CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 2

Heiselberg, Per Kvols

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Heiselberg, P. K. (Ed.) (2016). *CLIMA 2016 - proceedings of the 12th REHVA World Congress: volume 2*. Department of Civil Engineering, Aalborg University.

Development of novel roof finishing materials using PCM for detached houses to mitigate urban heat island and to improve thermal condition

Chang Sub Shin[#1], In Sung Kang[#2], Young Kwon Yang[#3],
Min Hee Chung[*4], Jin Chul Park[*5]

[#] *Department of Architectural Engineering, Chung-Ang University*
Seoul, South Korea

[1]mesersin@naver.com

[2]suuung222@nate.com

[3]dora84@naver.com

[*] *Centre for Sustainable Architecture and Building System Research, School of Architecture, Chung-Ang University, Seoul, South Korea*

[4]mhloveu@cau.ac.kr

[5]jincpakr@cau.ac.kr

Abstract

In this study, an experiment with a Phase Change Material (PCM) and Wood Plastic Component (WPC) was conducted to mitigate the urban heat island effect in summer and to improve the thermal environment in winter. An experiment was conducted to measure the thermal performance in an external environment in summer weather conditions. The measurements were compared with different melting temperatures and albedo. The n-docosane-PCM, the melting point of which is 44℃, and Bio-PCM, the melting point of which is 26℃ are used to determine the optimal combination of WPC and PCM which is applicable in summer. PCM with the temperature range of 24~28℃ is usually used in the interior of a building. However, in this study, PCM with the melting temperature of 44℃ was used to consider increasing the surface temperature. WPCs with two different PCMs were compared. The temperature of the bio-PCM with a melting point of 26℃ increased continually after phase changing. This means that the sensible heat of PCM was stored after latent heat storage. On the other hand, the PCM with a melting temperature of 44℃ maintained a lower surface temperature than the PCM with the melting temperature of 26℃ because of its higher melting temperature and its latent heat. The result shows that PCM with a higher melting temperature is more effective in controlling the surface temperature and mitigating the urban heat island.

Keywords – PCM(Phase Change Material); Cool Roof System; Urban Heat Island; Scale Model Test; Surface Temperature

1. Introduction

Urban heat island (UHI) due to increased temperature and population as well as climate change is occurring throughout the world. UHI is a phenomenon when temperatures in the heart of city are significantly higher than those of the surrounding areas due to increase in population, various artificial establishment, traffic vehicles on thoroughfare, artificial heat emission, and greenhouse effect. The emission rate or intensity of UHI depends on the time and area. In a previous study on the distribution and intensity of UHI in Seoul [1], the most significant UHI was generated before sunrise in high percentage of residential complex with regard to daily change of UHI.

Some materials such as cool and green roofs have been applied to reduce UHI. However, cool roofs have disadvantages such as hindrance to thermal environment due to their high reflectivity in the winter. Green roofs also have disadvantages, including excessive initial installation costs, waterproofing for drainage, and increase in load.

To overcome the disadvantages of cool roof and green roofs, phase-change material (PCM) was developed. PCM refers to a material that can accumulate and release thermal energy as a form of latent heat. It can change its state according to temperature changes. A PCM has the advantage of changing temperature suitable for field use so that energy can be used efficiently. Research studies utilizing PCM thermal storage performance are being actively carried out. Li et al. [2] has conducted a study to obtain a thermal comfort environment based on energy consumption reduction and heat storage performance by applying PCM to a detached house and estimated the surface temperature through simulation. Chou et al. [3] has evaluated thermal performance of a common wavy shape roof, a roof with insulation, and a roof with both insulation and PCM. Kosny et al.[4] and Karlessi et al. [5] have confirmed that applying a PCM to a building can reduce surface temperature and loads of cooling and heating [4-5]. For a typical house, the roof has an effect of about 14% of a total cooling load. The temperature of roof surface in the summer can increase the cooling load of a building significantly. Thus, to increase comfort for occupants, it is important to lower the temperature of the roof surface and reduce UHI.

A published thermal performance test [6] utilizing PCM Cool Roof System as finishing materials for wood, aluminum, or tile roof has confirmed that the indoor temperature is lower in a PCM wood roof house compared to houses with other roof materials because wood has low thermal conductivity. However, using wood as a finishing material has disadvantages because wood does not have good durability. In addition, it does not make the most of PCM's characteristics when it is used with PCM together. As an alternative of wood finishing materials, wood plastic component (WPC) was used. As a result, heat transfer into the inside of PCM was not idea due to the low thermal conductivity of wood finishing materials. WPC with good thermal conductivity and durability would be more suitable for the development of surface finishing material using PCM.

