phase change materials. Energy and Buildings 40(5): 937-944.

Zhou, D., Zhao C. Y. & Tian, Y. 2012. Review on thermal energy storage with phase change materials (PCMs) in building applications. *Appl. Energy* 92: 593–605.