COMPARATIVE ANALYSIS OF THE OUTDOOR THERMAL COMFORT IN URBAN ENVIRONMENTS - CASE STUDY OF BIJELJINA AND LOZNICA

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Abstract

This paper presents the comparative analysis of the Outdoor Thermal Comfort (OTC) of two urban environments - Bijeljina (Republic of Srpska) and Loznica (Serbia). Universal Thermal Climate Index (UTCI), which represents the heat stress of the human organism caused by meteorological conditions, was used as a measure of thermal comfort in the study. The main goal of the research was to monitor changes in the index values, as well as the frequency of various categories of thermal stress during the hottest summer months (June, July, August), over a ten-year period (2009-2018). For the purpose of determining the UTCI index, mean daily values of meteorological data were used, which were measured at the weather stations Bijeljina (44° 75' N, 19° 20' E, 97m) and Loznica (44° 32' N, 19° 14' E, 121m). The obtained results show a gradual change in the bioclimatic conditions of these areas, which are generally less favorable during July and August, somewhat more in Bijeljina, then in Loznica.

Keywords: UTCI, outdoor thermal comfort, urban environments, Bijeljina, Loznica

Introduction

Constant urban population growth and intensive urbanization lead to increased pressure on urban areas leading to uncomfortable living conditions. The quality of urban living conditions often depends on the thermal comfort of the open urban spaces, which are used on a daily basis (Dunjić, 2019). Besides, progressive modification of city's morphological characteristics, i.e. the replacement of natural, permeable surfaces with mineral, rough materials such as concrete and asphalt, resulting in large quantities of solar radiation stored and then re-emitted in urban areas, which results in more severe bioclimatic conditions (Tsoka et al., 2017). So, it is necessary to investigate different technical solutions to mitigate the microclimatic conditions and to improve the thermal comfort of the citizens of a densely populated area (Battista et al., 2019). That is the reason why the attention towards outdoor thermal comfort is increasing in the last decade (Dunjić, 2019). Human thermal comfort is defined as a condition of mind which expresses satisfaction with the surrounding environment, according to ANSI/ASHRAE Standard 55. High temperatures and humidity provide discomfort sensations and sometimes heat stress. People react differently to environmental elements, depending on the physical and mental health and their adaptation to certain conditions. Common for everyone is that they are not immune to meteorological conditions, especially air temperature and humidity (Đurić, Topalić-Marković, 2019).

In 2011, the International Society of Biometeorology (ISB) announced a new thermal index for outdoor thermal environments called the Universal Thermal Climate Index (UTCI). The index was developed under ISB Commission 6 by COST Action 730, under the umbrella of the WMO Commission on Climatology (Park et al., 2014). The UTCI is heat budget index

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in function of both physiological and meteorological parameters, which describes the physiological heat stress that human body experiences in the attempt to maintain thermal equilibrium with the surrounding outdoor environment (Blazejczyk et al., 2013).

UTCI is a widely accepted human thermal index, whose results can be mapped as human bioclimatic maps and it is a useful tool for analyzing outdoor human thermal effects in urban landscapes (Park et al., 2014). Nowadays, UTCI application can be found in numerous scientific studies. Roshan et al. in 2018 presented a spatiotemporal analysis of bioclimatic comfort conditions for Iran using mean daily meteorological data from 1995 to 2014, analyzed through PET and UTCI. Park and others, in 2014 have investigated the microclimatic effects for human thermal sensation on human bioclimatic maps in summer 2009 using UTCI. Study locations were downtown Nanaimo, BC (Canada) and Changwon (Republic of Korea). Kolendowicz et al. (2018) have studied human-biometeorological conditions in the southern Baltic coast based on the UTCI. In study conducted by Mölders (2019), data from 456 surface meteorological sites in Alaska, eastern Russia and northwest Canada for 1979-2017, were used to model hourly Universal Thermal Comfort Indices (UTCIs) under consideration of Alaska-appropriate clothing. The results served to determine a high-resolution climatology of thermal comfort levels for Alaska at various temporal and spatial scales, as well as the frequency of thermal stress levels.