The purpose of this study was to mitigate UHI in a residential complex in the summer by developing a PCM Cool Roof System capable of reducing the cooling and healing loads by using WPC as PCM as roof material. The concept for PCM Cool Roof System was defined and a small scale model in the form of 1/10. It was made and installed in open air. Specimens from each layer were measured.

2. Concept of PCM Cool Roof System

The PCM Cool Roof System was used to prevent an increase in heating loads in the winter through preventing overheating roofing materials, thus increasing insulation performance by using the phase change characteristic of PCM. Unlike existing roofing materials that the heat of roof surface is stored as the form of sensible heat, PCM should be able to prevent buildings from overheating by maintaining a constant temperature thorough accumulating heat as a form of latent heat before the temperature of PCM reaches a phase change temperature. The purpose of using PCM is to prevent roof from overheating by maintaining its surface temperature at 30~40℃ as opposed to 50~80℃ of elevated temperature of existing roofs as shown in Fig. 1.

The PCM Cool Roof System was developed in the form of lightweight plate so that it can be applied to existing buildings and new buildings to reduce UHI. Materials with high reflectivity and emissivity are needed for surface finishing in order to minimize heat transfer into the inside of buildings. After surface finishing, phase change is made due to internal enthalpy increase by inserting a PCM into the hollow layer inside to minimize heat transfer into the structure. Cool Roofs have been proposed to reduce UHI in the city. They are effective in air-conditioning by minimizing heat gain through the roof during the summer cooling season. However, they have limitations in that they can lead to annual energy consumption increase because they can increase the heating load during the winter season at climatic zones with large heating loads. The PCM Cool Roof System lacks the reduction performance of surface temperature compared to existing Cool Roofs. However, it is superior for occupants' comfort because it can reduce temperature variation inside the building. The purpose of PCM Cool Roof System is to conserve energy by reducing both cooling and heating energy. Thus, the reflexibility of the PCM Cool Roof System may be lower than that of Cool Roofs or other existing roofing materials.

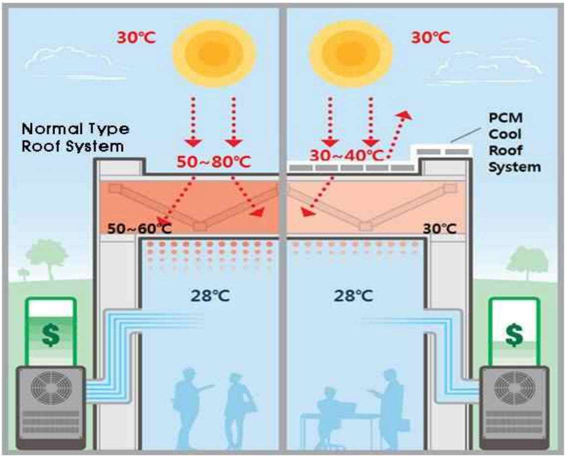


Fig. 1. Effect of PCM cool roof system.

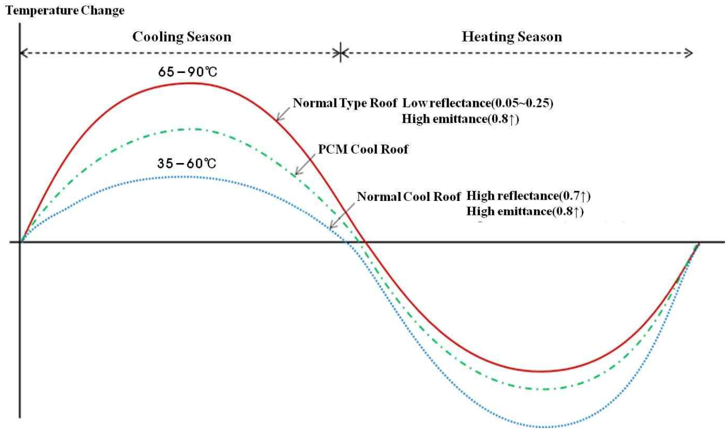


Fig. 2. Temperature range of PCM cool roof system.

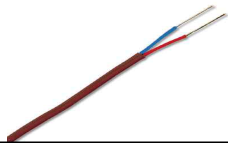
3. Scale Model Test

In this study, a PCM that could be applied to a collective housing area during the summer season was selected by measuring the temperature of the roof layer according to phase change temperature of the PCM. Cool Roof System covers changing of building roof surface temperature during summer climate. The size of the scale model was determined to be about one-tenth size of the existing office building for convenience of installation during the external test. Typical flat roof was selected for the configurations of the specimen. However, in this test, it was removed because it was determined that it might not affect thermal performance.

Equipments used in the experiment are listed in Table 1. Monitoring of the outside air environment was performed by checking temperature changes of each layer using data logger (GL-820) and T-type thermocouple with a pyranometer and a digital thermos-hygrometer.

