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THERMAL COMFORT IN BELGRADE, SERBIA: UTCI-BASED SEASONAL AND ANNUAL ANALYSIS FOR THE PERIOD 1991-2020

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ABSTRACT

The main goal of this research is to examine thermal comfort in the central area of Belgrade (Serbia), over a period of 30 years (1991-2020). The Universal Thermal Climate Index (UTCI) was used as a measure for evaluating outdoor thermal comfort (OTC). The obtained results were considered separately for each season, as well as at the annual level. The analysis was carried out on the basis of an extensive database, which included hourly values (7h, 14h, 21h CET) of meteorological parameters, as well as their average daily, minimum, and maximum values.

The obtained values of UTCIs show a positive growth trend during all four seasons. A significant increase in the annual values of UTCIs was also recorded. Four of five years with the highest average UTCIs were recorded in the last decade of the survey, more precisely in the period 2015-2020. The years that stand out for the frequency of record spring, autumn and winter UTCIs values are 2017, 2018, 2019 and 2020. On an annual level, minimum UTCI value has rising trend of 0.099°C/year, while at maximum UTCI value, that trend is 0.081°C/year.

Key words: *UTCI, Belgrade, outdoor thermal comfort, seasonal analysis*

INTRODUCTION

The impact of climate change on the quality of life and the sustainability of urban environments has been the subject of scientific research for decades. It is clear that human society is in a very challenging period, where every new IPCC report only further emphasizes the danger of the climate crisis, while in practice hardly anything is really done to mitigate the impact of climate change. Developing countries that are trying to make up for their economic development deficit (like Serbia) are particularly at risk. The pressure of the global economy, markets and capital is leading to an explosion in the construction and expansion of cities. Climatic and morphological transformations of urban areas take place in parallel. A similar scenario is unfolding in the Serbian capital (city of Belgrade).

The urbanization of Belgrade has received a special acceleration in recent years. According to Mitić-Radulović et al., construction in Belgrade has significantly intensified in recent years: 30% of all construction works in Serbia in 2020 were performed in Belgrade. In the period 2016-2020 number of apartments built per year increased by 70%. In the same time, the annual value of construction work increased by 105%, and the number of square meters of high-rise buildings built per year increased by 350% [1,2,3]. The transformation of Belgrade's landscape further enhanced the impact of climate change [3].

Although the link between urban planning, microclimate, and outdoor thermal comfort (OTC) has been scientifically proven (e.g. studies conducted for Valladolid (Spain), Nanjing (China), Sao Paolo (Brasil), Cairo (Egypt), Hanover (Germany), Sydney (Australia), Bursa (Turkey), etc.) [4,5,6,7,8,9,10], such practice is not represented in the local context. In the planning of the urban development of Belgrade, consideration of OTC as one of the significant indicators is still not represented, unlike some other European metropolises where different concepts of bioclimatic urban design are applied.

Given that the average summer temperature at Belgrade increases at the rate of 0.1316◦C/year [11], local urban planners must take into account changes in the local microclimate and thermal comfort if they want to develop the city in a way that is ready to respond to the challenges of the coming climate crisis.

The aim of this research is to show how the Belgrade's microclimate and OTC have changed during three decades (1991-2020), during which the morphology of the city also changed significantly, and during which we recorded some of the warmest years since meteorological measurements have been made in Serbia (according to Republic Hydrometeorological Service of Serbia). The analysis of thirty-year thermal comfort using the bioclimatic index Universal Thermal Climate Index (UTCI) will give a useful insight into the current situation, as well as indications of what changes we can expect in the future. The results of this work may be of importance for the improvement of the domestic practice of urban planning.

STUDY AREA

Belgrade, the capital of Serbia, is located in the area of South-Eastern Europe (Balkan Peninsula), and belongs to the region of the Western Balkans countries [12]. City lies on the Sava and Danube river bank, near the Mountain Avala (511m) [13,14]. According to the Köppen-Geiger climate classification, Belgrade's area belongs to the Cfa type which is characterized by the humid subtropical climate [14,15,16]. Geographically speaking, the region of Southeast Europe has been recording an evident increase in average annual temperatures for years. This has been confirmed by numerous scientific studies, and the same growth tendencies are recorded in this region. As Milovanović et al. and Tošić et al. have stated: the mean annual temperature in Belgrade for the 1961–2010 period was 12.3°C, while during the 2000–2017 period that value was 13.4°C [17,18]. The average air temperature in the first decade of the 20th century was 11.3°C, while in the last decade, it was 12.5°C [12]. In addition, Belgrade is characterized by the existence of an urban heat island [12,16].

