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ANALYSIS OF HUMAN THERMAL COMFORT IN CENTRAL EUROPEAN CITY DURING SUMMER OF 2015: A CASE OF NOVI SAD (SERBIA)

Abstract: Urban meteorological network (UMN) was established in the Central European City of Novi Sad (Serbia) based on "local climate zones" (LCZs) system. Physiologically Equivalent Temperature (PET) index was used for the assessment of outdoor thermal comfort in the "built" and "land cover" LCZ classes of Novi Sad. The index was calculated in the RayMan software based on the meteorological, physiological as well as building and vegetation data. Temporal analysis was performed for extreme heat stress days (PETmax ≥ 41 °C), extreme heat stress hours (PETav ≥ 41 °C) and days with occurrence of "tropical nights" (Tmin > 20 °C) during exceptionally hot summer of 2015. Our results show that extreme heat stress hours are the least frequent in compact midrise LCZ 2, followed by dense trees LCZ A. On the contrary, countryside (low plants - LCZ D) showed to be the most uncomfortable area during daytime followed by compact low-rise areas (LCZ 3). Tropical nights are the most frequent in midrise LCZs 5 and 2 (40-46 nights) and decreasing towards open, sparsely built and natural LCZs (6-8 tropical nights in LCZs A and D). This is almost 800% decrease and it has implications for health and recreation of urban population and emphasizes the need for UMN development based on LCZ system.

Key words: outdoor thermal comfort, PET, Extreme Heat Stress, tropical nights, RayMan

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Introduction

Urban areas are not uniform in their structure, yet often heterogeneous with zones of the city devoted to different human needs and consequently with different architectural solutions applied (e.g. downtown, residential areas, industrial zones, etc.). Climatic conditions (Lau et al., 2019), urban design and morphology (Bajšanski et al., 2015; Milošević et al., 2017; Paramita & Matzarakis, 2019; Bajšanski et al., 2019) and personal characteristics (Gulyás et al., 2006; Lenzholzer & van der Wulp, 2010) have different thermal, radiative, moisture and aerodynamic properties in the urban areas and can modify the atmospheric processes that occur above them, thus creating a specific type of "urban" climate different from surrounding, regional climate (Oke, 1987). In order to analyse climate characteristics of different urban zones, one option is to develop urban meteorological network (UMN) that will measure the basic climate elements (e.g. air temperature and humidity, wind speed, global radiation, etc.) inside them. Another option is to use satellite data that usually have good spatial, yet poor temporal resolution.

Development of UMN in Novi Sad (Republic of Serbia), called as Novi Sad Urban Network (NSUNET) started in 2013 as part of an EU-founded project (URBAN-PATH, http://en.urban-path.hu). The city of Novi Sad and its surrounding was mapped using "local climate zone" (LCZ) classification system that enables the classification of urban and rural landscape into ten "built" and seven "land cover" classes with different surface structure and land cover properties. Even though, the LCZ classification system was primarily designed to provide a framework for reporting and comparing field measurement sites and their temperature observations in urban areas and their surroundings (Stewart & Oke, 2012) it showed to be practical for the development of new UMNs (Unger et al., 2011). Consequently, LCZ classification system was used for the mapping of Novi Sad with the application of GIS based Lelovics-Gál method (Lelovics et al., 2014). "Built" and "natural" LCZs of Novi Sad were delineated and air temperature (Ta) and relative humidity (RH) sensors were installed at 27 locations inside them.

The main purpose of the developed UMN is to provide real time data about temperature, humidity and thermal comfort conditions in different areas of the city. Thermal comfort is defined as "that condition of mind which expresses satisfaction with the thermal environment" (ASHRAE, 1966; ISO-7730, 1984) and is influenced by environmental and behavioral factors (Fanger, 1970). It is clear that outdoor thermal comfort is particularly relevant during heat waves. Climate projections demonstrate that heat waves will occur more frequently and will become more severe in Europe (Fischer & Schär, 2010; Jacob et al., 2018). Outdoor human thermal comfort in Novi Sad was assessed (Dunjić, 2019) using hourly values of Physiologically Equivalent Temperature (PET) index (Höppe, 1999) calculated in RayMan model (Matzarakis et al., 2007) that takes into account the meteorological, physiological as well as building and vegetation data.

The aims of this study are to analyze outdoor human thermal comfort conditions in different "LCZs" of Novi Sad during extreme heat stress days (PETmax ≥ 41 °C), extreme heat stress hours (PETav ≥ 41 °C) and days with occurrence of "tropical nights" (Tmin > 20 °C) in summer of 2015. The results will uncover thermal differences between "built" LCZs as well as between "built" and "land cover" LCZs during daytime and nighttime period.