Temperature was measured at locations such as finishing material surfaces, interior finishing materials, and the bottom parts of finishing material (the upper side of concrete mortal) as show in Fig. 3.

Table 1. Measuring instruments

	
Datalogger	Thermocouple
	
Pyranometer	Digital Thermo-Hygrometer

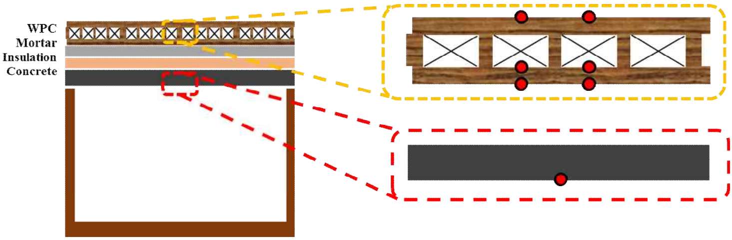
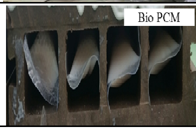


Fig. 3 Measurement locations

PCM with a hollow wall WPC was prepared by applying n-docosane (44℃) and Bio-PCM (26℃) with different melting points to WPC. Since a PCM can cause phase changes in liquid state, consideration is required for applying roof finishing materials. Therefore, we made PCM as a Packing Type with construction finishing materials that had a hollow layer (Table 2). The experiment was performed when shadow was not generated for a week in an open air from September 22 to September 24, 2015.

Table 1. PCM Packing production and plate interior insertion

PCM Type	Bio PCM	RT 44 PCM (n-paraffins)
Melting Point	26℃	44℃
Main materials	Vegetability	Paraffin
Weight per 1 pack (Latent heat)	34.77g (~200J/g)	36.18g (241J/g)
Picture of packing PCM		
Picture of inserting PCM packing on to WPC		

4. Results

An analysis was carried out on September 24 when the highest accumulated solar radiation amount was found from September 22 to September 24. The average temperature on September 24 was 23.4℃. The average cloud cover was at scale of 3.0. The average wind speed was 1.9m/s. The accumulated solar radiation amount was 4,632Wh/m^2.

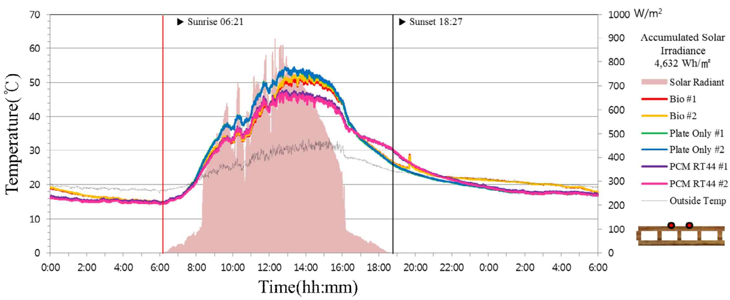


Fig. 4 The surface temperature

Regarding the finishing materials with PCM packing type for the insertion into WPC, the highest temperature of the plate surface temperature was 54.5℃ in a single plate, followed by 52.2℃ in a Bio-PCM and 47.7 ℃ in n-docosane-PCM. Thus, the surface temperature was the highest in a single plate without containing PCM. The maximum difference was 6.8℃ between a single plate and a n-docosane-PCM (Fig. 4).

Plate internal temperature measurement results also showed that the highest temperature was 54.5℃ in a single plate, followed by 50.1 ℃ in a Bio-PCM and 43.2 ℃ in n-docosane-PCM. It was confirmed that the time of peak internal temperature was delayed for about an hour to one and a half hours compared to the time of peak surface temperature (Fig. 5).

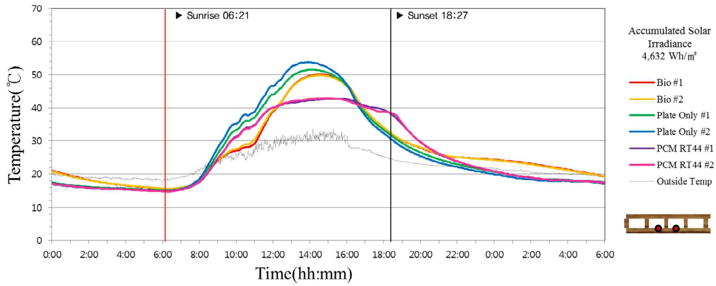


Fig. 5 Plate internal temperature.

The temperature measurement results for the bottom side of the plate showed that the temperature was 48 ℃ in a single plate, followed by 45 ℃ in a Bio-PCM and 42 ℃ in n-docosane-PCM, similar to results of internal plate temperatures.

