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Development and testing of PCM doped cool colored coatings to mitigate urban heat island and cool buildings

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ABSTRACT

In this study the performance of organic PCMs used as latent heat storage materials, when incorporated in coatings for buildings and urban fabric, is investigated. Thirty six coatings of six colors containing different quantities of PCMs in different melting points were produced. Accordingly, infrared reflective (cool) and common coatings with the same binder system and of the same color were prepared for a comparative thermal evaluation. The samples were divided in six groups of different color and eight samples each: three PCM coatings of different melting temperatures (18 °C, 24 °C, 28 °C) each one of two different PCM concentrations (20% w/w, 30% w/w), an infrared reflective and a common coating of matching color. Surface temperature of the samples was recorded at a 24 h basis during August 2008. The results demonstrate that all PCM coatings present lower surface temperatures than infrared reflective and common coatings. Analysis of the daily temperature differences showed that peak temperature differences occur between PCM and common or cool coatings from 7 am to 10 am. Investigating the temperature gradient revealed that for this time period the values for PCM coatings are lower compared to infrared reflective and common. From 10 am to 12 pm, temperature gradients for all coatings have similar values. Thus coatings containing PCMs store heat in a latent form maintaining constant surface temperatures and discharge with time delay. PCM doped cool colored coatings have the potential to enhance thermal inertia and achieve important energy savings in buildings maintaining a thermally comfortable indoor environment, while fighting urban heat island when applied on external surfaces.

1. Introduction

Urban microclimatic conditions have a very serious impact on the energy consumption of buildings, outdoor comfort conditions and pollutants concentration. Urban heat island phenomenon in combination to the global climatic change deteriorate the microclimatic conditions that are characterized by increased ambient temperatures, longer duration of hot spells and more frequent heat waves [1,2].

Urban heat island refers to increased temperatures in cities compared to the surrounding environment because of the positive urban thermal balance [3–5]. It is the most documented phenomenon of climatic change, and is associated with a very important increase of the cooling energy demand of buildings and a global deterioration of the local environmental conditions [6–8]. Various studies performed have shown that urban heat island may increase the cooling energy demand of urban buildings between 20 and 100% [9–13].

Mitigation techniques aiming to counterbalance the heat island phenomenon deal with the intensive usage of green spaces, application of highly reflective materials, decrease of the anthropogenic heat, solar control of open spaces, use of environmental heat sinks and increase of the wind flow in the canopy layer [14–18]. In particular the use of materials presenting a high reflectivity in solar radiation and a high emissivity value, cool materials, have gained an increasing acceptance [19–21]. Both properties contribute to a lower surface temperature of the materials which may be applied in roofs, walls and pavements [22,23]. Lower surface temperatures of external roofing coatings decrease the heat penetration through the building envelope and reduce the cooling load of buildings [24], while when applied in pavements and other urban surfaces contribute to decrease the ambient temperature as the heat convection intensity from a cooler surface is lower [25,26].

Research on new generation cool materials aims either to decrease the penalty of low absorptivity during the winter period,

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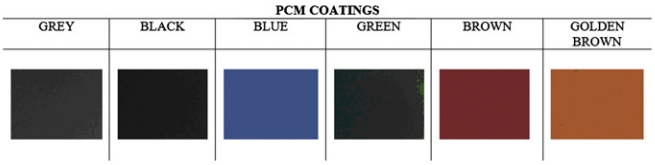

Fig. 1. Color appearance of the cool colored PCM coatings.

Table 1
Meteorological conditions for August 2008.

Months	Tamb (°C)			RH%	Average global solar radiation (W/m^2)	Average direct solar radiation (W/m^2)	Wind Speed (m/sec)
	mean	max	min				
August	29.4	35.5	25.3	44	7017	5682	3.6

or further decrease the surface temperature in summer. As it concerns the first option, dynamic cool materials like thermochromic coatings [27], can change their color as a function of their surface temperature, present a high absorptivity during winter and high reflectivity during the summer and thus contribute to decrease both the cooling and heating needs of the buildings [27].

To further decrease the surface temperature of cool coatings, three main technical options are available: a) Increase the solar reflectivity of the materials, b) Increase their thermal capacity and c) Dope the coatings with latent heat materials. The present paper investigates the potential of phase change nanomaterials doped in infrared reflective cool coatings to further decrease the surface temperature of urban structures and buildings.