Study area, data and methods

Geographical characteristics of the study area

Study area is the City of Novi Sad and its hinterland located in the northern part of the Republic of Serbia (45° 15' N, 19° 50' E) in Central Europe. City is located on plain relief, except for southern suburbs located on the slopes of low Fruška gora Mountain. The Danube River flows by the southern edge of the city area and separates it from the Fruška gora Mountain. In the north-eastern part of the city flows narrow Danube-Tisza-Danube Canal that is connected to the Danube River. According to the Köppen-Geiger climate classification (Kottek et al., 2006), the city is located in the area of temperate climate, fully humid with warm summer and at least four months with air temperature ≥ 10 °C (i.e. Cfb climate). The mean monthly Ta in Novi Sad ranges from -0.3 °C (January) to 21.8 °C (July) with mean annual precipitation of 623 mm for the period 1949-2015. Novi Sad is the second largest city in Serbia with the population of 330,000 (data from 2019) living in built-up area of 102 km^2.

"Local Climate Zones" and the Urban Meteorological Network in Novi Sad

Two different GIS-based LCZ mapping methods were applied for the city of Novi Sad until now: Lelovics-Gál (Lelovics et al., 2014) and Geletič and Lehnert method (Geletič & Lehnert, 2016). Both applied methods defined and delineated 13 LCZs in Novi Sad and its surroundings: 7 "built" and 6 land cover' types. Delineated "built" LCZs are: compact midrise (LCZ 2), compact low-rise (LCZ 3), open midrise (LCZ 5), open low-rise (LCZ 6), large low-rise (LCZ 8), sparsely built (LCZ 9) and heavy industry (LCZ 10). Delineated "land cover" LCZs are: dense trees (LCZ A), scattered trees (LCZ B), low plants (LCZ D), bare rock or paved (LCZ E), bare soil or sand (LCZ F) and water (LCZ G). Outcomes of both methods (i.e. defined LCZs) were reviewed and validated during field works and with the usage of the local urban climate experts' knowledge. LCZs with larger area have larger number of measurement sites inside them, while the opposite is for smaller LCZs. Measurement sites of UMN in Novi Sad are defined inside homogenous LCZs based on Lelovics-Gál method (Lelovics et al., 2014), at least 250 m from their delineated borders.

Air temperature (Ta) and relative humidity (RH) sensors are located on lampposts due to their need for power supply and at 4 m height due to the security reasons. In order to provide data on wind speed (v) and global radiation (g), one automatic weather station (PMF-1) is installed on the roof of the Faculty of Sciences in Novi Sad at 35 m height. This NSUNET stations system is equipped with Ta and RH sensors (ChipCap2) in naturally ventilated radiation screens (200 × 240 mm). Fully calibrated sensors are obtained from the General Electric Measurement & Control Company with the accuracy of the Ta sensor of ±0.3 °C, and that of the RH sensor of ±2% (20% - 80% RH) (Šećerov et al., 2019). The sensors and accompanying equipment were connected to lamp post via 0.5 m long arms. The sensors in urban areas are located four meters above the ground and in rural areas they are located at two meters above the ground. We assume that Ta measured at 2 m and 4 m have nearly equal values based on the work by Nakamura & Oke, (1988). The stations are activated each minute to perform measurements and each 10 minutes they send the averaged 10-minutes readings to the server. Stations use Universal Time coordinated (UTC) as the system time, which is synchronized with the server (Šećerov et al., 2015).

Thermal indices and applied methods

Outdoor human thermal comfort in "built" and "land cover" LCZs of Novi Sad was assessed using hourly values of Physiologically Equivalent Temperature (PET) index (Höppe, 1999) calculated in RayMan model (Matzarakis et al., 2007). Temporal analysis was performed for extreme heat stress days (PETmax ≥ 41 °C; that represents maximum measurement value within 24 hours), extreme heat stress hours (PETav ≥ 41 °C; that represents the daily average value based on 24 daily measurement) and days with occurrence of "tropical nights" (Tmin > 20 °C; that represents value during the nighttime) during summer period of 2015 (June-August). Summer of 2015 was exceptionally hot with 2.2 °C above long-term average (1981-2010). These indices were chosen in order to access extreme heat stress conditions in "LCZs" during daytime (daily PETmax ≥ 41 °C, hourly PETav ≥ 41 °C) and nighttime period (Tmin > 20 C). Selected days were characterized by prevailing anticyclonic conditions and lack of clouds.

