An Experimental Study on PCM (Phase Change Material) Cool Roof System

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ABSTRACT

This is a study on mitigating urban heat island phenomenon. The purpose of a Phase Change Material(PCM) cool roof system is to reduce the temperature of the roof's surface during summer seasons and stabilize the interior temperature by heat storage capability of the PCM during winter seasons. The study covers two scale model tests for measuring PCM heat performance. One is an indoor artificial environment test, the other is an external environment. Tests results are significant in that they show the surface/inside temperature of the PCM and cool roof system to be lower than the general roof system. Therefore, it is expected that a PCM cool roof system could reduce urban heat island phenomenon.

KEYWORDS

PCM(Phase Change Material), Cool Roof System, Urban Heat Island Phenomenon, Scale Model Test, Surface Temperature

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INTRODUCTION

Due to the change in urban heat balance caused by population concentration/the progress of urbanization with rising temperatures according to a global climate change, urban heat island phenomenon [effect] is also occurring in cities in Korea. Urban heat island phenomenon affects global warming and increase building heating/cooling peak loads. This vicious circle of energy demands causes the earth's temperature to rise. Researchers have looked into ways to reduce urban heat island phenomenon by studying green roofs, urban green belts, and cool paint. However, each method of reducing urban heat island phenomenon has defects such as installation costs, water leakages, and costs for maintaining. Especially, cool paint, which has a critical defect to increase heating loads in the winter season.

The purpose of this study is to reduce urban heat island phenomenon through the development of a Phase Change Material(hereinafter PCM) Cool Roof System utilizing PCM, making up for the weakness of existing roof systems like the above.

RESEARCH TRENDS OF PCM (LITERATURE REVIEW)

The purpose of a phase change material cool roof system is to reduce the temperature of the roof's surface during cooling seasons for mitigating urban heat island. The result of literature review analysis for research trends is as follows. L. Dong, Z. Yumeng(2015) et al. furthered studies by obtaining a thermal comfort environment based on energy consumption reduction and heat storage performance by

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applying a PCM to a private house and estimate surface temperature through simulation[1]. A. Pasupathy (2008) observed changes in the temperature of the ceiling side by using a PCM panel[2]. Huann-Ming Chou (2013) evaluated thermal performance of typical wavy-shaped roof, insulation-applied roof and the roof that insulation and PCM were added to[3]. There was also a measurement experiment to determine the indoor room temperature reducing effect etc. by applying a PCM heat storage board to the model building's roof as a practical application study [4-6]. The examples of studies related to Cool Roof System using PCM are as follows. T. Karlessi(2010) conducted an experiment to compare surface temperature of normal color and PCM coated finishing materials [7]. A.R. Gentle(2011) conducted a study to compare Peak Loads according to Albedo values of the Cool Roof System [8-10].

PCM(Phase Change Material) SPECIFICATION

PCM has the advantage that it can change phases and change temperatures suitable for the fields of its usage and its purpose so that it can use energy efficiently (Figure 1,2).

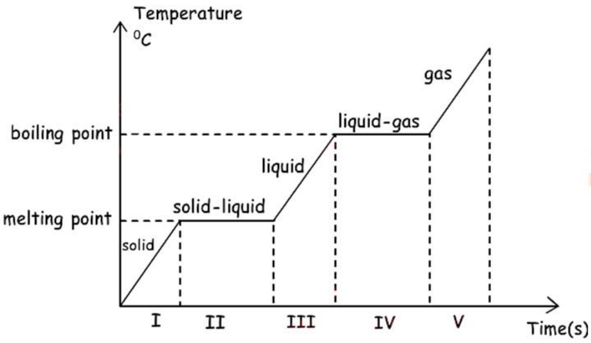


Figure 1. Phase change graph

Figure 2. PCM Thermal characteristic

CONCEPT OF PCM COOL ROOF SYSTEM

A PCM Cool Roof System is intended to prevent overheating of roofing materials in the summer by using a phase change characteristic of the PCM and to prevent the increase in heating loads in the winter through increased insulation performance. Unlike conventional roofing materials, the heat of the roof surface is stored as a form of sensible heat by accumulating heat as a form of latent heat, PCM is intended to prevent the city from overheating by maintaining a constant temperature when the temperature of the PCM reaches the phase change temperature. As opposed to the temperature of the existing roof that is raised up to 65~90℃, PCM is intended to prevent the roof from overheating by keeping the surface temperature at around 35~60℃.