Wu et al. (2019) have used UTCI as a measure of outdoor thermal comfort in China between 1966 and 2016. Annual and seasonal UTCI were calculated using the daily dataset collected from 591 stations to developed a REOF-cluster-EOF hybrid model to optimize regionalization and assess regional-scale variations for UTCI. Bleta and others (2014) have analyzed the human bioclimatic conditions of Crete Island, by applying two human thermal indices: PET and UTCI, covering the 30-year period (1975–2004). In 2015, Pappenberger et al., have assessed the potential of using the UTCI for forecasting thermal health hazards. It is shown that probabilistic UTCI forecasts are superior in skill to deterministic forecasts and that despite global variations, the UTCI forecast is skillful for lead times up to 10 days. The paper also demonstrates the utility of probabilistic UTCI forecasts on the example of the 2010 heatwave in Russia.

In recent years, outdoor thermal comfort (OTC) in urban areas of Western Balkan countries was subject to several studies (Basarin et al., 2016; Basarin et al., 2018; Dunjić, 2019; Đurić, Topalić-Marković, 2019; Kendrovski et al., 2011; Lukić, et al., 2019; Pecelj et al., 2017; Pecelj et al., 2018; Trbić et al., 2017; Vučković et al., 2019; Zaninović, Matzarakis, 2014). In spite of the fact that in the last decade in Serbia, articles have been published containing an analysis of bioclimatic conditions, the detailed bioclimatic condition has not yet been thoroughly analyzed by means of the UTCI. The interest of researchers is growing, so in the coming period, we should expect the development of this scientific discipline in our region.

Study area

The research involved studying two synoptic stations – Bijeljina (Figure 1) and Loznica (Figure 2). The first weather station (44° 75' N, 19° 20' E, at an altitude of 97 m) is located in the territory of the city of Bijeljina, in the northeastern part of the Republic of Srpska. Geographically, it is located in the Peri-Pannonian area, more precisely in the Semberija region. According to Köppen's climate classification, Bijeljina belongs to the Cfb type – where the climate is moderate continental, with moderately cold winters and warm summers, and the average annual temperature is 11.6°C (Republic Hydrometeorological Service of Republic of Srpska, 2019).

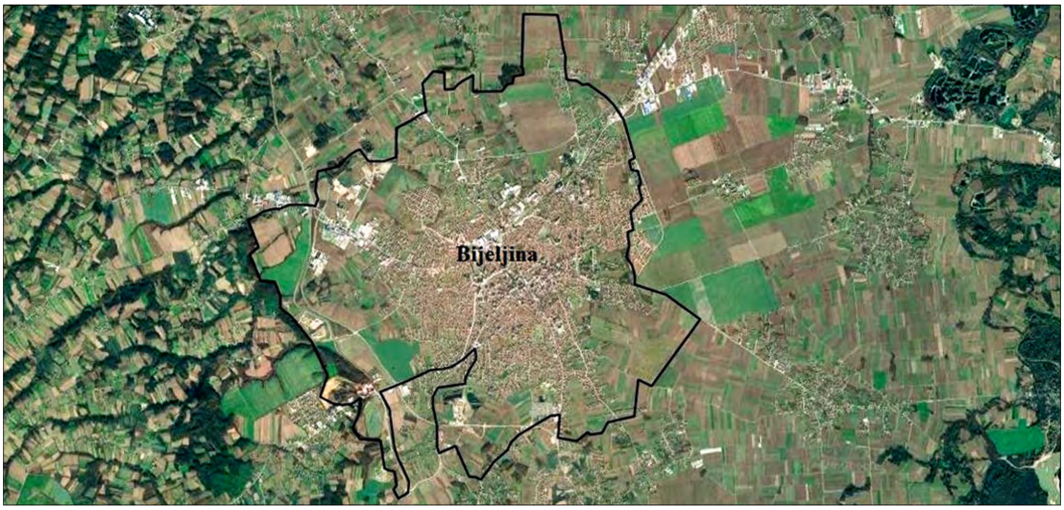


Figure 1. The urbanized area of Bijeljina (Map ratio 1: 60,000)

Figure 2. The urbanized area of Loznica (Map ratio 1: 35,000)

The second station (44° 32' N, 19° 14' E, at an altitude of 121 m) is located in the territory of the city of Loznica (Serbia). Loznica is located in the Jadar region, in the northwestern part of Serbia, and it belongs to the Peri-Pannonian and Podrinje region (Gajić, Vujadinović, 2010). City is positioned in Lozničko polje, near the Drina River. Downstream from Zvornik, the Drina Valley extends considerably and transforms into a flatland called Lozničko polje. The area is surrounded by low and medium-sized mountains which have a significant impact on the climate (Bilić, 1978). The territory of Loznica is characterised by temperate continental climate, where the average annual temperature is 11.6°C (Stojićević, 2016). According to Köppen, this climate is classified as Cfb type.

