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Effect of high-albedo materials on pedestrian heat stress in urban street canyons

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A B S T R A C T

Extensive use of high-albedo materials has been advocated as a means of mitigating the urban heat island, especially in warm-climate cities. The implicit assumptions of this strategy are that by lowering canopy layer air temperature, cities will enjoy (a) reduced air conditioning loads in buildings and (b) improved thermal comfort for pedestrians in outdoor urban spaces. The second of these assumptions is examined here by means of computer modeling, in a two-stage approach whereby thermal comfort (represented by the Index of Thermal Stress) is calculated using detailed microclimatic input data simulated by a canyon model (CAT). The analysis suggests that although use of high-albedo materials in canyon surfaces may lower air temperature, the reduction is not enough to offset increased radiant loads. As a result, pedestrian thermal comfort may in fact be compromised.

1. Introduction

When the temperature of the ground surface is warmer than that of the overlying near-surface air, the direction of sensible heat flux is upward, leading to an increase in canopy layer air temperature. Unlike many rural areas, where plant cover and evaporation of soil moisture may moderate the increase of surface temperature that occurs when solar radiation is absorbed, a large proportion of urban areas consists of dry impervious materials – pavement or buildings. To mitigate the heating of such surfaces, which results in elevated air temperature and may contribute to the urban heat island, numerous researchers (Akbari et al., 2001; Synnefa et al., 2008; Santamouris et al., 2008,

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2012; Synnefa et al., 2006) have suggested that wherever possible, they should have a high albedo. Although much of the focus has been on developing materials for cool roofs, there has also been considerable work on so-called cool paving, some of which also incorporates high-albedo materials. These studies have led to recommendations and guidelines for urban planners and architects on practical implementation of cool paving (Gartland, 2008; Bretz and Akbari, 1998; Ferguson et al., 2008; Akbari et al., 1992).

The implicit assumptions of this strategy are that by lowering canopy layer air temperature, cities will enjoy (a) reduced air conditioning loads in buildings; and (b) improved thermal comfort for pedestrians in outdoor urban spaces. The aim of this paper is to examine the second of these assumptions by means of computer modeling.

1.1. Magnitude of air temperature change due to albedo modification

The temperature of urban (and rural) surfaces reflects the energy balance that is the sum of all exchanges of energy. Although surface temperature may be closely linked to air temperature, in the presence of strong solar fluxes and in the absence of evapotranspiration or strong wind the difference may be very substantial – and depend on the material in question. Fresh asphalt has been observed to reach temperatures as high as 65–70 °C at mid-day and may be warmer than the air by as much as 35 K, while light-colored paving tiles may be only 5–7 K warmer than the air under the same conditions (Doulos et al., 2004). Changing surface albedo alone, by application of white paint to dark asphalt, was reported to have resulted in a reduction of maximum daily surface temperature of over 7 K (Kusuda, 1975). Santamouris et al. (2012) report a maximum temperature difference of 7.6 K between conventional tiles and 'cool pavement' on a hot summer day in Greece. However, although albedo has an important effect, the thermal coupling of the pavement with the substrate has a substantial effect as well: asphalt, which has a lower thermal admittance than concrete, heats up more quickly during daytime and, conversely, cools down more rapidly at night.

The magnitude of air temperature modification due to a change in albedo depends on the spatial scale of the area in question. There are practically no experimental studies documenting the effect of albedo modification on air temperature in realistic urban locations, even at a local scale. Assessing the effect of albedo change is therefore done primarily by computer modeling. Santamouris et al. (2012) report that a park renovation project in Athens, Greece, implementing high-albedo paving resulted in a decrease of 1.9 K in peak temperatures. Similarly, Gaitani et al. (2011) predict a potential air temperature reduction of 1–2 K in a public square through implementation of cool paving, adding vegetation and installation of ground-air heat exchangers in the sub-surface soil.

The effect of albedo modification on air temperature at an urban scale has been modeled using meso-scale models such as CSUMM, urbanized MM5 and WRF. In all cases, achieving a substantial increase in urban albedo assumed extensive implementation of cool roofs, while cool paving is generally considered a secondary strategy. Rosenfeld et al. (1995) reported that application of practical changes in the albedo of materials, yielding an overall increase of 0.08 over the entire Los Angeles basin, could reduce summertime peak air temperature by as much as 1.5 K. Although an increase of 0.08 seems modest, it represents an increase of about 40–50% for most urban land use categories in US cities, which have an overall albedo ranging from 0.14 to 0.20 (Taha et al., 1999). Further studies (Taha et al., 1997, 1999; Silva et al., 2009) reported that air temperature reductions could be achieved ranging from 0.5 to 5.0 K, depending on assumptions regarding the extent of high albedo surfaces. Synnefa et al. (2008) report that daytime peak temperatures in Athens may be reduced by 1.3–1.6 K, depending on the scenario tested. Santamouris (Santamouris et al., 2012) reports that the calculated reduction of peak air temperature is estimated at 0.57–2.3 K for every 0.1 increase in urban albedo, equivalent to a total effect of 1–3.5 K. The broad range of estimates is the result of different modeling assumptions regarding: the extent of the areas whose albedo may be modified in given urban locations; the initial surface cover of the urban areas in question; topography; and the combination of increased albedo with other strategies such as increased vegetation.

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