METHODOLOGY

Universal Thermal Climate Index (UTCI)

Within the project of the International Society of Biometeorology (ISB) and framework of the European COST Action 730, the UTCI has been made available as an operational procedure by which to assess the outdoor thermal environment from the point of view of the core fields of human biometeorology [19]. By searching databases containing scientific papers from the most representative and reputable scientific journals, we can simply conclude that this index stands out as one of the most commonly used in the evaluation of outdoor thermal comfort.

Błażejczyk et al. in their research titled "An introduction to the Universal Thermal Climate Index (UTCI)", have defined UTCI (°C) as "the air temperature of the reference condition causing the same model response as actual conditions"[20]. UTCI was obtained from the "Fiala multi-node model", developed by Fiala et al. [21-23]. As this index is an indicator of thermal comfort, it considers both meteorological and physiological parameters describing thermal comfort through the assessment of human energy balance [20,22,24].

This model includes 10 different categories of thermal stress, which are presented in Table 1. The UTCI is calculated as follows: UTCI = f (t, f, v10m, Tmrt)

Where: t = air temperature (°C), f = relative humidity (%), v10m = wind speed (m/s), Tmrt = mean radiant temperature (°C). Tmrt was calculated using the BioKlima 2.6 software [25].

Table 1. UTCI scale and corresponding physiological responses [16,20-22]

UTCI (ºC)	Stress category	Physiological responses
UTCI > 46	Extreme heat stress	Increase in rectal temperature time gradient. Steep decrease in total net heat loss. Averaged sweat rate >650 gh^{-1}, steep increase.
38 < UTCI < 46	Very strong heat stress	Low core–skin temperature gradient. Increase in rectal temperature at 30 min.
32 < UTCI < 38	Strong heat stress	Averaged sweat rate >200 gh^{-1}. Increase in rectal temperature at 120 min. Instantaneous change in skin temperature.
26 < UTCI < 32	Moderate heat stress	Change of slopes in sweat rate and rectal and skin (mean, face, hand) temperature. Occurrence of sweating at 30 min. Steep increase in skin wettedness.
9 < UTCI < 26	No thermal stress	Averaged sweat rate >100 gh^{-1}. Plateau in rectal temperature time gradient.
0 < UTCI < 9	Slight cold stress	Local minimum of hand skin temperature.
-13 < UTCI < 0	Moderate cold stress	Vasoconstriction. Face skin temperature at 30 min <15°C (pain).
-27 < UTCI < -13	Strong cold stress	Numbness. Increase in core–skin temperature gradient.
-40 < UTCI < -27	Very strong cold stress	Frostbite, numbness, shivering. Steeper decrease in rectal temperature.
UTCI < -40	Extreme cold stress	Frostbite. Decrease in rectal temperature time gradient.

Data set and software used in the study

Determination of UTCIs was conducted based on an hourly (07:00, 14:00, 21:00 CET) and "day by day" meteorological data set. Apart from the hourly values, average daily (avg.), minimum (min), and maximum (max) values of meteorological parameters were also used. The data set was extracted from the Republic Hydrometeorological Service of Serbia (RHSS), ie. from the Meteorological Yearbooks 1991-2020 [26]. Meteorological data were collected on the Meteorological Observatory Belgrade (44°48′ N, 20°28′ E, 132 m), located in the most densely populated part of Belgrade, called Vračar. The data collected in such conditions best describe the thermal comfort of the central city core [16].

Meteorological parameters which were used are: air temperature (t), relative humidity (f), wind speed (v10m) at 10m above the ground, total cloud cover (N or cloudiness) and air pressure (p). The UTCI was calculated by the BioKlima 2.6 software [25], developed by Prof. K. Błażejczyk, PhD.

For the purposes of seasonal analysis of thermal comfort, the obtained data are grouped into four seasons: spring (March, April, May), summer (June, July, August), autumn (September, October, November) and winter (December, January, February) in accordance with the Meteorological division of the seasons. After that, the results were processed and presented on the annual basis.

