Heat transfer characteristics of building walls using phase change material

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Heat transfer characteristics of building walls using phase change material

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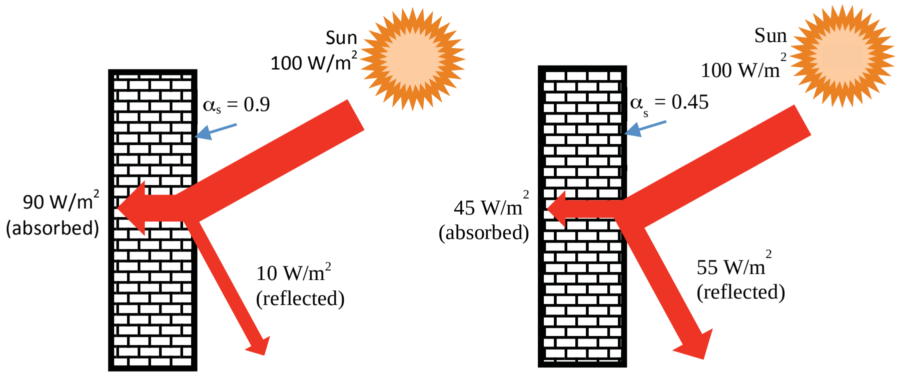
Abstract. Minimizing energy consumption in air conditioning system can be done with reducing the cooling load in a room. Heat from solar radiation which passes through the wall increases the cooling load. Utilization of phase change material on walls is expected to decrease the heat rate by storing energy when the phase change process takes place. The stored energy is released when the ambient temperature is low. Temperature differences at noon and evening can be utilized as discharging and charging cycles. This study examines the characteristics of heat transfer in walls using phase change material (PCM) in the form of encapsulation and using the sleeve as well. Heat transfer of bricks containing encapsulated PCM, tested the storage and released the heat on the walls of the building models were evaluated in this study. Experiments of heat transfer on brick consist of time that is needed for heat transfer and thermal conductivity test as well. Experiments were conducted on a wall coated by PCM which was exposed on a day and night cycle to analyze the heat storage and heat release. PCM used in these experiments was coconut oil. The measured parameter is the temperature at some points in the brick, walls and ambient temperature as well. The results showed that the use of encapsulation on an empty brick can increase the time for thermal heat transfer. Thermal conductivity values of a brick containing encapsulated PCM was lower than hollow bricks, where each value was 1.3 W/m.K and 1.6 W/m.K. While the process of heat absorption takes place from 7:00 am to 06:00 pm, and the release of heat runs from 10:00 pm to 7:00 am. The use of this PCM layer can reduce the surface temperature of the walls of an average of 2°C and slows the heat into the room.

1. Introduction

Room thermal comfort is a human need in which to rest and do activities. In Indonesia room thermal comfort standard is based on Indonesian National Standard (SNI) 03-6390-2011 which is at the temperature of 25°C±1.5°C and relative humidity of 60%±5% [1]. There are several factors which influence room thermal comfort, namely thermal loads from occupants, equipment, lights/lamps, and thermal load coming from sun rays. In tropical area, the main thermal load is due to the average temperature of ambient air exceeding the thermal comfort temperature, as well as sun shine which hits buildings continues into the rooms. Solar radiation which reaches the wall surface partly continues through the wall and a part is reflected as shown in Figure1. In Indonesia, cooling load of which generates from thermal load from outside the building, reaches 70% [2]. With this condition, the use of air conditioning system is highly necessary to acquire room thermal comfort.



(a) Dark-colored wall (b) Light-colored wall

Figure 1. Distribution of thermal energy on walls that receive solar radiation [3].

Thermal load which enters the room is solar radiation energy received by wall surface and then through conduction is continued to the surface of the inside part of the wall. Solar radiation energy which can be continued to the inside surface of the wall can reach 90%, depending on the darkness level of the wall [3]. The heat transfer on the wall is also influenced by wall thermal conductivity. The varied thermal conductivity of wall material is as shown in Table 1.

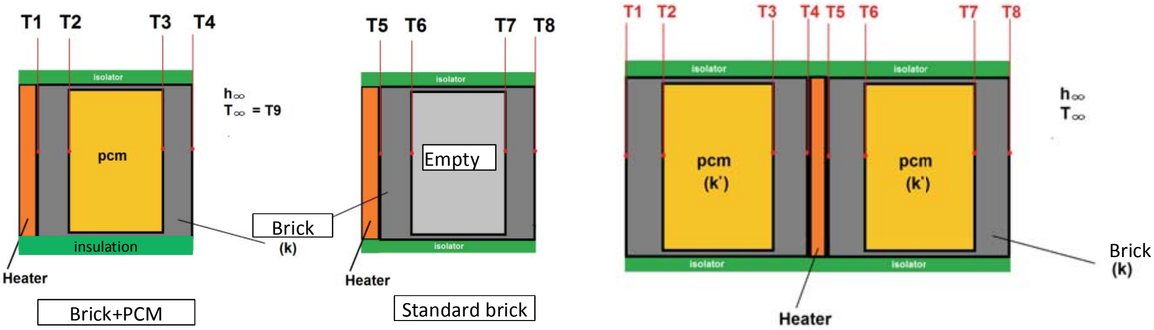
Table 1. Properties of wall materials [4].