Geographical proximity, similar morphological and climatic characteristics are the main reason why these two urban areas were selected as the subject of this study. In addition, these are synoptic stations located in the territory of the two neighboring states, therefore they are considered relevant to the analysis.

Materials and methods

This study implements the methodological approach of the Universal Thermal Climate Index (UTCI) based on the human heat budget model relying on the evaluation of human energy balance. UTCI is the equivalent temperature for the environment derived from a reference environment. It is defined as the air temperature of the reference environment which produces the same strain index value in comparison with the reference individual's response to the real environment (Zare et al., 2018). As a thermal comfort indicator, the UTCI considers combined meteorological and physiological parameters describing thermal comfort through the evaluation of human energy balance.

In terms of physiological conditions, the metabolic rate (MET) has a very important role (Błażejczyk et al., 2013). As a measure of physical activity, a unit of MET was defined, which corresponds to the release of human heat of 58.2 $W.m^{-2}$ for average body surface area (1.8 m^2), i.e. it is equal to the energy rate produced per unit surface area of an average person seated at rest (ANSI/ASHRAE Standard 55). According to ISO 8996 for standard applications, the metabolic heat energy is M = 135 $W.m^{-2}$ i.e. 2.3 MET, for a person moving at a speed of $1.1 m.s^{-1}$.

The human reaction was simulated by the UTCI-Fiala multi-node model of human thermoregulation (Fiala et al., 2012), which was integrated with an adaptive clothing model. For any combination of meteorological parameters (Eq. 1), based on the conception of an equivalent temperature, the UTCI is the air temperature of the reference environment which, according to the model, produces an equivalent dynamic physiological response under a set of reference conditions (Bröde et al., 2012). In other words, this model simulates the same sweat production or skin wettedness in human body response as the actual environment condition (Błażejczyk et al., 2013; Błażejczyk et al., 2014). The UTCI can be represented in general function as bellow:

$$UTCI = f\,(t, f, v, t_{mrt}) \quad (1)$$

UTCI = f (air temperature, relative humidity, wind speed, mean radiant temperature)

For a given combination of air temperature, wind speed, radiation, and humidity, the UTCI is defined as the air temperature of a reference environment that would elicit in the human body the same UTCI-Fiala model's response (sweat production, shivering, skin wettedness, skin blood flow, and rectal, mean skin and face temperatures) as the actual environment (Di Napoli et al., 2018). The reference environment is described as a condition of calm air, i.e. wind speed 0.5 m/s at 10 m above the ground, no additional thermal irradiation, i.e. radiant temperature equal to air temperature, 50% relative humidity (capped at 20 hPa for air temperatures above 29°) where an average person walks at 4 km/h (1.1 m.s^{-1}), generating a metabolic rate equal to 135 W.m^2 (2.3 MET) (Błażejczyk et al. 2013; Bröde et al., 2012; Di Napoli 2018; Jendritzky et al., 2012).

Although UTCI is one of the best indices, it also has some weaknesses. One of them is a necessity of reduce wind speed to human-biometeorological reference height (1.1 m a.g.l) which is done in UTCI procedure by use of a relatively simply approach. Next problem is estimation of T_{mrt} (mean radiation temperature) which is calculated on the base of solar radiation. However, it is worth to emphasize that the solar radiation measurements are relatively rare; Tmrt is calculated in BioKlima software package (Błażejczyk, 2011) indirect with consideration of cloudiness and geographical position of measurement point (Kolendowicz et al., 2018).

As this study focuses on the summer months, five stress levels ranging from slight cold stress to very strong heat stress, are considered. Particular ranges of UTCI are categorised according to thermal stress (Table 1).

Table 1. UTCI thermal stress classification

UTCI (°C)	Stress category
UTCI > 46	Extreme heat stress
38 < UTCI < 46	Very strong heat stress
32 < UTCI < 38	Strong heat stress
26 < UTCI < 32	Moderate heat stress
9 < UTCI < 26	No thermal stress
0 < UTCI < 9	Slight cold stress
-13 < UTCI < 0	Moderate cold stress
-27 < UTCI < -13	Strong cold stress
-40 < UTCI < -27	Very strong cold stress
UTCI < -40	Extreme cold stress

Source: Błażejczyk et al., 2013; 2014.