RESULTS AND DISCUSSION

The results are presented individually for all four seasons, as well as on an annual basis. Outdoor thermal comfort was estimated through six different UTCIs: UTCI07h (morning data values at 07:00 CET), UTCI14h (midday data values at 14:00 CET), UTCI21h (evening data values at 21:00 CET), UTCIsr (average daily values), UTCImax (maximum daily temperature was used) and UTCImin (maximum daily temperature was used).

Frequencies of different cold and heat stress are shown on the Figure 1-4, while trends are shown on Figures 1,2,3,4,5.

Thermal comfort in Belgrade: spring 1991-2020

The results of this study confirm the results of previously conducted scientific research on the topic of the urban bioclimate and thermal comfort of Belgrade. Regarding OTC, spring is rated as the most favorable part of the year for being outdoors [12,16,17]. Figure 1. shows frequencies of different cold and heat stress (according to the UCTI scale) in the Belgrade center. From left to right, results are shown for UTCI07h, UTCI14h, UTCI21h, UTCIsr (average), UTCImax, and UTCImin.

The prevalent category of spring OTC in Belgrade is the one marked as "no thermal stress" (NTS, Figure 1, green color), where the value of UTCI is in range from 9°C to 26°C. The pleasant feeling of being outdoors is mainly present during the morning hours (UTCI07h).

The NTS category takes a 60.5% share in the total number of days for UTCI07h. For UTCI14h and UTCImax we see a greater participation of next heat stress categories: MHS (moderate heat stress, 26<UTCI<32) and SHS (strong heat stress, 32<UTCI<38).