Material	Thermal conductivity [W/m.K]	Specific heat capacity [kJ/kg K]	Mass density [kg/m^3]
Tuff	0.630	1.300	1500
Concrete	1.263	1.000	2000
Brick	0.500	0.840	840
Plaster	0.900	0.910	1800
Insulating material	0.170	0.920	1200

Besides the choice of material, to slow down heat transfer in walls, nowadays there has also been a development on the use of phase change material (PCM) on walls. This PCM is functioned as thermal energy storage, thus the transfer energy in the wall is collected in the PCM. The utilization of PCM on walls according to Baetensa et al. [5] is grouped into three types namely the use in wall board, the use in concrete, and the use as insulation material. A number of research results of PCM use in wall showed positive results on the decrease of thermal energy which enters a room. Diaconu et al. [6] used PCM made of composite on building walls and can decrease cooling load up to 35.4%. Indartono et al. [7] used micro-encapsulation phase change material (MPCM) from coconut oil as material in brick mixture and can decrease room temperature and can delay the incident of peak load. Barrenech et al. [8] used PCM DS5001 Micronal as material of Portland cement mixture and gypsum with mass fractions of 5 and 15%. The use of this material can reduce wall thermal conductivity up to 50%. Catsell et al. [9] used MPCM which has been commercialized as type RT27 and SP25. The use of this material can decrease building energy consumption of 15%. Arce et al. [10] used Micronal, BASF product PCM in portable building walls and can decrease peak temperature of 6%. Besides that it can also slow down the occurrence of peak temperature of 36%. For the application of PCM in building material in Indonesia, study on heat transfer characteristics in materials is needed, either laboratory test or application test on building type.

2. Experimental

In this study, heat transfer characteristics were tested for bricks added with encapsulated PCM, and building wall made of bricks with the inner side coated with PCM were conducted. In brick test, temperature was measured at several points by using thermocouple and data logger lutron type 224SD either for standard brick or brick containing encapsulated PCM. Scheme of test tool (Figure 2a). Heat source was from heater and surface temperature of 80^{o}C was maintained by using thermo controller. Besides that thermal conductivity test in standard brick and brick containing encapsulated PCM was conducted (Figure 2b). While in the building model wall test, points with thermocouple are outer and inner wall surfaces, PCM container surface, ambient temperature. At the same time, a standard building model has been tested as a comparison. Test equipment is shown in Figure 3. PCM used was Barco brand coconut oil.



(a) Heat transfer time (b) thermal conductivity

Figure 2. Test equipment scheme of heat transfer characteristics in brick.

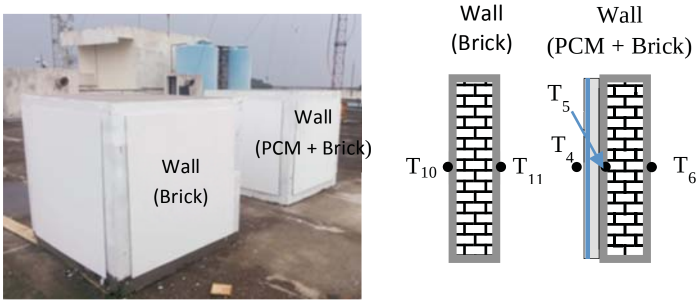


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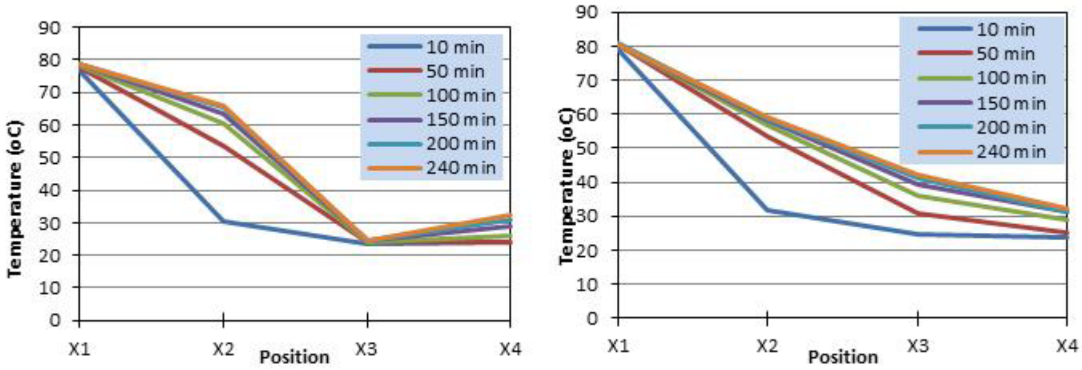
Figure 3. Heat transfer test on walls in building models.

