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Bioclimatic Analysis of External Thermal Comfort in Local Climate Zones of Novi Sad During the Summer

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A B S T R A C T

The topic of the paper is the bioclimatic analysis of external thermal comfort in the local climate zones of Novi Sad during the summer. Based on the value of the index of physiological equivalent temperature (PET), differences in local climate zones during different periods were quantified. The obtained results showed that the biggest differences in PET values occur between local climate zone 2 and local climate zone A. Also, the values decrease going from the central to the peripheral parts of the city. LCZ 2 is the most uncomfortable and LCZ A is the most comfortable.

Keywords: Novi Sad, urban climate, thermal comfort, local climate zones

1. Introduction

The term "urban heat island" indicates that cities are warmer, ie. have higher air temperatures compared to their natural or rural environment. This phenomenon arises as a consequence of human changes in surface and atmospheric properties and processes accompanying urban development (Oke, 1995). The phenomenon got the name "island" because the isothermal values above the city are higher than the isothermal values of the colder environment, which represents a "sea" of colder air. Consequently, the heat island is defined based on the differences in air temperature between urban and natural or rural environments (Oke, 1995).

Modern bioclimatic research focuses on the study of direct connections between the atmosphere and the human organism, so for the purposes of such research, the so-called "bioclimatic conditions".

External thermal comfort is defined in the ASHRAE Standard (ASHRAE, 2010) as "a state that expresses the thermal comfort of a person in a built or unbuilt environment, and is assessed by subjective evaluation." The definition is accepted at the international level and determines six basic factors that must be taken into account when defining the conditions for thermal comfort: metabolism, level of clothing, air temperature, mean radiation temperature, wind speed, and relative humidity.

Local climate zones (LCZs) represent parts of the city and its surroundings with a specific type of substrate (e.g. asphalt, natural soil), structure (height of buildings and the space between them), materials (concrete, glass, earth, etc.) and human activities (traffic, industry, housing) that extend from several hundred meters to several kilometers in the horizontal scale. As a result, specific microclimatic conditions are expected in different LCZs, which have arisen as a result of changes in the regional climate under the influence of urbanization. 17 LCZ have been defined, 15 of which are based on the structure and properties of the surface cover, and two based on construction materials and anthropogenic heat release. Ten LCZs belong to the so-called "built types" and 7 LCZ belong to the so-called "unconstructed types" or "natural types" (Stewart and Oke, 2012).

The main goal of the research carried out in the paper is the analysis of external thermal comfort in different parts of the city, i.e. local climate zones. The outcome should show whether local climate zones have different indicators and if they do, that these indicators should be quantified.

2.Methodology

2.1 Methods for the analysis of the external thermal comfort of a person

So far, over 100 different indices have been developed that can be used to evaluate the impact of bioclimatic conditions on the human body. These models simulate the occurrence of heat exchange between man and his environment, taking into account anatomical, physiological, and meteorological parameters. One of the most commonly used bioclimatic indices today is the Physiologically Equivalent Temperature (PET) index, which contributes to a better knowledge of bioclimatic conditions both at the level of regional assessments and in local climate research. In addition to the PET index, the UTCI index or the universal thermal climate index (Universal Thermal Climate Index - UTCI) is most commonly used to determine the conditions of human thermal comfort (Lukić et al. 2019).

2.2 Database

The database based on which the calculations and analyzes were performed includes the time series of 2 seasons (201-2016). PET values were calculated for all local climate zones, and at the seasonal (summer) level.

The input data used by the model are hourly values of air temperature, relative air humidity, wind speed, and solar radiation. Considering that solar radiation is not equal on the earth's surface and especially in urban areas, a correction of the solar radiation was made where the modeled buildings and vegetation around the stations were taken into account. The physiological characteristics of the man, as well as his level of clothing, were entered into the model. All the mentioned factors influence the subjective thermal sensation and the level of physiological stress that people feel in the environment, which is expressed by the values of the mentioned PET index (Table 1).