Mean daily values of meteorological parameters: air temperature (t), relative humidity (f), wind speed (v) and cloud cover data from the two urban (Bijeljina and Loznica) weather stations were considered for the determination of specific UTCI thermal heat stress in the summer months (June, July, and August), covering the data period from 2009 to 2018. The meteorological data for Loznica was retrieved from the Meteorological Yearbook for the period from 2009 to 2018 (Republic Hydrometeorological Service of Serbia), while the data set for Bijeljina was provided by the Republic Hydrometeorological Service of Republic of Srpska. The UTCI index was calculated by applying the BioKlima 2.6 software package (available at http://www.igipz.pan.pl/Bioklima-zgik.html).

Results

Under the influence of climate change, the climate and microclimate of Serbia and its surrounding countries, especially urban areas are subject to constant change, and adverse weather conditions are becoming more frequent. Minimizing their effects, establishing sustainability and improving living conditions in urban areas is becoming a true challenge (Lukić, 2019). As a result, an increasing number of studies are emerging related to the observation of heat waves and their frequency, outdoor thermal comfort, the occurrence of extreme temperatures in the hotter part of the year and drought across the region etc. (Basarin et al., 2016; Lukić et al., 2019; Pecelj et al., 2017; Unkašević, Tošić, 2009). The findings of numerous studies exploring different aspects of the weather conditions in Serbia indicate a steady increase in the average annual air temperature and show that these changes are especially noticeable during the summer season. The findings that have been obtained in this paper are in keeping with the above studies.

Figures 4, 5, and 6 show the ratio of the total number of days for each category of thermal stress which was recorded during the investigation period, for both synoptic stations. Out of 10 categories of thermal stress defined by this methodology, 5 categories were recorded: slight cold stress, no thermal stress, moderate heat stress, strong heat stress and very strong heat stress.

The graphs clearly show that June is the most favorable month from the bioclimatic point of view during summer season. June is the only month where results of UTCI calculation showed all five mentioned categories (five in Bijeljina and four in Loznica) (Figure 4). The prevalent category of heat stress is the one defined as “moderate” (26<UTCI>32). However, its presence has varied over the years, especially in 2016 in Bijeljina, when 23 such days (of which 16 consecutive days) were recorded, while in 2018 were recorded only 8 days. The highest number of days in category of "moderate heat stress" in Loznica was also recorded in 2016 (21 days). Apart from this category of outdoor thermal comfort, days in which UTCI belongs to the category of "strong heat stress" (32<UTCA>38) on a daily level were also registered. Strong heat stress showed some differences between these two weather stations, wherein Bijeljina were recorded a higher number of days compared to Loznica, for each year during the observed period (2009-2018). Both cities have reached the highest number of days in this category in 2012, Bijeljina 17 days, of which 9 consecutive, and Loznica 13 days, of which 8 consecutive. On the territory of Serbia the year 2012 was the second hottest year since 1951, with the greatest number of tropical days recorded within the period 1951-2012 according to Republic Hydrometeorological Service of Serbia.

The isolated case of "slight cold stress" was observed in 2010, in both cities, when the mean daily temperature was 10.7°C in Bijeljina (UTCI = 1.89, June 1^{st}) and 11.6°C in Loznica (UTCI = 8.68, June 1^{st}). In general, in June occures lower temperatures than in July and August, and it has the highest number of days with "no thermal heat stress", meaning the highest number of pleasant days. In the city of Loznica, in this category (9<UTCI>26) at least one day was recorded every year, with minimum of 1 day in 2016, and the maximum of 9 days in 2009 and 2014. On the other hand, regarding the category "no thermal stress", Bijeljina proved to be somewhat less favorable, with a lack of such days during two years, 2012 and 2016.

As regards the thermal stress category "very strong heat stress" (38<UTCI<46) during the discussed period of 10 years in June, there are only a few cases of the UTCI exceeding its threshold value in Bijeljina: only two such days in 2010 (UTCI=38.15, June 12^{th}) and 2013 (UTCI= 38.56, June 20^{th}). On the same day was recorded the maximum daily temperature in June that year (respectively Tmax=36.3°C and Tmax=36.1°C), for both synoptic stations.