In particular, the purpose of the PCM Cool Roof System is to maintain characteristics of an air conditioner of the existing Cool Roof to some extent, and to reduce the urban heat island phenomenon by correcting heating load increases caused by the high reflectivity, which is a disadvantage of a heater, and lowering the surface temperature. (Figure 3,4,5).

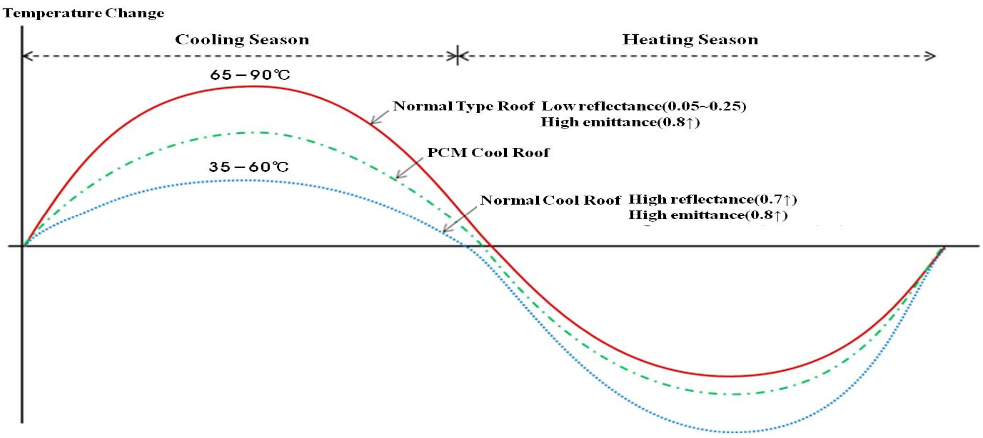


Figure 3. Temperature range of PCM cool roof system

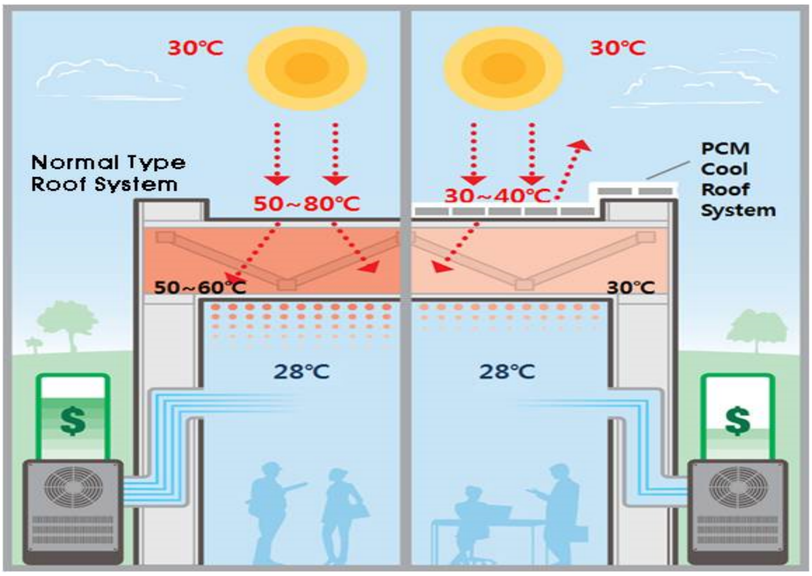


Figure 4. Effect of PCM cool roof system

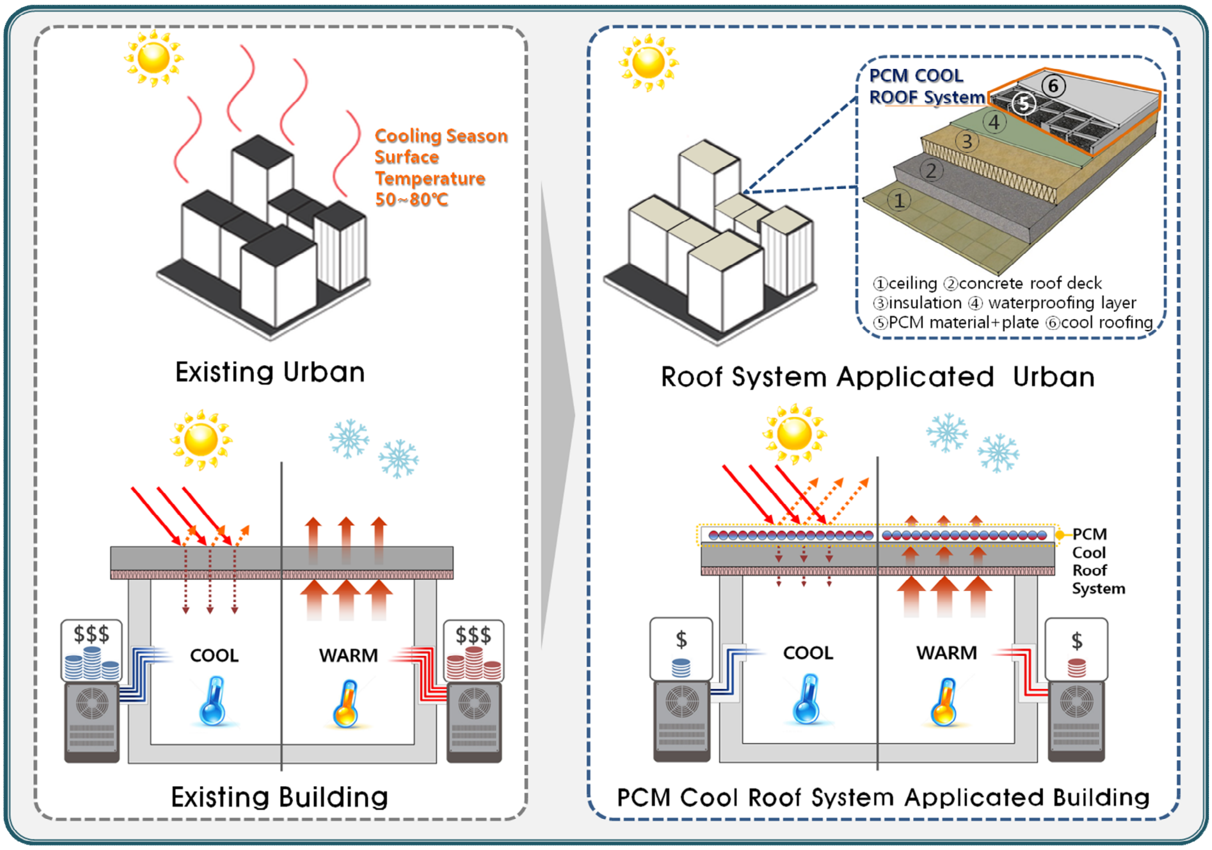


Figure 5. Concept of PCM roof system

SCALE MODEL TEST

Artificial Environment Test Room

Cool Roof System covers changing of building roof surface temperature during summer climate. We installed artificial environment test room because Korea has four difference climate seasons. 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 indoor and external test.

During the indoor artificial environment test, the indoor temperature was maintained at about 30℃ by installing halogen lamp having summer solar irradiance and heat in 2㎥ space. The phase change temperature applicable to the thermal properties of the PCM and roof surface through the summer test through the indoor artificial environment was confirmed (Figure 6).