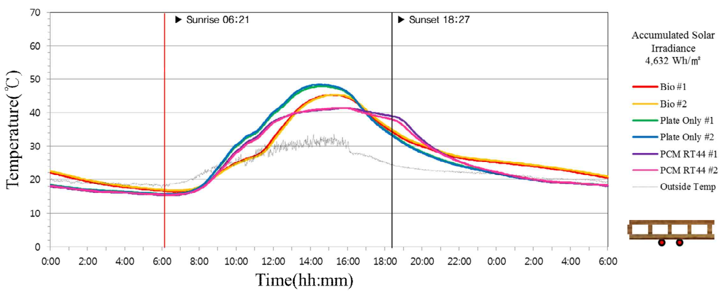


Fig. 6. Plate bottom side temperature.

The measurement results of indoor ceiling side are shown in Fig. 7. The temperature was 38 ℃ in a single plate, followed by 36.5℃ in a Bio-PCM and 35.6℃ in n-docosane-PCM. The time to reach peak temperature was 16 hours 40 minutes for a single plate, which was the fastest, followed by 17 hours 20 minutes for a Bio-PCM and 17 hours 31 minutes for n-docosane-PCM. During cooling after sunset, the cooling rate of Bio-PCM was slower compared to other specimens (Fig 7).

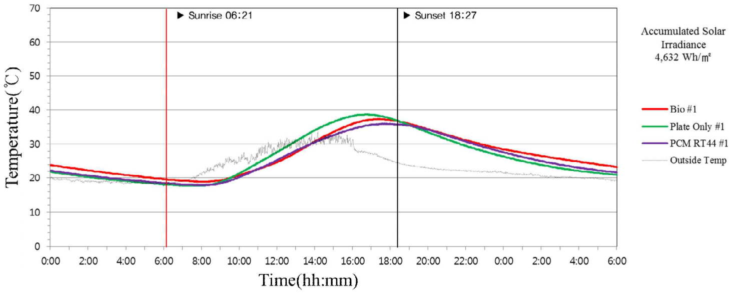


Fig. 7. Indoor ceiling side temperature.

5. Conclusion

In this study, the thermal performance of roof finishing materials using PCM and WPC was conducted in order to reduce the cooling and heating loads of collective housing area and alleviate UHI at the same time.

Our results showed that the surface temperature of a WPC to which a n-docosane-PCM with a high temperature of phase change was inserted to was 4.5℃ lower than a bio-PCM with a low temperature of phase change. There was a 6.8℃ difference between a plate with PCM insertion and the one without a PCM insertion. This confirmed that a time lag existed in the phase change temperature of each PCM since an internal plate is connected to a PCM. Bio-PCM maintained constant temperatures (24~27℃) for about 2 hours and 30 minutes while n-docosane-PCM maintained constant temperatures (within 43℃) for about 6 hours. The temperature of the indoor ceiling side was measured to be about 1℃ lower in n-docosane-PCM than that in a bio-PCM. Thus, the surface temperature appeared to be lower than general building finishing materials when PCM was used as a roof finishing material. Therefore, n-docosane-PCM with a high phase change temperature is more appropriate in the summer season than a Bio-PCM with a low phase change temperature to reduce UHI.

This is a study on methods for reducing UHI generated in residential complex during the summer season. The primary purpose of this study was to develop a PCM Cool Roof System. The PCM Cool Roof can be developed by selecting a plate design that can be installed on the rooftop of residential complex. A PCM with the best phase change temperature needs to be studied in the future.

Acknowledgment

This is research was supported by a grant (15CTAP-C078014-02) from Infrastructure and transportation technology promotion research program funded by Ministry of land, infrastructure and Transport of Korean government.

References

[1] Y. J. Kim. A study on the distribution and intensity of urban heat island in seoul. Master thesis paper Kon-Kuk university. Seoul. Korea.

[2] D. Li, Y. Zheng, C. Liu and G. Wu. Numerical analysis on thermal performance of roof contained PCM of a single residential building. Energy Conversion and Management. 100 (2015) 147-156.

[3] H. Chou, C. Chen and V. Nguyen. A new design of metal-sheet cool roof using PCM. Energy and Buildings. 57 (2013) 42-50.

[4] J. Kośny, K. Biswas, W. Miller and S. Kriner. Field thermal performance of naturally ventilated solar roof with PCM heat sink. Solar Energy. 86 (2012) 2504-2514.

[5] T. Karlessi, M. Santamouris, A. Synnefa, D. Assimakopoulos, P. Didaskalopoulos and K. Apostolakis. Development and testing of PCM doped cool colored coatings to mitigate urban heat island and cool buildings. Building and Environment. 46 (2011) 570-576.

[6] J. L. Jeong, S. G. Bang, M. H. Chung and J. C. Park. Thermal Performance test of finishing materials of PCM cool roof system. Proceedings in 2015 AIK Annual Fall concevence at Seoul, pp. 595-596, Seoul, Korea, 29-30 October 2015 595-596.