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The effect of using a high-albedo material on the Universal Temperature Climate Index within a street canyon

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A B S T R A C T

This study investigates the effect of different high-albedo adaptation strategies on air temperature, mean radiant temperature and the Universal Temperature Climate Index (UTCI) for an idealized 2D street canyon. The used numerical model computes the heat transport in the canyon, and specifically takes into account the effect of multiple scattering of radiation. In general the mean radiant temperature has a much larger impact on the UTCI than the air temperature. Moreover, the mean radiant temperature exhibits strong spatial variations in the canyon due to its sensitivity to shading. The impact of albedo-differences on the UTCI is thus relatively small compared to the large shading effects. The best strategy to minimize the UTCI for the outdoor environment with building height to width ratio $H/W = 0.5$ is found to be a uniform albedo of 0.2. For $H/W = 1.0$, an albedo gradient from high at the bottom part to low at the top of the vertical walls showed the lowest UTCI. Although using high-albedo materials can mitigate the atmospheric urban heat island effect, it is very likely to increase pedestrian heat stress.

1. Introduction

Several studies (Whitman et al., 1997; Vandentorren et al., 2001; Baccini et al., 2008) have reported a relation between the ambient air temperature and the number of heat related deaths. This heat–mortality

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relation, in combination with the Urban Heat Island effect (UHI, which is the phenomenon wherein the presence of buildings causes the temperature in the city to be higher than in its rural surroundings), poses a challenging problem on city planners to reduce the ambient air temperature inside the city. To achieve this air temperature reduction, the use of high-albedo materials for roofs or paving is often advocated, amongst others by Akbari et al. (2001) and Synnefa et al. (2008).

As a result, the use of these high-albedo materials is also incorporated as guidelines for architects and city planners. For instance, the New York High Performance Infrastructure Guidelines (2005) and Philadelphia High Performance Building Renovation Guidelines (2004) both recommend to use high-albedo pavement as a substitution for black asphalt to counter the local urban heat buildup. The general idea is that high-albedo materials absorb less solar radiation and thereby reduce the outdoor air temperature, which has been shown by many (Silva et al., 2009; Santamouris et al., 2012; Erell et al., 2014). For instance, Taha et al. (1999) studied the impact of large scale albedo changes for ten regions in the USA. A high-resolution regional weather forecast model was used, where the response of buildings and streets on the surface energy balance was specifically taken into account. The regions were characterized and simulated in reference- and modified-surface conditions. The results suggested that large-scale increases in the albedo and vegetative fraction can result in spatially-averaged decreases in mid-day air temperature of −0.5 K to −1.5 K during a typical summer day. The highest reduction found locally was −5 K.

Changing the albedo also influences the indoor air temperature (or the cooling load of obstacles, which is more often studied (Taha et al., 1988; Simpson and McPherson, 1997; Bretz et al., 1998). The effect of a different exterior albedo on the indoor air temperature has been demonstrated by Cheng et al. (2005), who performed idealized scale-experiments on a resolution of 1.5 m. These experiments were performed with separate black and white test-boxes and little insulation (20 mm thick waterproof plywood and 25 mm thick Styrofoam as interior thermal insulation). Both in summer and fall, the maximum indoor air temperature inside the black test box was roughly 12 K higher compared to the white test box.

Although a reduction in outdoor and indoor air temperature is considered positive, there are also downsides of using high-albedo materials. One of the adverse effects was demonstrated by Erell et al. (2014), in which the response of high-albedo materials on the outdoor pedestrian heat stress was investigated for four cities by using the Canyon Air Temperature model (CAT, Erell and Williamson (2006)). The CAT model uses meteorological measurement data from nearby rural locations to compute the canyon air temperature, wind speed and radiative properties inside the urban canyon. Radiative properties are based on the sky view factor and H/W ratio of the canyon, while urban wind speed and air temperature are computed from empirical formulations. The CAT model was used to compute the effect of different albedo values on the local urban climate inside the street canyon. The output of this model was then used to compute the Index of Thermal Strain (ITS model, Pearlmutter et al. (2007)), which is a pedestrian heat stress parameter. The ITS model empirically relates the clothing insulation, humidity of air, wind speed and the thermal and solar radiative fluxes to the thermal comfort of a standing human in units of Watt. For example, Erell et al. (2014) found that although a high-albedo material can lead to lower air temperatures, it may also cause a higher value of the heat stress, which is due to the increase in reflected radiation that can reach the pedestrian. The thermal stress is decreasing with increasing H/W ratio, independent of the albedo that is used. To quote the authors: “The results of this study indicate that local benefits, in terms of pedestrian thermal comfort, are likely to be marginal at best and that high-albedo paving materials may actually increase thermal stress in warm environments.” (Erell et al., 2014).

1.1. Goals

The current research aims to take the study by Erell et al. (2014) one step further. Instead of assuming a uniform albedo for the entire canyon as Erell et al. (2014), a variety of adaptation measures are tested. A building resolving model, called URBSIM (Schrijvers et al., 2015), is used which computes radiative transfer, heat conduction into the urban material, and ventilation within the urban canyon at a 1 m spatial resolution. Temperature and wind in the canyon are computed at this resolution (compared to a single point in the study by Erell et al., 2014). The different adaptation measures include differentiation between the north-facing and south-facing walls and albedo gradients along the vertical walls. In this way the impact of using different albedo values on the air temperature, mean radiant temperature and the Universal Temperature Climate Index (UTCI, Fiala et al., 2012) can be studied.

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