Urban Climate 24 (2018) 175–184

Contents lists available at ScienceDirect

Urban Climate

journal homepage: www.elsevier.com/locate/uclim

The impact of increasing urban surface albedo on outdoor summer thermal comfort within a university campus☆

Mohammad Taleghani

University of Salford, Manchester, UK

ARTICLE INFO

Keywords:
Outdoor thermal comfort
Surface albedo
University campus
PET
Heat balance

ABSTRACT

The impact of increasing urban surface albedo on outdoor thermal comfort was studied in two phases:

Firstly, the thermal conditions of three locations with different ground surface materials were compared. The study used CFD modelling followed by a measurement campaign to validate the control simulation. It was observed that the physiological equivalent temperature (PET as the outdoor thermal comfort index) in the campus park (covered with grass) was 11.0 °C lower than the parking lot (paved with concrete) at 16:00 CET.

As the next step, the albedo of the roofs and walls were increased from 0.2 (control) to 0.3, 0.4, 0.5 and 0.6. It was found that increasing the albedo made the open space of the courtyard uncomfortable due to the higher reflectivity of high-albedo materials. An increase of every 0.1 albedo of the surfaces led to 1.2 °C higher mean radiant temperature, and consequently, 0.8 °C higher PET. The study also showed that the increase of albedo radiated more sun to the ground surface. This increased average ground surface sensible heat flux (6.7 W/m^2) and surface temperature (0.4 °C) during the day. This finding shows that the position and orientation of high albedo materials can significantly affect pedestrians' thermal comfort in urban open spaces.

1. Introduction

Outdoor thermal comfort has been studied recently due to the ongoing global warming. Several heat waves caused thousands of heat related mortality all around the world (Andersona and Bell, 2009). As a consequence, heat has become the first natural cause of mortality in the US and many countries (Kalkstein et al., 2013). Nowadays, most of the large cities deal with heat waves, even in cold climates like Moscow (Lokoshchenko, 2014). During the summer 2003, around 3000 heat related mortality were reported in the Netherlands (Robine et al., 2008). The higher air temperature in cities compared to suburbs is called the urban heat island phenomena (Oke, 2002; Rosenfeld et al., 1995). UHI affects energy consumption (Akbari and Matthews, 2012; Rodríguez-Álvarez, 2016; Santamouris et al., 2001; Ward and Grimmond, 2017), air quality (Li and Bou-Zeid, 2014; Taha et al., 1997) and peoples' health (Epstein and Moran, 2006; Metzger et al., 2010; Taleghani et al., 2016) in cities. This paper is focused on pedestrians' thermal comfort in outdoor environment where there is limited access to a cool spot or a cold drink. Thermal comfort is defined as "*that condition of mind which expresses satisfaction with the thermal environment*" (ISO-7730, 2005).Thermal comfort includes environmental factors (such as air temperature and wind speed), biological factors (such as age and gender), and physiological factors (such as clothing and metabolism) (Ali-Toudert and Mayer, 2007; Nicol et al., 2012; Taleghani, 2014).

☆ Portions of this paper has appeared in PLEA Conference 2017 in Edinburgh, Scotland.
E-mail address: m.taleghani@salford.ac.uk.

https://doi.org/10.1016/j.uclim.2018.03.001
Received 12 October 2017; Received in revised form 26 February 2018; Accepted 10 March 2018
2212-0955/

Table 1
Air temperature change in the Netherlands in 2050 and 2085 (retrieved from KNMI, 2015b).