The calculation of PET takes into account meteorological (Ta, RH, v, g – using hourly measurements from NSUNET) and physiological data (level of clothing, metabolic rate, age, weigh – using standard values from RayMan software). Previously, environment around measurement sites (i.e. geometrical characteristics of buildings and trees) were modeled in RayMan. Ta and RH data were obtained from 27 measurement sites, while v data was obtained from automatic weather station (PMF-1). Roughness Mapping Tool (Gál & Unger, 2009) was used for the calculation of v correction factors for all measurement sites. Firstly, the v values were modeled on 2 m heights for PMF-1 station, and in the next step this new v value was calculated for other measurement sites. Global radiation was calculated in RayMan model taking into account the influence of the surrounding environment. Obtained results are presented in Local Standard Time (Central European Summer Time) for Serbia during summer which is UTC + 2h.

Results and discussion

Obtained results from this study suggest that different LCZs have different outdoor thermal comfort conditions in Novi Sad. Good indicators of this are days and hours with extreme heat stress occurrence. Number of days with PETmax ≥ 41 °C is increasing from LCZ 9 (38 days) towards LCZ 3 (47 days). In the countryside are noticed maximum and minimum numbers of extreme heat stress days, i.e. 34 days in LCZ A and 48 days in LCZ D (Fig. 1). The thermal comfort differences between "LCZs" are even more pronounced when analysing number of hours with PETav ≥ 41 °C. The "urban canyons" of LCZ 2 have the smallest number or extreme heat stress hours (138 hours) within research area, even less than LCZ A (144 hours). Countryside (LCZ D) showed to be the most uncomfortable area during daytime with 259 extreme heat stress hours followed by open low-rise areas (LCZ 3) with 233 extreme heat stress hours (Fig. 1). In our previous study (Milošević et al., 2016), we compared average PET values during heat wave period in different "LCZs" of Novi Sad and obtained similar results with strongest heat stress noticed in LCZs 5, D and 3 during daytime. As the urban population in Europe is projected to increase in the future (UN, 2014) as well as heat wave frequency and intensity due to climate change (Schar et al., 2004), the influence of heat stress on mortality in urban areas could increase, especially without adaptation measures.

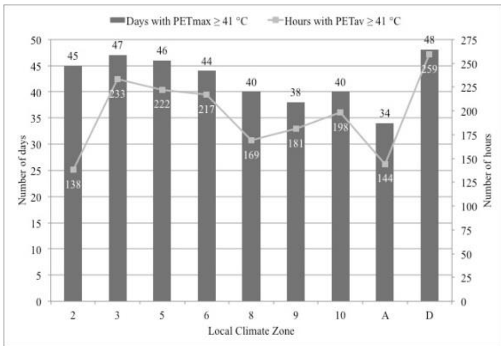

Fig. 1. Number of days with PETmax ≥ 41 °C and number of hours with PETav ≥ 41 °C in 'LCZs' of Novi Sad (June-August 2015)

Study of Muthers et al. (2010) showed that the heat-related mortality could increase up to 129% until the end of the 21st century in Vienna, if no adaptation takes place. The strongest heat-related mortality increase occurred due to the increase in extreme heat stress days (PET ≥ 41 °C). Therefore, it is important to obtain detailed spatial and temporal information about human biometeorological conditions in different LCZs and provide them to city planners and health institutions in order to develop mitigation and adaptation measures for the future.

Tropical nights are important indicator of human thermal comfort during nocturnal period. When Ta remains above 20 °C during night, high thermal load is experienced by population leading to their discomfort and lack of rest. Our results showed that the number of tropical nights decreases from the midrise "LCZs" towards low-rise, heavy industry, sparsely built and natural "LCZs". The LCZs 5 and 2, as the most urbanized parts of Novi Sad, experience 40-46 tropical nights and that is double compared to LCZ 9 (sparsely built) representing the city outskirts. The influence of urbanization on climate in Novi Sad is even more noticeable by the fact that "land cover" LCZs (A and D) have 6-8 tropical nights, which is almost 800% decrease from city downtown towards countryside (Fig. 2). Observed differences, for example, are in accordance with the results of the study of of Lelovics et al. (2016) for Novi Sad and Szeged (Hungary), Skarbit et al. (2017) for Szeged (Hungary) and Müller et al. (2014) for Oberhausen (Germany) who clearly noticed that the number of tropical nights increases with the density of the built environment and decreases with the fraction of green surfaces and pervious cover.