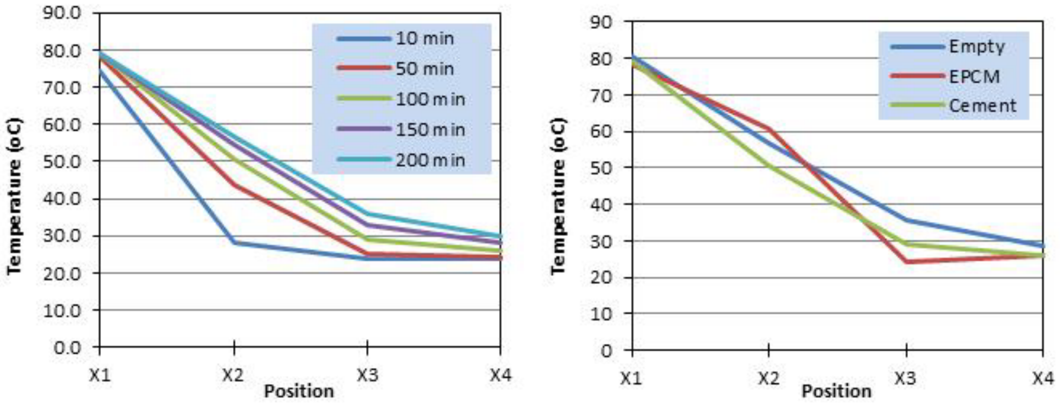
3. Result and discussion

In this part heat transfer in bricks, temperature change in each part, thermal conductivity, as well as PCM coated wall heat transfer characteristics to the surrounding air are discussed. Data of test result were compared to bricks and standard wall.



(a) Brick+PCM.

(b) Hollow Brick (standard brick).



(c) Cement + brick.

(d) Temperature of 200th min.

Figure 4. Temperature distribution in brick and brick + PCM.

In the test of thermal transfer in bricks, the use of encapsulated PCM in bricks could slow down heat transfer into inner surface of brick, thus the time to increase surface temperature was longer (Figure 4). The thermal energy entering through PCM was used for the process of phase change. The use of thermal energy did not result in significant change in temperature. Energy required was great, compared to using sensible heat. After 240th min, brick surface received heat, position 3 did not experience significant temperature change, but in position 4 which is the back surface of the brick, there was a significant increase in temperature. This increase is predicted to come from heat transfer on the sides of the brick.

The result of thermal conductivity test is shown in Figure 5. Brick with hollow inside has higher thermal conductivity compared to brick with encapsulated PCM in the hollow part itself. The thermal conductivity is for one piece of brick. Observed from each brick material, such as sand and cement, thus coconut oil has lower thermal conductivity. The thermal conductivity decrease is also made possible as a result of the encapsulated layer.

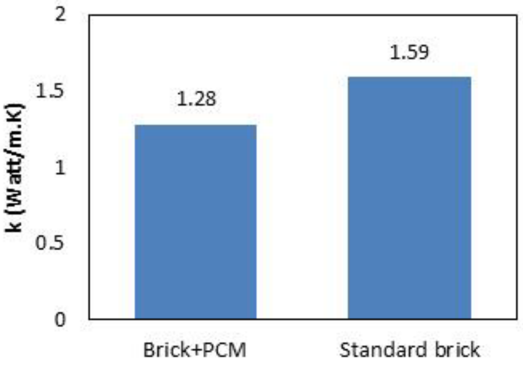
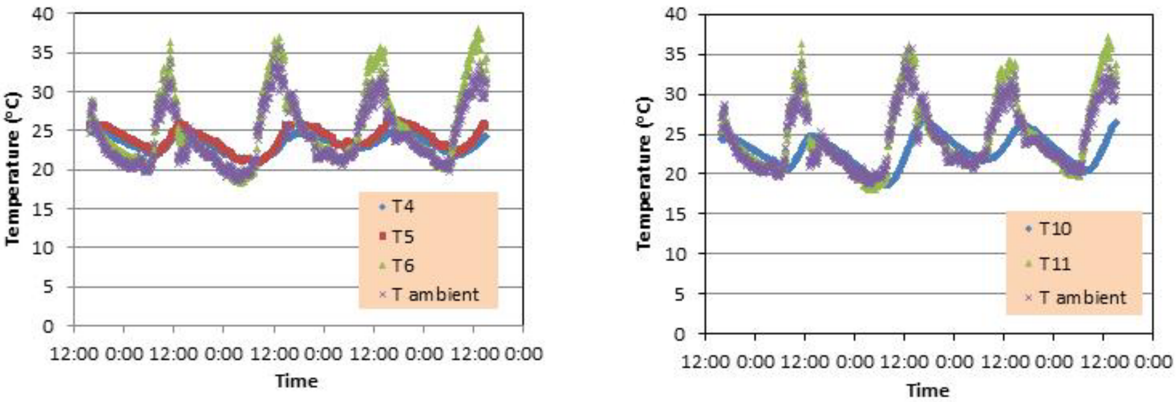


