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Original article

Influence of changing trees locations on thermal comfort on street parking lot and footways

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ABSTRACT

Locations of trees in street parking lots (SPL) impact outdoor thermal comfort and should be considered during the urban planning process. In this paper we developed a procedure for changing trees locations in order to improve outdoor thermal comfort on SPL and associated footways. Furthermore, a sensitivity test on the effect of different tree crown shapes on outdoor thermal comfort was carried out. We applied theprocedure on real-world SPL design in the City of Novi Sad (Serbia). A temporal analysis is performed for the heat wave period using Universal Thermal Climate Index (UTCI) calculations in the Ladybug software.

The results showed improvement of outdoor thermal comfort on 77 % of all body locations in proposed SPL design with predetermined number of trees. The largest outdoor thermal comfort improvement was noticed in the afternoon hours with up to 3.3 °C UTCI decrease on single body location. By adding trees to the SPL, heat stress was reduced on 84 % of all body locations with maximal UTCI decrease of 3.7 °C on single body location. Furthermore, heat stress reduction by cylinder-shaped tree crowns showed to be more pronounced compared to the sphere-shaped and the cone-shaped tree crowns. Proposed procedure showed that the locations of trees as well as tree crown shapes are very important for the improvement of outdoor thermal comfort and creation of environmentally conscious SPL design.

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1. Introduction

Parking areas are associated with higher air temperatures (T) (Aniello et al., 1995; Ca et al., 1998) as a consequence of its artificial impervious surface and lower proportion of vegetation cover. In order to improve outdoor thermal comfort at parking areas, usage of vegetation is recommended. Urban vegetation reduces parking space temperature during summer months (Akbari et al., 1997; Asaeda et al., 1996) leading to more comfortable open urban spaces (Gillner et al., 2015; Klemm et al., 2015; Mullaney et al., 2015). This is a consequence of the influence of vegetation canopies that cool microclimates by direct shading of the ground surface (Lee, 1978; Oke, 1987). For example, the tree crown can prevent up to 95% of incoming radiation (Akbari et al., 1992). Studies showed that the shading and cooling potentials of parking lot trees are determined by size, growth and spatial arrangement (Bajsanski et al., 2016; Beatty, 1989; National Arbor Day Foundation, 1995; Scott et al., 1999; Simpson, 2002).

Noticeable share of the city areas are covered by parking lots occupying from 7% to 30% of its surface (Akbari et al., 1992; Kishii, 2015; McPherson, 2001; Nakamura et al., 2007; Willson, 2013; Wolf, 2004). In the City of Novi Sad (Republic of Serbia), 8% of the area is covered by parking lots. Increase in the number of parking lots is planned for the City in the future in order to fulfill the needs of its growing population (Public Enterprise JP Urbanizam, 2016). In order to improve outdoor thermal comfort, parking lot shading ordinances in cities require up to 50% tree shading over the total paved area (McPherson, 2001). Researchers investigated the influence of trees species (de Abreu-Harbich et al., 2015; Shahidan et al., 2010), growth (Picot, 2004) and changing tree numbers (Andreou, 2013; Taleghani et al., 2016; Yahia and Johansson, 2014) on outdoor thermal comfort in urban areas. The lack of studies on the influence

Abbreviations: UTCI, universal thermal climate index; SPL, street parking lot; *T*, air temperature; RH, relative humidity; *v*, wind speed; *g*, longwave and shortwave radiation fluxes; UTC, universal time coordinated; LCZ, local climate zone; HRE, height of roughness elements; SVF, sky view factor; BSF, building surface factor; ISF, impervious surface factor; PSF, pervious surface factor; ALB, albedo; WRF, weather research and forecasting; NOAA/NCEP GFS, National Oceanic and Atmospheric Administration/National Centers for Environmental Prediction Global Forecast; .epw file, Energy Plus weather data; SAMRT, solar adjusted mean radiant temperature.

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Fig. 1. Location of Serbia and Novi Sad.