Compared to June, in July there was a lower representation of the category with no thermal stress, both in Bijeljina and in Loznica during a ten-year period, only 15 and 19 days respectively - which means that July is the least favorable summer month for outdoor activities (Figure 5). Moreover, the years 2012, 2014 and 2015 stands out as years when in July there was not recorded even one day when UTCI mean daily value was between 9 and 26. With its average temperature of 26.9°C, July 2012 was the hottest one ever since meteorological data started being recorded and August 2012, with its average temperature of 26.4°C, was the second hottest August in the last 120 years according to Republic Hydrometeorological Service of Serbia. Categories "moderate heat stress" and "strong heat stress", which are dominant in the city of Bijeljina in July, make this urban area slightly less favorable for living in comparison to Loznica, during the same period. Total number of days in "strong heat stress" category (32<UTCI>38) in Bijeljina was 164 (14 consecutive days in 2012) and in Loznica 110. Further, in the territory of Bijeljina 5 days in the category of "very strong heat stress" (38<UTCI>46) were recorded: in 2013 (1 day, UTCI=38.54, July 29^{th}), 2015 (2 days, UTCI=38.35 and 38.13, July 8^{th} and 22^{nd}), 2016 (1 day, UTCI=38.47, July 13^{th}) and 2017 (1 day, UTCI=38.56, July 10^{th}).

In August (2009-2018), according to results obtained for Bijeljina synoptic station, the category of "strong heat stress" was singled out as a dominant, with 159 such days (or 51.29% of the total share). The following was the "moderate heat stress" category, with 130 such days (41.94%). Furthermore, there were 4 days with a mean daily value of UTCI that belonged to the "very strong heat stress" category (38<UTCI>46). This has occurred in 2012 with 2 days (August 5^{th} and 6^{th}, UTCI=39.25 and 38.43), and in 2017 with also 2 days (August 4^{th} and 9^{th}, UTCI=38.73 and 39.13). The highest value of UTCI on the mean daily level reached for all three months at the Bijeljina weather station, was 39.25 (August 5^{th}, 2012).

In the territory of Loznica, during August (2009-2018), as a dominant category of thermal heat stress, the "moderate" category was singled out. Of the total number of days in August, during the 187 days on the mean daily level, the value of thermal comfort was between 26 and 32. With a 60.32% share "moderate heat stress" category was in the first place. In the second place was the "strong heat stress" category with 101 days (32.58%). The highest number of days in this category was recorded in 2018 (19 days), 2015 (18 days), and 2017 (14 days). As the most adverse 2012, 2015, 2017 and 2018 year stands out. The highest value of UTCI on the mean daily level reached for all three months at the Loznica weather station was 37.84 (August 11^{th}, 2017). During the observed period at Loznica weather station was not recorded even one day belonging to the category of "very strong heat stress", even though the air temperatures exceed 40°C on some days. In these situations, the importance and impact of the other meteorological parameters (wind speed, relative humidity, cloud cover data, and air pressure) used for the purpose of determining the UTIC is clearly evident. This is the main advantage of UTCI over other simple heat indices.

The most significant difference between these two urban areas in terms of bioclimatic conditions is seen

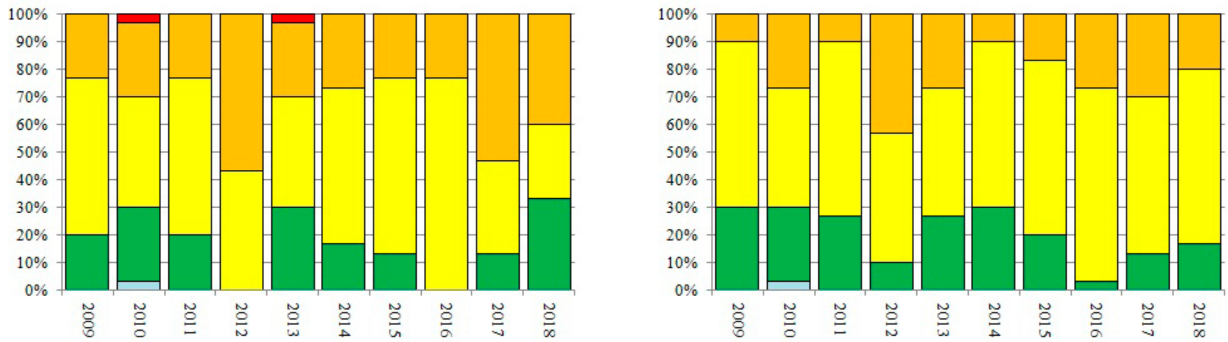


Figure 3. UTCI thermal stress categories in total, Bijeljina and Loznica, June 2009-2018