Unlike sensible storage materials as masonry or stone, PCMs store heat in a latent form. Latent heat materials offer a large energy storage density and nearly isothermal nature of the storage process during which PCMs undergoes a change in phase. The thermal energy transfer occurs when a material changes from solid to liquid, or liquid to solid. Heat storage and its recovery occur isothermally, preventing temperature swings. During daytime, the PCM absorbs part of the heat through the melting process and at night, the PCM solidify and releases the stored heat. The net effect is a reduction of the daytime surface temperature of the coatings and a reduction of the heat flow from outdoor to indoor space. Incorporated in building envelopes they can increase thermal capacity, thus reducing and delaying the peak heat load and reducing room temperature fluctuation [28–31]. Also when used in pavements contribute to decrease the convective heat flow to the ambient environment and reduce the heat island intensity.

Kissock et al. [32] presented the results of an experimental study on the thermal performance of wallboards imbibed to 30 wt.% with commercial paraffin PCM in simple structures. The results indicated that peak temperature in the phase change test cell was up to 10 °C less than in the control test cell during sunny days.

Cabeza et al. [33] prove that the maximum temperature in a wall with PCM appears about 2 h later than in the one without PCM, i.e., the thermal inertia of the wall is higher. This appears in the afternoon due to the freezing of the PCM, but also earlier in the morning due to the melting of the PCM. The morning temperatures are approximately the same in both cubicles but the temperatures show differences in the cooling down in the afternoon. The main difference is that when the windows are continuously opened, the thermal inertia due to the freezing of the PCM is not so obvious. Thus the user behavior will be an important issue with respect to thermal behavior of the buildings, the PCM performance and the potential energy savings.

It is stated that PCM wallboards could save up to 20% of residential space conditioning [34].

Monitoring the thermal conditions of test cells constructed by phase change wallboards during winter time, Shilei et al. [35] reported that indoor temperature fluctuation is up to 5 °C in ordinary wall room and 3 °C in phase change wall room. Maximum thermal flow in ordinary wall room is 59.5 W/m^2 while in phase change wall room is 51.5 W/m^2, proving that heat-transfer through phase change wall is lower than the ordinary wall.

Gypsum board impregnated with PCM for thermal storage in a passive solar test room was investigated by Athienitis et al. [36]. It was shown that the utilization of the PCM gypsum board may reduce the maximum room temperature by about 4 °C during the daytime.

Stetiu and Feustel [37] used a thermal building simulation program to numerically evaluate the latent heat storage performance of PCM wallboard in a building environment. They found that in the case of a prototype building located in California, PCM wallboard could reduce the peak-cooling load by 28%.

Modelling the effect of the usage of 5–11% PCM in the roof and wall insulation Halford et al. predicted a 19–57% reduction in peak-cooling load [38].

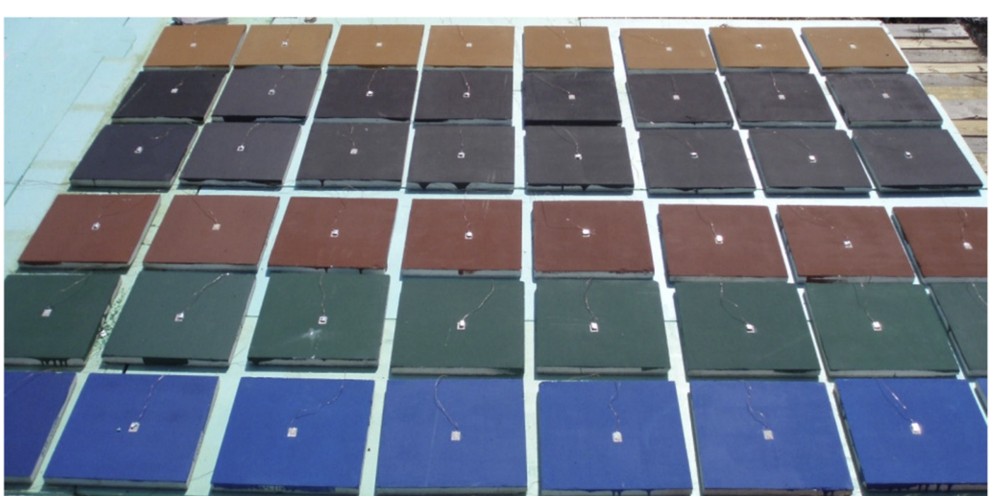

Fig. 2. Tested tiles coated with common, cool and PCM coatings.