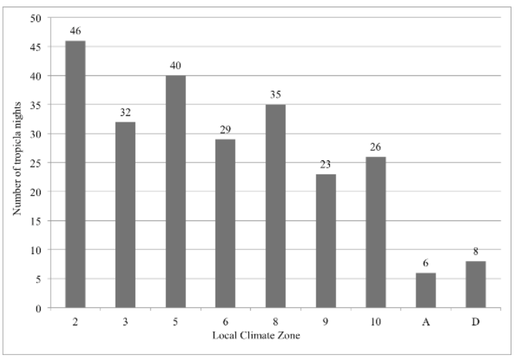

Fig. 2. Number of tropical nights (Tmin > 20 °C) in 'LCZs' of Novi Sad (June-August 2015)

Conclusions

In this study, the outdoor human thermal comfort was investigated in different "LCZs" of Central European City of Novi Sad during hot summer of 2015. Our results showed substantial differences of thermal comfort conditions in "LCZs" classes during extreme heat stress days and tropical nights. For example, the difference in number of heat stress hours between "built" LCZs is by 95 (ΔPETLCZ3-LCZ2) and by 121 between 'land cover' and "built" LCZs (ΔPETLCZD-LCZ2). This is mainly a consequence of different insolation/shading patterns of individual measurement sites during daytime. In the nighttime, we noticed that tropical nights are more frequent in midrise LCZs, followed by low-rise LCZs. This is a problem for the population of Novi Sad that mainly lives in these areas and their health and recreation is adversely affected by noticed thermal conditions. Therefore, our results can be useful for urban government and city planners in tackling this problem in the future.

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АНАЛИЗА ЉУДСКОГ ТЕРМАЛНОГ КОМФОРА У ЦЕНТРАЛНО ЕВРОПСКОМ ГРАДУ ТОКОМ ЛЕТА 2015. ГОДИНЕ: СТУДИЈА СЛУЧАЈА НОВИ САД (СРБИЈА)

Резиме: У овој студији представљене су анализе и резултати везани за услове спољашњег термалног комфора људи у урбаним срединама на примеру Новог Сада (Србија). Анализе термалног комфора базиране су на принципу "локалних климатских зона" (енг. LCZs), односно целокупна урбана зона Новог Сада је дефинисана на основу различитих типова изграђености. На основу тога, главни циљеви рада су анализе спољашњег термалног комфора у различитим LCZs, и то (1) током дана са екстремним топлотним стресовима (PETmax ≥ 41 °C), затим (2) сати са екстремним топлотним стресовима (PETav ≥ 41 °C), и (3) данима са појавом тропских ноћи (Tmin > 20 °C), током летњих месеци 2015. године. Истовремено, резултати треба да открију топлотне разлике између различитих типова урбанизације унутар урбане зоне Новог Сада, као и разлике између урбанизованих и природних зона (у окружењу Новог Сада) током обданице и ноћи.

Улазни подаци за израчунавање спољашњег термалног комфора на основу класификације LCZs за летњи период 2015. године су: (1) метеоролошки подаци са урбане мреже Новог Сада (NSUNET мрежа) која садржи 10-минутна мерење температуре ваздуха, релативне влажности, ветра и радијације; (2) класификација LCZ базирана на GIS методама, које су креиране од стране Lelovics-Gál метода (Lelovics et al., 2014) и Geletič/Lehnert метода (Geletič & Lehnert, 2016). На основу наведених метода мапирања, у Новом Саду је дефинисано 13 урбанизованих и природних зона; и (3) за калкулацију спољашњег термалног комфора коришћен је физиолошки индекс еквивалентне температуре (PET).

Наведени термални индекс је израчунат у софтверу RayMan на основу метеоролошких, физиолошких, као и података о зградама и вегетацији. Резултати наведени у овој студији показују да су PETav ≥ 41 °C најмање учестала у LCZ 2 (зона компактне урбанизације са зградама од 3 до 10 спратова), а потом LCZ A (шумска подручја са густим засадима дрвећа). Супротно томе, LCZ D (пољопривредне површине и ниско растиње) зона се показала као термално најнекомфорније подручје, а прати га LCZ 3 зона (зона компактне ниске градње, до 3 спрата). Тропске ноћи су најфреквентније у LCZ 5 (зона отворене урбанизације са зградама од 3 до 10 спратова) и LCZ 2, са 40 до 46 тропских ноћи. Овакви резултати показују смањење за скоро 800% у односу на најурбанизованије средине, и то највероватније узрокује импликације на здравље и рекреацију градског становништва и наглашава потребу за даљим развојем урбаних метеоролошких мрежа за метеоролошки мониторинг, које би биле засноване на LCZ систему.