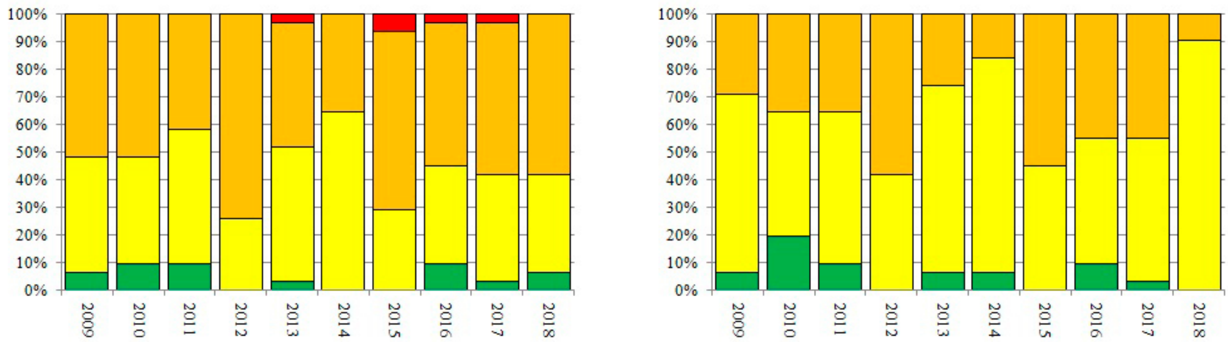
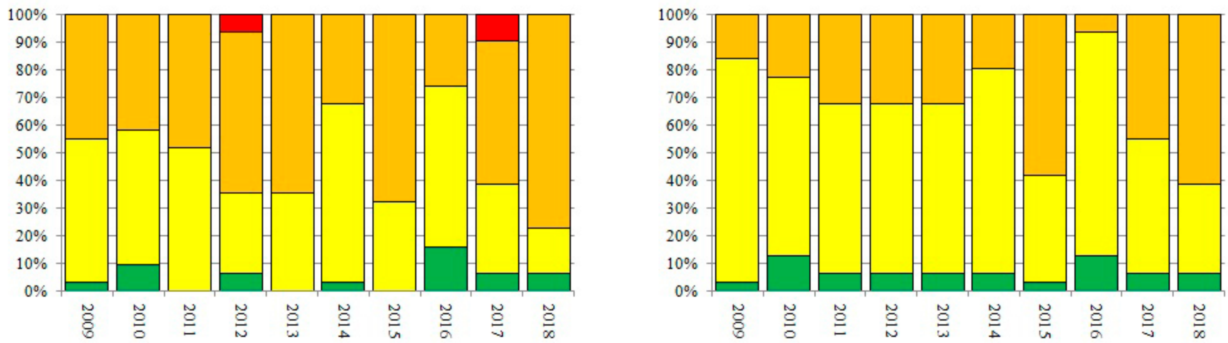


Figure 4. UTCI thermal stress categories in total, Bijeljina and Loznica, July 2009-2018



Slight cold	No thermal	Moderate	Strong	Very strong
0<UTCI<9	9<UTCI<26	26<UTCI<32	32<UTCI<38	38<UTCI<46

Figure 5. UTCI thermal stress categories in total, Bijeljina and Loznica, August 2009-2018

in the presence of days when outdoor thermal comfort exceeded the threshold of the UTCI category of "very strong heat stress" (38<UTCI>46). Based on meteorological data obtained from the Bijeljina weather station, a total number of such days were 11, while not a single one day in that category was recorded at the Loznica weather station (Figure 6). The main reason for this we can find in the high influence of the steppe climate (semi-arid climate) which comes from the wide Pannonian Plain and modifies the moderate continental climate of Semberija. On the other hand, low and medium-sized mountains that surrounds the city of Loznica have a significant impact on the climate of this area.