Emission scenario	2050		2085	
	Lowest	Highest	Lowest	Highest
Mean temperature	+1	+2	+1.5	+3.5

1.1. Climate change in the Netherlands

The Netherlands, as a delta country, is affected by climate change. Climate change is contributing to rising sea levels, and this makes coastal cities vulnerable. The oldest weather station in the Netherlands is located in De Bilt. This weather data has been recorded since 1901. According to the historical data, the average air temperature has increased 1.4 °C between 1951 and 2013. This increase is twice the global average (KNMI, 2015b). The Royal Netherlands Meteorological Institute (KNMI), as the Dutch national weather service has produced four climate scenarios based on IPCC fifth report (IPCC, 2013) for 2050 and 2085. Based on these scenarios, air temperature increase for December, January and February (winter) is larger than March, April and May (spring). The temperature changes in the scenarios are briefly described in Table 1. Based on these future scenarios, urban spaces must be designed in a way to mitigate the impact of global warming on citizens' health. A practical way to make urban spaces ready for warmer futures is to adjust the albedo of surfaces. In the following section, the importance of high-albedo materials is explained.

1.2. Reflective pavements as a heat mitigation strategy

Heat mitigation strategies are generally referred to changing the land cover in a way to reduce solar absorption. It should be noted that to reduce the energy consumption in cities, several heat mitigation strategies researched and implemented in different climates and in various scales. However, few efforts and studies have addressed the impact of such heat mitigation strategies on outdoor thermal comfort.

Heat mitigation strategies are used to reduce net radiation from a system. In this paper, the system is a neighbourhood. In this case, net radiation is the balance between incoming and outgoing energy at the neighbourhood scale. Net radiation is calculated by Eq. (1):

$$R_n = H + LE + G \tag{1}$$

where; R_n is net radiation, H is sensible heat flux, LE is latent heat flux, and G is soil heat flux (all units are in W/m^2).

Erell (2017) divides heat mitigation strategies to cool roofs, cool pavements, and vegetation. This paper focuses on cool pavements, which in practice means to implement light coloured materials on the ground surface (Akbari et al., 2008; Kleerekoper et al., 2017; Taha, 2008; Taleghani, 2018; Zhang et al., 2017). These materials may reflect a large portion (depending on their albedo) of sun to the sky. In this way, high-albedo materials reduce H (sensible heat flux) in Eq. (1). Consequently, the system (neighbourhood) becomes cooler.

As most of the current urban spaces are covered with asphalt and concrete, solar radiation is absorbed (because of the low albedo) and trapped (because of the high heat capacity) in cities (Dan et al., 2014). In a large scale, white surfaces in Almeria (Spain) have made the air temperature of this city 0.3 °C cooler than its suburbs (Campra et al., 2008).

In a neighbourhood scale, Santamouris et al. (2012) studied the effect of adapting 4500 m^2 of high-albedo pavements on the local microclimate of a park in Athens. In a typical summer day, they observed that the air temperature was 1.9 °C reduced while the ground surface temperature showed 12 °C reduction. Similar to this study, Kyriakodis and Santamouris (2017) investigated the cooling effect of another large scale implementation of high-albedo materials in Wester Athens (37,000 m^2). They observed that their "*cool asphaltic and concrete pavements*" could reduce the air temperature and surface temperature by up to 1.5 °C and 11.5 °C, respectively.

There is a body of literature that shows the positive impacts of high-albedo materials on local microclimate and building energy use; however, a few studies have shown changing the albedo of the roofs may not affect near ground surface thermal conditions (Taleghani et al., 2016). Furthermore, Erell et al. (2014) showed that using high-albedo materials could reduce air temperature, but increased the heat stress of pedestrians. Therefore, more studies need to be done on the impact of high-albedo materials at the ground level on pedestrians' comfort.

To address this gap in the current knowledge on high-albedo materials, in this paper, pedestrian thermal comfort within a university campus will be studied through computer simulation. This phase of the study will be followed by a measurement campaign to validate the control simulations. As the next step, the impact of high-albedo materials at the roofs and walls of the university building on pedestrians' comfort will be investigated.

2. Methodology

This research investigated outdoor summer thermal comfort at (a specific part of) the campus of Delft University of Technology in The Netherlands. Computer simulations and field measurements have been carried out. The aim was to investigate the impact of high-