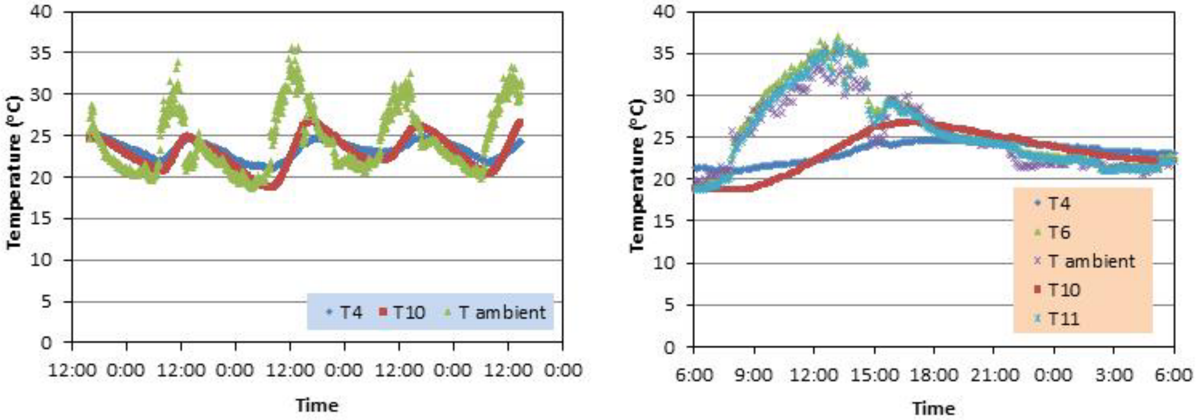
Figure 5. Thermal conductivity in brick and brick + PCM.

The result of PCM use test on building model wall from 15 to 19 August 2016 is shown in Figure 6. The temperature of standard building wall outer surface as well as that with PCM container was affected by ambient temperature and solar radiation. In peak condition, its temperature higher than ambient temperature. On the other hand, the inner surface temperature there was a delay when ambient temperature change took place. This is due to the occurrence of thermal energy storage in brick material. In brick wall installed with PCM container, energy stored increased thus the delay became longer. For peak temperature, it took place at 12:00. Peak temperature for inner surface of standard wall was at 17:00. While on the inner surface of the wall containing PCM, it was at 21:00. The decrease in thermal conductivity in PCM caused heat flow part to collect in brick wall. Thus, this is what causes temperature on the inner side of the brick to increase compared to standard brick. The placement of PCM container on the inner side of the wall can slow down heat transfer into the room (Figure 6d). When ambient temperature is lower than wall temperature, energy release occurs. In standard wall, outer and inner surface temperature can reach the ambient temperature. While in wall + PCM container, energy release to the surrounding still results in higher wall inner surface temperature than the ambient temperature. This is due to energy release stored in PCM in phase change process did not provide great temperature change effect. The use of coconut oil as PCM for the application on walls in the city of Bandung is still suitable because PCM temperature is still below its phase change temperature.



(a) Wall with PCM layer on inner surface.

(b) Standard wall.



(c) Comparison of temperature on inner wall inner surface of wall.

(d) Comparison of temperature on surface for 24 hr.

Figure 6. Temperature distribution on building model wall (5 – 19 August 2016 in Bandung).

4. Conclusion

The use of PCM could delay heat transfer from outer wall surface to inner surface due to increase in material thermal capacity. The addition of PCM in the hollow inside the brick slightly reduced thermal conductivity compared to hollow brick. The utilization of PCM from coconut oil applied on wall inner surface in the container is suitable for minimum ambient temperature ranging between 18 – 20^{o}C, because PCM can still undergo complete phase change process at 22^{o}C, thus the use of the PCM is still suitable with the weather in the city of Bandung. PCM wall inner surface temperature can be lower on average 2^{o}C compared to standard wall. The process of heat absorption in PCM wall takes place from 7:00 to 18:00, while the process of heat release then takes place at 22:00 to 6:00.

Acknowledgment

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