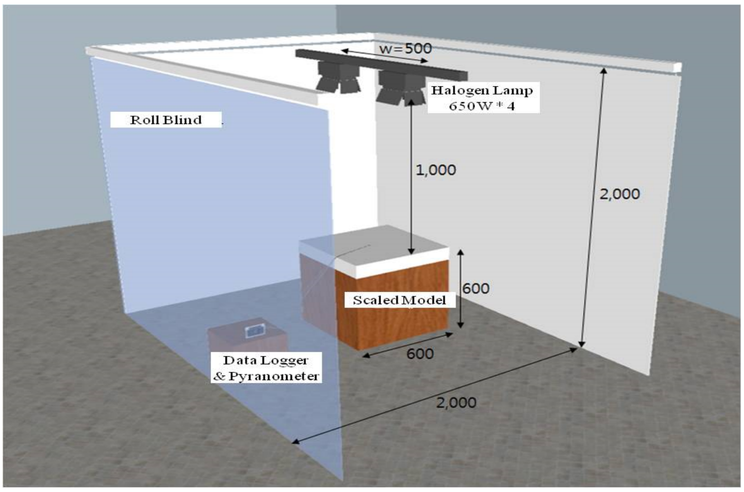
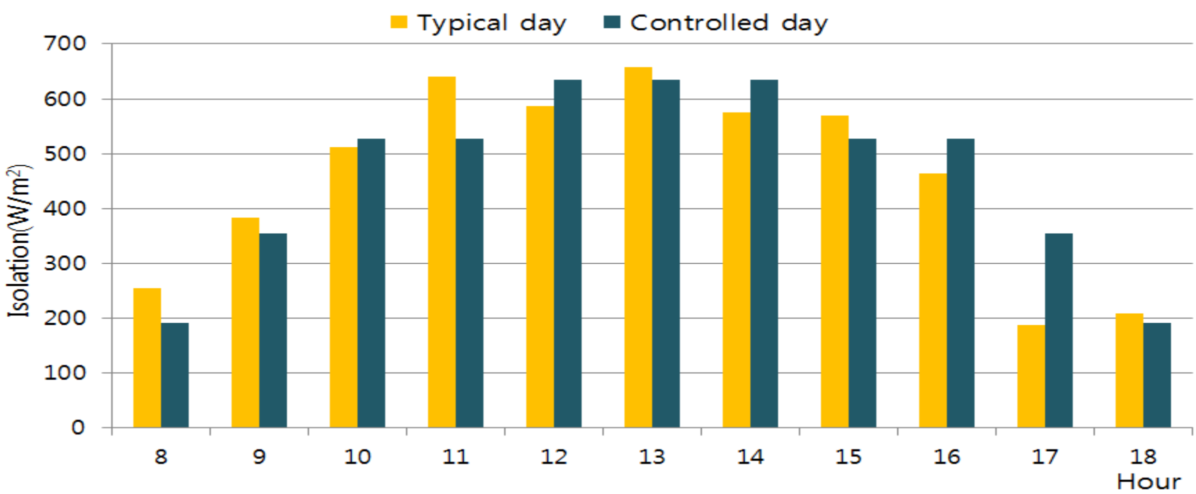


Figure 6. Indoor artificial environment test layout

During the indoor artificial environment test, solar irradiance was selected to the closest control by comparing the solar irradiance of an average day with that of a maximum day, measured by standard meteorological data. Solar irradiance control simulated the changes in solar irradiance over time from sunrise to sunset in four steps (Table 1).

Table 1. Artificial solar irradiance control

Time		8	9	10	11	12	13	14	15	16	17	18	Total
Standard meteorological data	Maximum day (W/m^2)	316	475	669	788	875	897	833	783	669	488	266	7,059
	Typical day (W/m^2)	255	383	511	641	586	658	575	569	464	188	208	5,038
	Average day (W/m^2)	61	222	347	538	438	597	519	338	272	250	127	3,709
Experimental data	Control day (W/m^2)	191	354	528	528	634	634	634	528	528	354	191	5,104
	solar a source of light control	1 (50%)	2 (100%)	3 (150%)	3 (150%)	4 (200%)	4 (200%)	4 (200%)	3 (150%)	3 (150%)	2 (100%)	1 (100%)	-



Domestic normal flat roof was selected for the configurations of the specimen. In general, a film of vapor retarder and waterproofing membrane was installed on the general flat roof. However, in this test, it was removed because it was determined that it might not affect thermal performance (Figure 7). In addition, each measurement point of the specimen measured the surface temperature and temperature per each floor according to solar irradiance by embedding a temperature sensor in each layer (Figure 8).

