Urban Climate xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Urban Climate

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

The effect of pavement characteristics on pedestrians' thermal comfort in Toronto☆

Mohammad Taleghani [a,*], Umberto Berardi [b]

[a] University of Salford, Manchester, UK
[b] Ryerson University, Toronto, Canada

ARTICLE INFO

Article history:
Received 21 September 2016
Received in revised form 28 March 2017
Accepted 21 May 2017
Available online xxxx

Keywords:
Urban heat island
Pavements
Cool materials
Outdoor thermal comfort
Physiological equivalent temperature

ABSTRACT

Urban heat island (UHI) has proved to have an important effect in urban microclimate of large cities. In particular, the materials used for the pavements of urban spaces and sidewalks affect pedestrians' comfort significantly. Dark materials store solar radiation during the day and re-radiate it overnight. Reversely, cool materials, given their high albedo, are often proposed for mitigating UHI issues. This paper focuses on the effect on the outdoor thermal comfort of different materials in a main urban square in Toronto. The study is performed at the neighborhood scale, using the high resolution software ENVI-met. Simulations done for a summer heat wave in 2015 allowed predicting the maximum effect of pavements with surfaces having different albedo. The physiological equivalent temperature (PET) is used to assess the pedestrians' thermal comfort. The results show the relative effectiveness of different pavement materials. In particular, thermal comfort evaluations are reported to assess the microclimate benefits of bright marbles over black granites.

1. Introduction

Urban heat island (UHI) is known as the phenomenon that the air temperatures in city centers are higher than suburban (Oke, 2002). This is due to the lack of vegetation and water bodies in the city centers. Moreover, dark surfaces like asphalt pavements cover most of the roads, roofs and urban spaces. Recent studies have shown that the increasing of UHI in cold climates like Moscow (Lokoshchenko, 2014), Stockholm

☆ Portions of this paper has appeared in the 4th IC2UHI Conference in Singapore 2016.

* Corresponding author.
E-mail addresses: m.taleghani@salford.ac.uk (M. Taleghani), uberardi@ryerson.ca (U. Berardi).

http://dx.doi.org/10.1016/j.uclim.2017.05.007
2212-0955 © 2017 Published by Elsevier B.V.

(Thorsson et al., 2011), and Toronto (Berardi & Wang, 2016) has significant impacts on citizens' health and thermal comfort.

The combination of UHIs and heat waves have caused heat related mortality in different climates. During a 2-week heat wave in August 2003, around 70,000 mortalities were reported in Europe. Toronto Public Health Department has estimated 120 heat related mortality in Toronto per year (Penney, 2008). Furthermore, it is estimated that cooling degree days in Toronto will be increased by plus 239 by 2040 (WTO-UNEP, 2008).

Wang et al. (2016) showed that increasing the amount of street vegetation by at least 10% over the current density of green areas would have a large impact on of the UHI effect. Moreover, combining more vegetation with reflective pavements and roofs together, it would be possible to reduce the average air temperature by up to 0.8 °C at mid-day and 0.6 °C at mid-night during the hot summer days (Wang et al., 2016). This is in accordance with literature that has often proved that the man maid materials with low albedo, and the lack of vegetation and water bodies in urban spaces contribute to the urban heat islands (Hart & Sailor, 2009; Sailor, 2014; Taleghani et al., 2015; Taleghani et al., 2014b). Asphalt and concrete surfaces constitute around 40% of Canadian urban areas (Gui et al., 2007). Krayenhoff et al. (2003) showed that on average, Toronto is covered with 16.2% asphalt, and 13.7% concrete. Based on Table 1, asphalt and concrete pavements have low albedos. Consequently, increasing the albedo of these large portion of urban surfaces would be an appropriate strategy for mitigating the UHI effect, substituting dark materials covering urban surfaces with materials with high albedo has been often proposed worldwide (Hashem Akbari & Konopacki, 2004; Akbari et al., 2001; Synnefa et al., 2007).

Taha et al. (1992) simulated the impact of high albedo surfaces and vegetation in streets in Toronto and three other Canadian cities. They could show that by increasing the vegetative fraction by 30%, the building energy demand for cooling in Toronto would reduce by 10% in urban houses and 20% in suburban areas. Regarding the roof albedo, they showed that implementing 0.2 higher albedo surfaces can reduce the cooling-energy use by about 30–40%. More recently, Taleghani et al. (2014a, b) showed that white roofs (with the albedo of 0.91) increased the globe and mean radiant temperature (0.9 °C and 2.9 °C respectively) while the air temperature was reduced by 1.3 °C compared to a dark pavement (albedo of 0.37) in the temperate climate of Portland (OR, USA).

Santamouris et al. (2012) looked at the impact of 4500 m^2 high albedo materials on the pavement of a park in Athens, Greece. This size of land surface modification to improve pedestrians' thermal comfort is among the largest in the world. They reported that this amount of cool pavements reduced the peak ambient air temperature by up to 1.9 °C, and the ground surface temperature was reduced by 12 °C.

Recently, several studies have been performed to investigate the cooling impact of water spray systems and water ponds on urban open spaces. As an example, Montazeri et al. (2017) used a high resolution CFD model to show the cooling potential of a water spray system on outdoor thermal comfort of pedestrians in Rotterdam, the Netherlands. They showed that the water spray with 15 hollow-cone nozzles could reduce the air temperature and thermal comfort unit (UTCI) by up to 7 and 5 °C, respectively during a heat wave in July 2006. In another study in Shanghai, measurement was done on the spray cooling technology to a pavilion. Similar to the results in the Netherlands, Huang et al. (2011) also showed that the air temperature could be reduced up to 7 °C while the ambient air temperature is 35 °C with the relative humidity of 45%.

In this paper, the microclimate of one of the most important urban open spaces in Toronto is studied. The square is covered with a black pavement, and a small water pond exists in there. The simulations were done for the hottest day of 2015 in Toronto. Most of the previous studies on pavement characteristics were done on building roof tops; however, modification of roofs can barely affect pedestrians in city centers with high-rise buildings (Taleghani et al., 2016). So, this paper focuses on ground pavement, and answers to the question

Table 1
The albedo of common urban surface materials (Baker & Canada, 1980; Bretz et al., 1992; Oke, 1987; Santamouris, 2012).

Material	Albedo
Asphalt	0.05–0.2
Concrete	0.10–0.35
Red brick	0.30
White marble chips	0.55
Gravel	0.72
White plaster	0.93

Please cite this article as: Taleghani, M., Berardi, U., The effect of pavement characteristics on pedestrians' thermal comfort in Toront..., Urban Climate (2017), http://dx.doi.org/10.1016/j.uclim.2017.05.007