In order to give a more thorough insight into the changes recorded in the analyzed period, we have given Figure 7, which shows the trendline of the number of days for categories of thermal heat stress according to UTCI for the whole summer (June, July, and August). This enables the simple insight into the changes of summer discomfort over the analyzed period. Table 2 shows annual trend of increase/decrease in the number of days per year, with a particular thermal stress category for both weather stations.

Linear graphs and values in Table 2 show that the most significant changes in outdoor thermal comfort are related to the category of "strong heat stress". There was an increase in the observed heat stress cat-

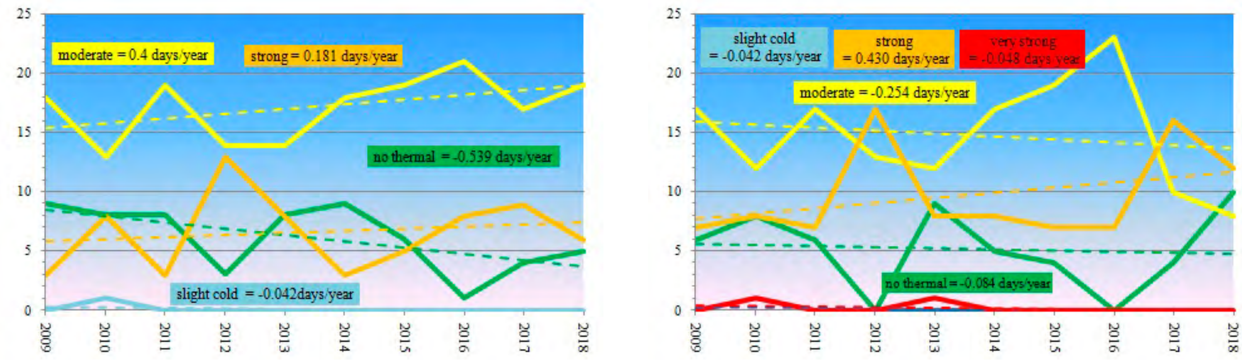
Table 2. Annual trend of increase/decrease in the number of days with a particular thermal stress category, Bijeljina and Loznica, 2009-2018

Month	Syn. Stat.	Annual trend (days/year)				
		Slight cold	No thermal	Moderate	Strong	Very strong
June	Bijeljina	-0.042	-0.084	-0.254	0.430	-0.048
	Loznica	-0.042	-0.539	0.4	0.181	/
July	Bijeljina	/	-0.090	-0.181	0.169	0.103
	Loznica	/	-0.321	0.446	-0.145	/
August	Bijeljina	/	0.133	-0.678	0.454	0.090
	Loznica	/	0.012	-0.951	0.939	/

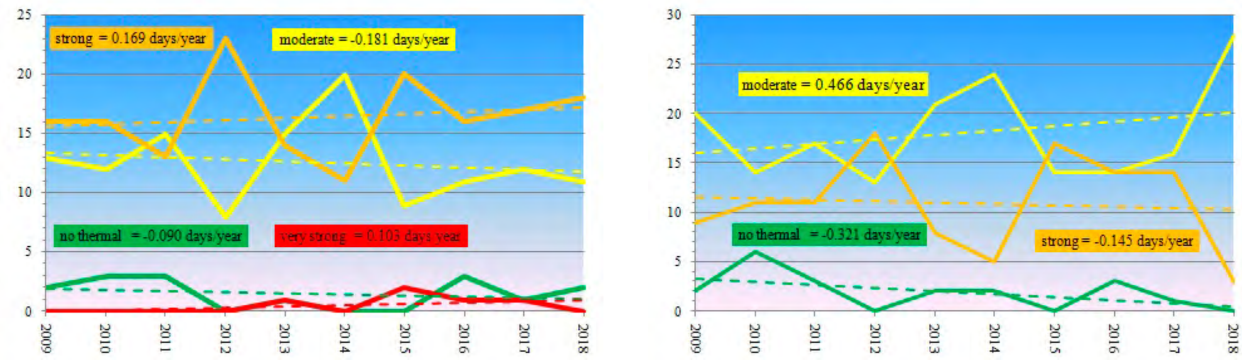
egory, at both weather stations, with the exception of Loznica in July, when an increase of the "moderate heat stress" category was registered (0.454 days/year).