Table 1 - Threshold values of the Physiological Equivalent Temperature (PET) index for subjective thermal sensation and the level of human physiological stress

PET (°C)	Subjective thermal sensation	Human physiological stress level
< 4	Very cold	Extreme cold stress
4-8	Cold	Strong cold stress
8-13	Moderately cold	Moderate cold stress
13-18	Slightly cold	Slight cold stress
18-23	Comfortable	No thermal stress
23-29	Moderately warm	Slight heat stress
29-34	Warm	Moderate heat stress
34-41	Hot	Severe heat stress
41 <	Very hot	Extreme heat stress

Source: (Matzarakis, A. and Mayer, H. 1996)

3. Local climate zones in Novi Sad

The urban climate monitoring system was established in Novi Sad in 2014 based on the classification system of Local Climate Zones (LCZ), calculation of GIS models, and fieldwork. Seven built and two types of unbuilt areas are defined, and 27 stations are equipped with temperature and relative humidity sensors distributed throughout all LCZ (Milošević et al. 2016). Using the developed GIS methodology, 13 LCZs were defined on the territory of Novi Sad and its surroundings: seven constructed LCZs and six natural LCZs. Built LCZ is: compact medium construction (LCZ 2), compact civil engineering (LCZ 3), open medium construction (LCZ 5), open civil construction (LCZ 6), large civil construction (LCZ 8), sparse construction (LCZ 9) and heavy industry (LCZ 10). Natural LCZs include densely distributed trees (LCZ A), sparsely distributed trees (LCZ B), bushes (LCZ C), low vegetation (LCZ D), and water (LCZ G). The largest part of the city includes LCZ 6 with 42.3% of the area, followed by LCZ 5 (15.1%) and LCZ 9 (13.0%). In Novi Sad, LCZ 10 and LCZ 3 are the least represented with around 5% of the area (Milošević 2018).

4. Analysis of external thermal comfort during the summer of 2015-2016.

Within this section, the absolute maximum, absolute minimum, and mean values for the two summers of 2015-2016 will be analyzed. at the level of daylight and nighttime for all LCZ. Since the database contains PET values for all summer months only for the measurement years 2015 and 2016, in this section the data are processed only for these two seasons. If we compare the summer of 2015 and 2016 at the day and nighttime level, it is evident that the summer of 2015 has higher PET index values compared to 2016, by 0.8 °C during the day and 1.2 °C during the nighttime (figure 1).

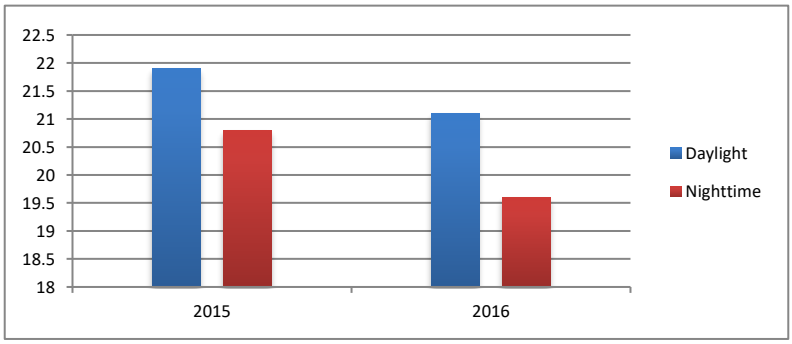

Fig. 1 - PET index values for the 2015 and 2016 seasons at the daylight and nighttime levels for all LCZ

Table 2 contains data on the absolute maximum, minimum, and mean values at the level of daylight and nighttime for the period 2015-2016. When analyzed in more detail, the following can be established: the highest mean values during the day and nighttime were recorded in LCZ 2 (23.6 °C and 23.4 °C) and the lowest in LCZ A (20.2 °C and 17.7 °C). The absolute maximum during the day is in LCZ 2 (34.2 °C) and during the nighttime also in LCZ 2 (32.6 °C). Absolute minimum values were recorded both during the nursery and the nighttime in LCZ A (9 °C during the nursery and 10 °C during the nighttime).

Table 2. Mean, absolute maximum, and absolute minimum values of PET index in LCZ Novi Sad for daylight and nighttime (season 2015-2016) Red numbers - highest values of PET index; blue color - the lowest values

***PET* (°C)**		**LCZ 2**	**LCZ 3**	**LCZ 5**	**LCZ 6**	**LCZ 8**	**LCZ 9**	**LCZ A**
Middle value	Daylight	23.6	22.6	21.7	21.0	22.3	21.1	20.2
	Nighttime	23.4	20.4	20.5	19.2	21.3	18.9	17.7
Max. value	Daylight	34.2	32.7	31.9	31.2	33.3	31.4	31.5
	Nighttime	32.6	30.2	29.8	29.8	30.8	28.9	27.7
Min. value	Daylight	14.2	11.4	11.6	9.9	12.0	9.6	9.0
	Nighttime	15.3	12.1	12.3	10.4	12.9	10.6	10.0

PET values for the seasons 2015 and 2016 at the daylight level when it comes to urban and natural local climate zones, show the biggest differences between LCZ 2 and LCZ A, by 3.4 °C. The smallest differences are between LCZ 6 and LCZ A (0.8 °C). When it comes to urban zones, the biggest differences are between LCZ 2 and LCZ 6 (2.6 °C), and the smallest between LCZ 6 and LCZ 9 (0.1 °C) (Fig 2a).