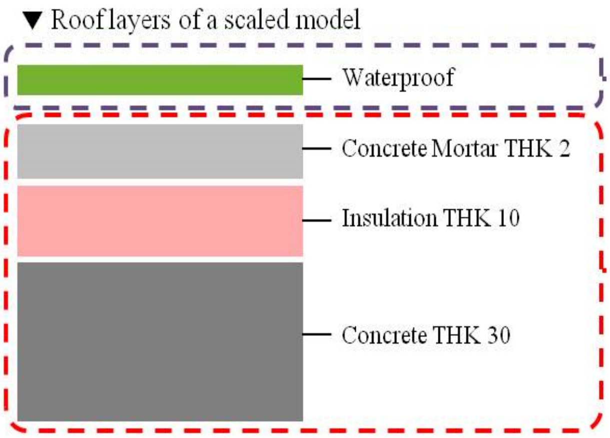


Figure 7. Scale model details

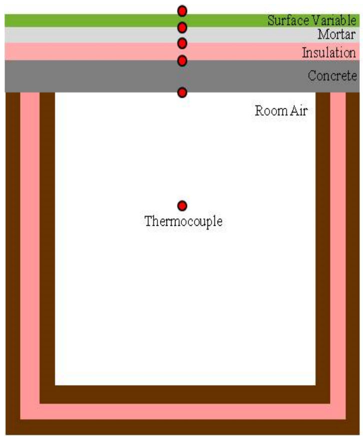
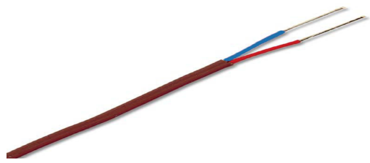


Figure 8. Thermocouple location

Measuring instruments used in this experiment are as follows (Table 2). The temperature change per each layer using a Datalogger and Thermocouple was checked and monitored about indoor artificial environment utilizing Pyranometer and Digital Thermo-Hygrometer was conducted.

Table 2. Measuring instruments

	
Datalogger, Thermocouple	**ThermoCouple**
	
Pyranometer	**Digital Thermo-Hygrometer**

Results

There are a total of four measurement objects for the indoor artificial environment test are as follows: Green urethane waterproof, Gray urethane waterproof, Cool paint, and PCM tile (Figure 9-12). Especially, PCM tile was a component tile with paint type PCM powder. The reason of adjusting PCM paint type is to apply to the existing roof system.

Figure 9. Green urethane waterproof

Figure 10. Gray urethane waterproof

Figure 11. Cool paint

Figure 12. PCM tile

Looking at the surface temperature measurement results, in the state of 28~30℃ ambient air temperature, the existing Green and Gray urethane waterproof reached a high of 70℃. PCM tile and Cool paint reached a high of 53℃. Thus, there showed a difference of about more than 17 ℃ (Figure 13).