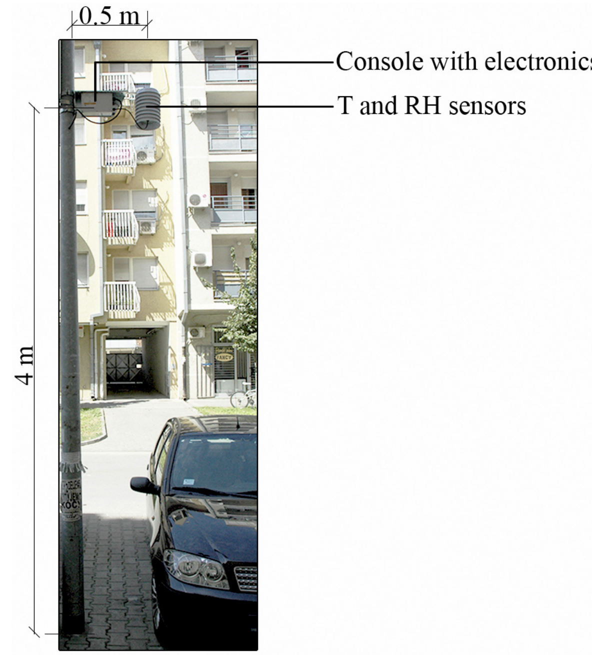

Fig. 2. Measurement station 2–1 mounted on a lamppost in the investigated street.

of changing locations of predetermined number of trees on outdoor thermal comfort in SPL and footways is evident.

The aim of this paper is to propose a procedure for changing trees locations in order to improve out door thermal comfort on SPL and associated footways. The approach takes into consideration weather factors, street orientation, surrounding buildings, simplified tree geometry as well as parking spots, tree is lands and trees location and number. The potential of the procedure is illustrated through the analysis of outdoor thermal comfort on typical street parking segment taken from the literature and on real-world SPL with predetermined and added number of trees. We compared the outdoor thermal comfort on present SPL and footways design with the designs provided by the procedure created in this paper. Heat wave period was chosen for the analyses when the improvement of outdoor thermal comfort is necessary.

2. Study area and weather database

2.1. Study area and urban climate monitoring network

Novi Sad is located in the northern part of the Republic of Serbia (45°15′ N and 19°50′ E) (Fig. 1) on a plain relief (80 and 86 m a.s.l.). It is the second largest metropolitan region in Serbia with a population of 340.000 and urban area of 112 km^2 (Šećerov et al., 2015). The city is characterized by Cfb climate (temperate climate, fully humid, and warm summers, with at least four $T_{mon} \geq +10$ °C) according to the Köppen–Geiger climate classification (Kottek et al., 2006). The mean annual T in Novi Sad is 11.2 °C, with an annual range of 22.1 °C. The coldest month is January (−0.4 °C), and the warmest month is July (21.7 °C) (based on data from 1949 to 2013) (Bajšanski et al., 2015).

Urban climate monitoring network and online information system regarding spatial distribution of T, relative humidity (RH) and human thermal comfort conditions in Novi Sad were developed in 2013–2014. The activities were funded by the EU project. The network consists of 27 stations located in different areas of the city (i.e. residential area, industrial area, etc.) and its surroundings (i.e. fields and forest) (Unger et al., 2014). The measurement stations consist

Table 1
UTCI assessment scale (International Union of Physiological Sciences – Thermal Commission, 2003).

UTCI [°C] range	Stress category
Above +46	Extreme heat stress
+38 to +46	Very strong heat stress
+32 to +38	Strong heat stress
+26 to +32	Moderate heat stress
+9 to +26	No thermal stress
+9 to 0	Slight cold stress
0 to −13	Moderate cold stress
−13 to −27	Strong cold stress
−27 to −40	Very strong cold stress
Below −40	Extreme cold stress

of *T* and RH sensors in a radiation protection shield. The accuracy of the *T* sensor is ±0.3 °C and for RH sensor is ±2%. Sensors are developed and calibrated by the General Electric Measurement & Control Company. Stations were installed at 4 m above the ground on 0.5 m long arms set to lampposts. Inside the station console are processor, data storage, modem, battery and charger. Stations measure the data every minute and send average values of *T*, RH and technical information to the server every 10 min. The stations times are in Universal Time Coordinated (UTC) and are synchronized by the server placed at the University of Novi Sad, Faculty of Science. Central European Summer Time is 2 h ahead of UTC and is used in Novi Sad. Analysis of outdoor thermal comfort was performed for the street in which measurement station 2–1 is located (Fig. 2).

2.2. Outdoor thermal comfort index

In order to assess outdoor thermal comfort conditions, UTCI (Table 1) is calculated. The UTCI is defined as T of the reference condition causing the same model response as the actual conditions (Błażejczyk et al., 2010; Fiala et al., 2012). This thermal comfort index is a one-dimensional quantity that summarizes the interaction of *T*, RH, wind speed (v) and long wave and short wave radiation fluxes (g) (Bröde et al., 2012a). Accordingly, *T*, RH, v and g were used in the UTCI calculation. The equation for UTCI calculation is a 200-term polynomial approximation across all of the data points that

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