PET values for the 2015-2016 season. at the nighttime level, they show more pronounced differences than at the nursery level. The biggest differences are between LCZ 2 and LCZ A by as much as 5.7 °C, which is a significant difference considering the relatively small distance between these two zones of 4.7 km as the crow flies (Google Earth). Such a large difference can be explained by the different thermal capacity of the substrate, i.e. the higher heat radiation in the undeveloped urban area as opposed to the built-up area. The smallest differences during the nighttime are between LCZ 9 and LCZ A (1.2 °C). When it comes to urban zones, LCZ 2 and LCZ 9 show the greatest contrasts (4.5 °C), and LCZ 3 and LCZ 5 show the least (only 0.1 °C) (Fig. 2b).

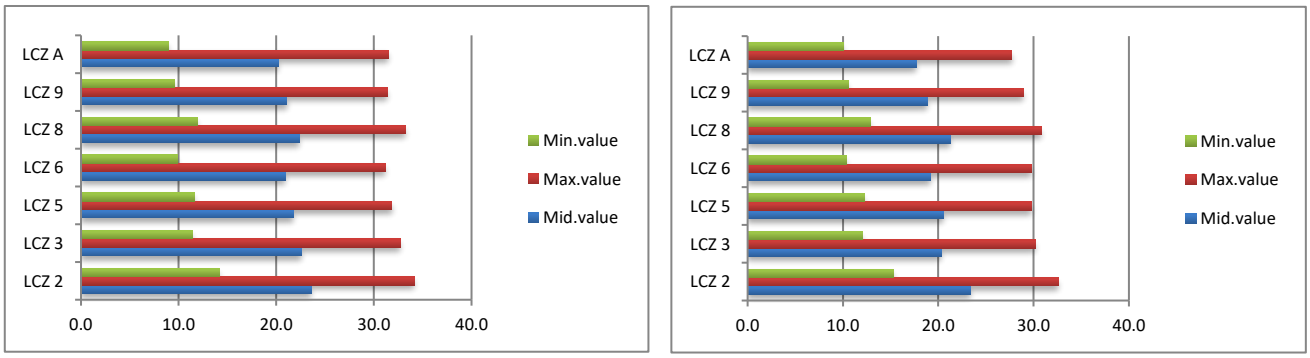

Fig. 2 - (a) PET values for urban and natural LCZ for daylight for summer 2015-2016; (b) PET values of LCZ during the nighttime for the season 2015-2016.

5. Conclusion

If all parameters are taken into account, i.e. all LCZ and the whole observed in 2015-2016, the following can be determined: the highest values of the PET index occur in LCZ 2 and LCZ 8 (both during the daylight and the nighttime) and the lowest values are in LCZ A (during the daylight and the nighttime). LCZ 5, LCZ 6, and LCZ 9 are characterized by lower and similar PET index values. Also, there is a noticeable regularity that PET values decrease going from urban, that is, central parts of the city to the periphery.

Observed on a seasonal, monthly, and daily level (daytime and nighttime) the following conclusions can be drawn: the summer of 2015 has higher index values compared to 2016 by 0.8 °C during the day and 1.2 °C during the nighttime.

When it comes to the level of human physiological stress, the mean PET values range within the comfortable subjective thermal sensation (18 °C to 23 °C), while the maximum values move far above the comfort zone. In almost all LCZ, moderate heat stress occurs in humans (23 °C to 29 °C), except in LCZ 2 during the nursery, where severe heat stress was recorded (34 °C to 41 °C). Therefore, LCZ 2, which is characterized by dense middle-class

buildings, is the most uncomfortable for the life of the population, while LCZ A, which represents an undeveloped zone, i.e. dense trees, is the most comfortable.

The general conclusion is that the local population of Novi Sad is under greater thermal stress in the more urbanized parts of the cities than in their natural surroundings. Consequently, it is necessary to develop and implement climate-conscious urban plans to improve the external thermal comfort of people in the city.

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