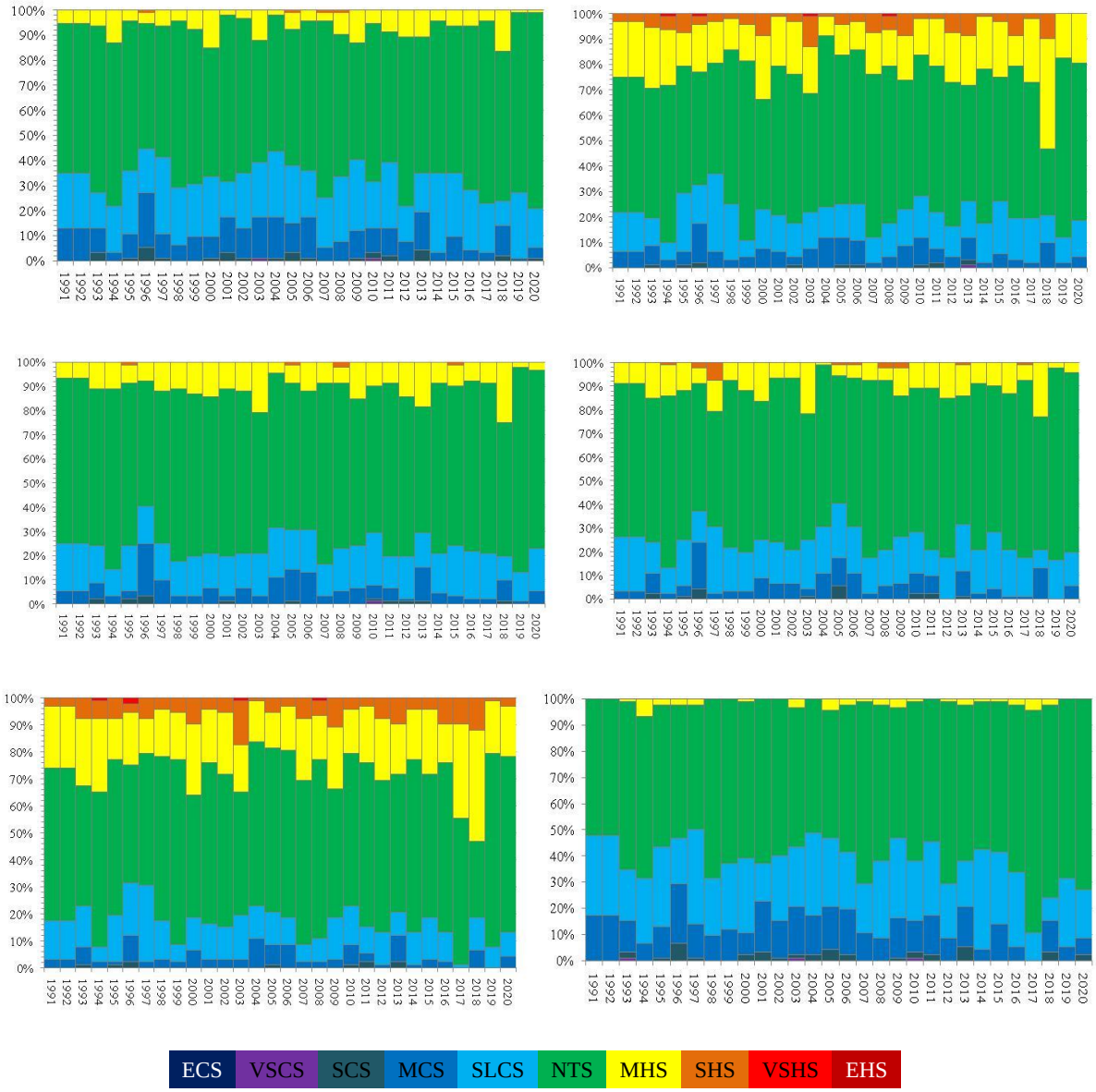


Figure 1. Frequencies of different cold and heat stress in Belgrade center; UTCI 07h, UTCI 14h, UTCI 21h, UTCIsr (average), UTCImax, and UTCImin during **spring**, over a period of 30 (1991-2020)

In Figure 2, we can clearly see that each of the spring UTCIs records a positive trend. The most pronounced positive trend has UTCImin (light blue color), where that trend is 0.101°C/year or 1.01°C/decade. It is followed by UTCImax (red color), where the recorded trend amounts to 0.083°C/year. The maximum spring UTCI value was registered in 2017 (UTCImax = 24.49°C).

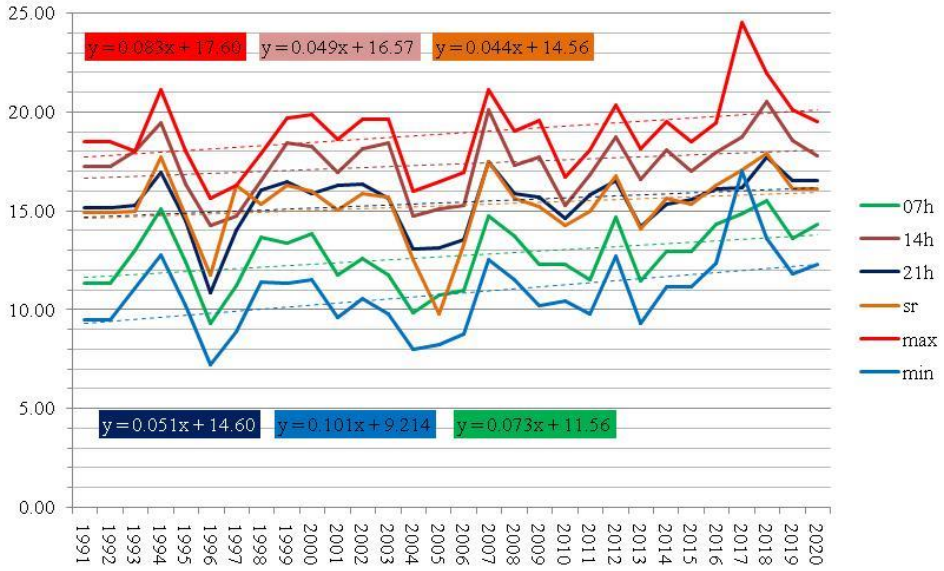


Figure 2. Average spring UTCI at: 7h, 14h, 21h CET, average daily value UTCI (sr), minimum UTCI (min) and maximum UTCI (max), Belgrade 1991-2020

Thermal comfort in Belgrade: summer 1991-2020

Figure 3. shows frequencies of different cold and heat stress during summer 1991-2020 in Belgrade. From left to right, results are shown for all six UTCIs again. It was once again confirmed that summer is the most unfavorable part of the year in terms of OTC, when the most pronounced temperature extremes (high temperatures, heat waves) occur [1213,14,16,17,18,24].