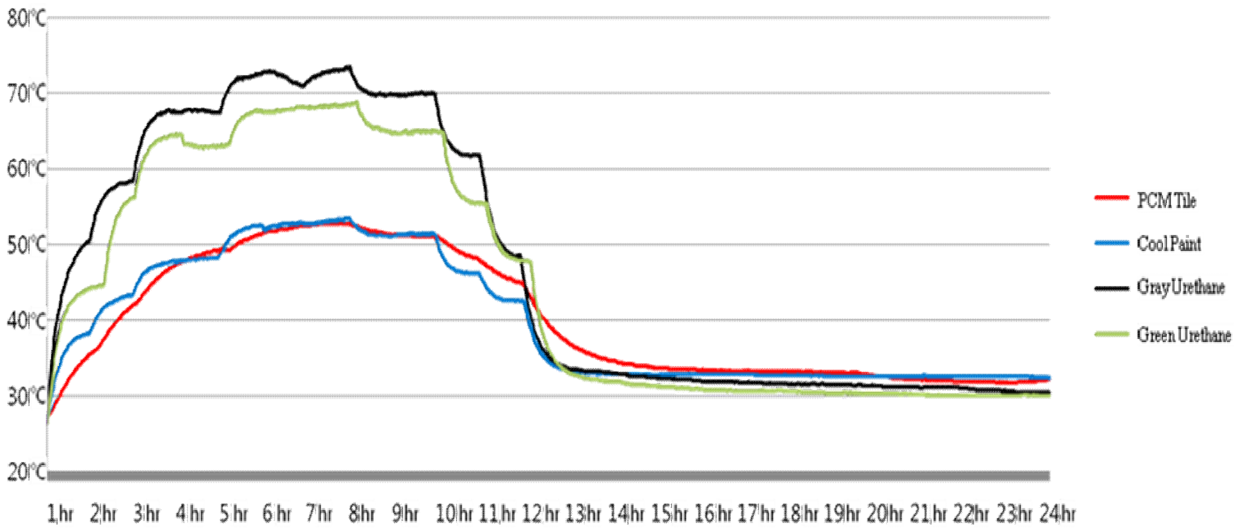


Figure 13. Surface temperature

Room air temperature corresponding to the surface temperature of each material was also shown similarly. It was confirmed that PCM tiles have a thermal storage performance and lower temperature deviation than Cool Paint (Figure 14).

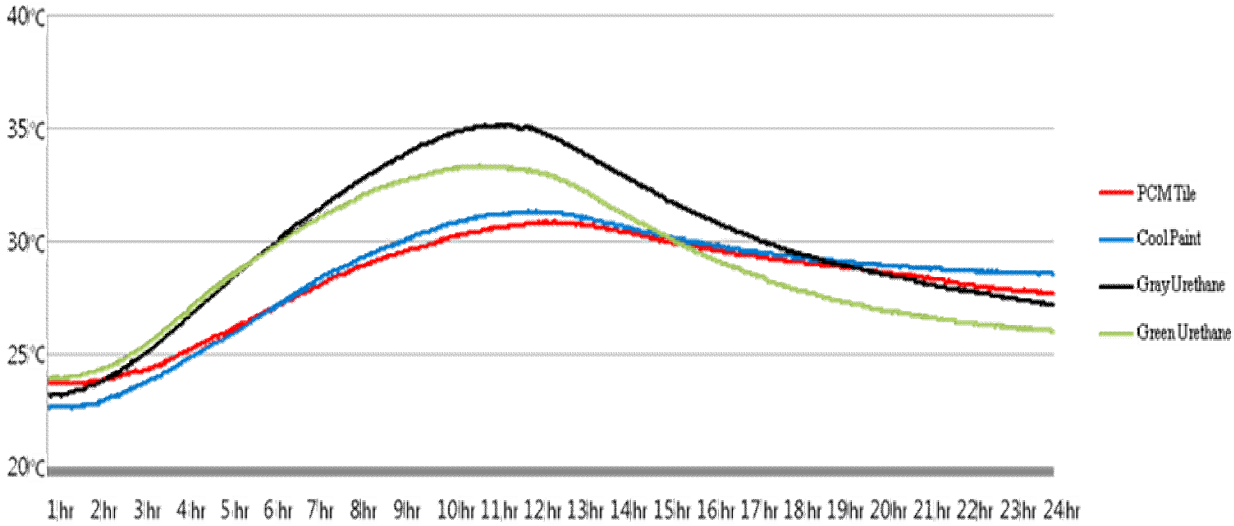


Figure 14. Room air temperature

CONCLUSION

Indoor room artificial environment test results are as follows. When the artificial and ambient temperature was at 25~26℃, the surface temperature measurement results of roofing materials showed that the existing Gray and Green urethane waterproof had maximum temperatures distributions of over 70℃, respectively, and both PCM tiles and Cool paint roof materials had that of 53℃. Thus, there showed a difference of about more than 17 ℃ in temperature distribution. At this time, it was confirmed that PCM tiles, having thermal storage performance, showed lesser temperature distribution in room air temperature than Cool paint.

The surface temperature in the heating season of the urethane waterproof type roof finish mostly used in flat roofs reached a very high of about 70℃. Cool Paint to reduce such a high surface temperature reached at about 53℃ which showed temperature distribution similar to the PCM cool roof, which was the goal for development.
Therefore, it is concluded that the initial study goals to reduce the summer surface temperature and cooling loads, and to resolve the increase of heating loads that is the disadvantage of Cool paint in the heating season can be attained through a PCM cool roof. In addition, further studies will be able to develop a PCM cool roof by selecting plate planning that can be installed on the roof and appropriate PCM.

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