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A study of the thermal performance of reflective coatings for the urban environment

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Abstract

This paper presents the results of a comparative study aiming to investigate the effect of reflective coatings on lowering surface temperatures of buildings and other surfaces of the urban environment, and thus test their suitability to lower ambient temperatures and fight the heat island effect. In total, 14 types of reflective coatings, selected from the international market were studied, from August to October 2004, on a 24 h basis. These coatings are used in buildings and some of them are used or could be used in the future in other surfaces of the urban environment (sidewalks, parking lots, etc.). In order to investigate the thermal performance of the reflective coatings, surface temperature sensors and a data logging system as well as infrared thermography procedures were used. The spectral reflectance and the infrared emittance of the samples were also measured. The collected data have been extensively analyzed. It was demonstrated that the use of reflective coatings can reduce a white concrete tile's surface temperature under hot summer conditions by 4 °C and during the night by 2 °C. It can be warmer, than the ambient air by only 2 °C during the day and cooler than the ambient air by 5.9 °C during the night. "Cool" coatings present superior thermal performance even compared to other "cool" materials. This study can assist in choosing more appropriate coatings for building envelopes and other surfaces of the urban environment, and thus contribute to the mitigation of the heat island effect as well as the reduction of cooling loads and electricity consumption of buildings.

Keywords: Passive cooling; Reflective coatings; Building envelope; Urban fabric; Weathering; Heat island

1. Introduction

The phenomenon of the heat island is becoming increasingly more intense in urban areas, changing their microclimate. Summer urban heat islands with daytime average air temperatures 5.6 °C higher than the surrounding rural areas, are present in many cities around the world. In Athens, Greece, according to climatic measurements performed at 30 urban and suburban stations during the summer of 1997, the daily heat island intensity was found to be close to 10 °C (Santamouris et al., 1999, 2001;

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Mihalakakou et al., 2002; Livada et al., 2002). Apart from the thermal discomfort, heat islands are an energy efficiency concern because increased air temperatures, raise air-conditioning loads in buildings, in turn raising energy consumption, peak energy demand and energy prices (Akbari et al., 1992; Hassid et al., 2000; Santamouris et al., 2001). Furthermore, heat islands increase smog production (Taha, 1994). Among the factors that contribute to the heat island effect, the thermal properties of the materials used in the urban fabric play a very important role. The presence of dark colored surfaces, particularly roofs and pavements, absorb solar radiation during daytime and reradiate it as heat during the night and furthermore the replacement of natural soil and vegetation by the materials, reduces the potential to decrease ambient temperature through evapotranspiration and shading (Santamouris, 2001; Akbari et al., 1996).

Therefore the use of high albedo urban surfaces is an inexpensive measure that can reduce summertime temperatures. Increasing the reflectance of surfaces can be achieved by using "cool" materials that are characterized by a high solar reflectance and high infrared emittance values. The use of cool materials in the urban environment contributes to lower surface temperatures that affect the thermal exchanges with the air (Akbari et al., 1992, 1997; Bretz et al., 1997; Berdahl and Bretz, 1997). Cool materials for the urban environment could be roughly divided into two categories: Cool materials for buildings and cool paving materials.

Commercially available cool materials for roofs and walls include cool roof coatings (elastomeric, acrylic, etc.), cool single ply membranes, reflective tiles and metal roofs. Regarding "cool" coatings for buildings, architects traditionally have recognized that reflective building colors can reduce building thermal loads. Several studies have been carried out regarding the cooling potential of the application of reflective coatings on buildings. Givoni and Hoffman (1968) reported that unventilated small buildings in Israel that had white colored walls were approximately 3 °C cooler in summer than when the same buildings were painted gray. Bansal et al. (1992) have studied the effect of external surface colour on the thermal behaviour of a building. They experimented with scaled down units of 1 m^3 volume, under different conditions and found that the black painted enclosure recorded a maximum of 7 °C higher temperature than the corresponding white painted enclosure during hours of maximum solar radiation. During the night the two enclosures showed nearly the same temperatures. Computer simulations showed similar results. The same software when used to simulate the behaviour of a normal sized heavy structure, predicted 4–8 °C higher temperature throughout a period of 24 h for a black coloured surface than the corresponding white one. Taha et al. (1992) measured the albedo and surface temperatures of various materials used in urban surfaces and found that white elastomeric coatings that have an albedo of over 0.72, were 45 °C cooler than black coatings with an albedo of 0.08. Chandra and Moalla (1992) have showed that roof sections with white reflective coatings present better thermal performance than conventional roofing systems, even white asphalt shingles. Simpson and McPherson (1997) have used 1/4 scale model buildings in Arizona found that white roofs (~albedo 0.75) were up to 20 °C cooler than gray (~0.30 albedo) or silver (~0.50 albedo), and up to 30 °C cooler than brown (~0.10 albedo) roofs. Measurements showed that simply increasing the albedo of a building surface may not be effective in reducing its temperature and heat gain if its emissivity is reduced simultaneously. Akbari et al. (1998) reported that increasing the roof reflectance of commercial buildings in California from about 20% to 60% dropped the roof temperature on hot summer afternoon by 7.2 °C. Akridge (1998) showed that the installation of a thermal control coating on a single storey building with identified high roof temperatures, reduced the peak roof temperature by 33 °C. Cheng and Givoni (2005) studied the effect of color on indoor temperatures in hot humid climates. They experimented with test cells and reported that for lightweight construction, the maximum air temperature inside the black cell was higher by about 12 °C than that of the white cell. Additionally the air temperature inside the white cell was only 2–3 °C higher than the outdoor. Their results also show that the influence of color was dependant to the solar radiation; the darker the color the more sensitive to solar radiation.

Various studies have been performed to understand better the thermal performance of paving materials. Berg and Quinn (1978), reported that in mid-summer, white painted roads with an albedo close to 0.55 have almost the same temperature with the ambient environment, while unpainted roads with albedo close to 0.15 were approximately 11 °C warmer than the air. Asaeda et al. (1996),