The highest growth trend for both areas was recorded in August (2009-2018), at the Loznica weather station in "strong heat stress" category, amounting to 0.939 days/year. At the same time, the highest declining trend was recorded at the same synoptic station, in "moderate heat stress" category, and it was -0.951 days/year. In Bijeljina, the category of "very strong heat stress" shows a linear increase during July and August, with a positive trend of 0.103 days/year, respectively 0.090 days/year. As for the "no thermal stress" category, the results indicate a declining trend during June and July (the highest decrease was -0.539 days/year in June, in Loznica), which confirms the fact that bioclimatic conditions change from year to year and became more severe.

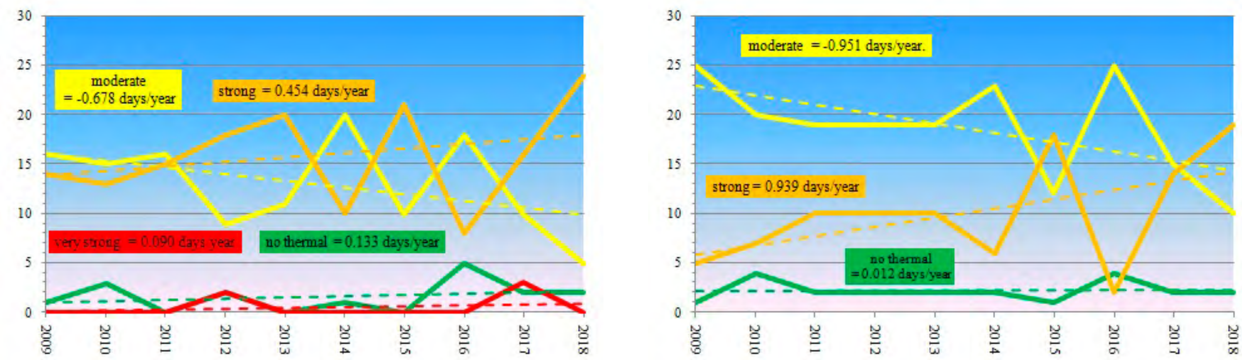
Considering the tendency of increasing daily temperatures and values of UTCI in August, it can be expected that in the coming decades a higher presence of the "very strong heat stress" category will occur, both in Bijeljina and Loznica.



a) June (Bijeljina and Loznica)



b) July (Bijeljina and Loznica)



c) August (Bijeljina and Loznica)

Slight cold	No thermal	Moderate	Strong	Very strong
0<UTCI<9	9<UTCI<26	26<UTCI<32	32<UTCI<38	38<UTCI<46

Figure 6. Trendline - number of days for each thermal stress category of UTCI, for Bijeljina and Loznica, 2009-2018, a) June, b) July, c) August

Concluson

The aim of this paper was to determine the outdoor thermal comfort of two urban environments - Bijeljina (the Republic of Srpska) and Loznica (Serbia), during the hottest part of the year (summer months June, July, and August). The assessment of human biothermal conditions for the investigation period from 2009 to 2018 was provided by using UTCI, heat budget index which represents the heat stress of the human organism caused by meteorological conditions. The results in this study help us to better understand how the bioclimatic conditions of the local environment change, and how it affects human beings and ecosystems in urban environments.

Regardless of their geographical proximity and similar morphological, climatic and urban characteristics, these areas have some differences relating to outdoor thermal comfort, but also a lot of similarities. Outdoor thermal comfort in both areas is generally more adverse in July and August. In the period of 10 years, 2012, 2015 and 2017 stands out as the most adverse ones. The highest UTCI mean daily value was recorded in August 2012 (UTCI=39.25), and this was recorded at the Bijeljina weather station. At the Loznica weather station the highest index value has occurred in August 2017 (UTCI=37.84). The most significant difference between these two urban areas in terms of bioclimatic conditions is seen in the number of days with a "very strong heat stress" on a daily level. There were 11 such days recorded in the territory of Bijeljina, while in Loznica were not obtained data in this category. In addition, the findings show that in the two-months period (June and July) during the 10 years, there was a considerable decline in the number of days characterized by the subjective perception of "no thermal stress" in an outdoor environment. The highest growth trend for both areas was recorded in August (2009-2018) in "strong heat stress" category.

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