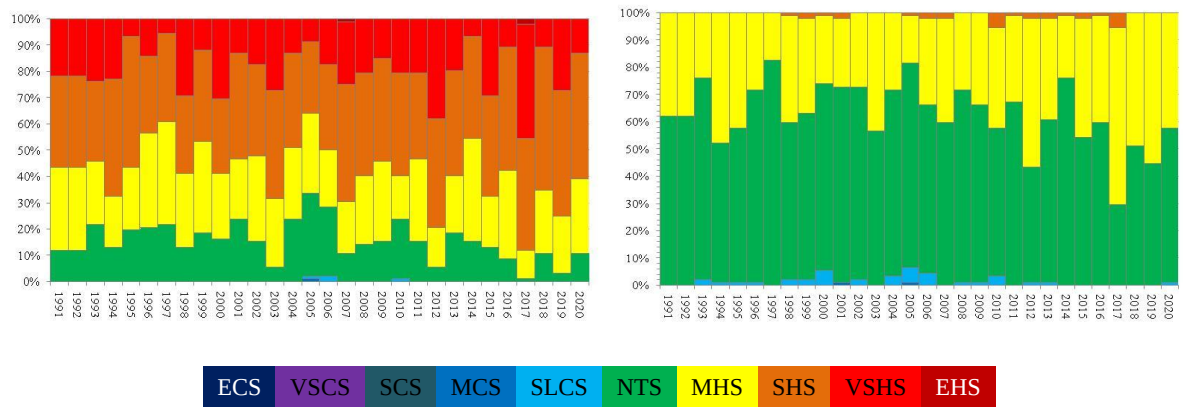


Figure 3. Frequencies of different cold and heat stress in Belgrade center; UTCI 07h, UTCI 14h, UTCI 21h, UTCIsr (average), UTCImax, and UTCImin during summer, over a period of 30 (1991-2020)

If we look at the three decades of the researched period separately (1991-2000; 2001-2010 and 2011-2020) on Figure 3. we can clearly see that the number of days in higher categories of thermal stress (especially MHS, SHS and VSHS) increases from decade to decade (regardless of which of the 6 different UTCIs we are considering). UTC14h records the largest share of days when OTC could be described as "strong heat stress" with 35% such days during 30 years. For UTCImax and SHS that share amounts to 38.5%. Frequency of MHS category for UTCI14h is 27.4%, and for UTCImax is 26.4%. VSHS category (very strong heat stress, 38<UTCI<46) covers 19.5% of the total number of days for UTCImax, and 15.4% for UTCI14h.

The increase in summer air temperatures affects the increase in the value of the UTCI index, which was confirmed by research. A positive trend is noted for all summer UTCIs (Figure 4). Again, the most pronounced positive trend has UTCImin (light blue color), and it is 0.081°C/year. In second place is UTCImax (red color), with an increasing trend of 0.068°C/year. The maximum summer UTCI was 37.22°C, and it was registered in 2017.

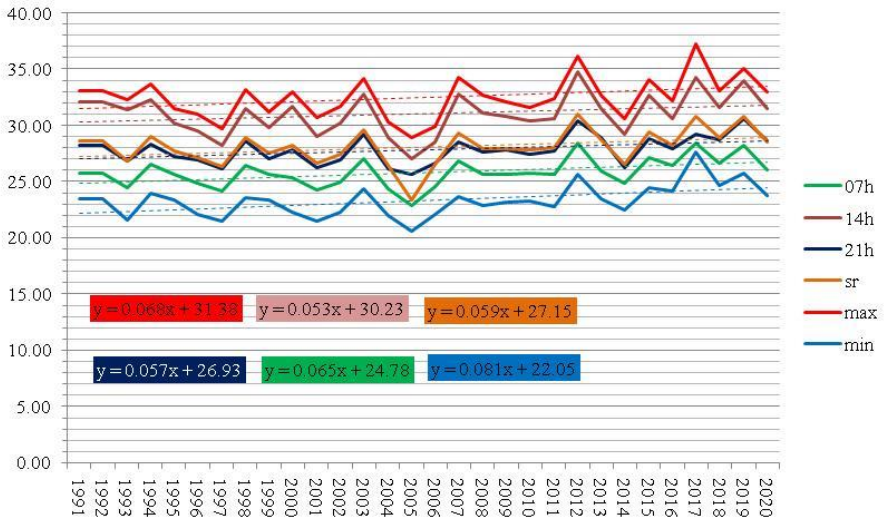


Figure 4. Average summer UTCI at: 7h, 14h, 21h CET, average daily value UTCI (sr), minimum UTCI (min) and maximum UTCI (max), Belgrade 1991-2020

Thermal comfort in Belgrade: autumn 1991-2020

Thermal comfort during the autumn months is most similar to the spring, but still with a clear difference, due to the greater number of days with cold stress: SLCS (slight cold stress) and MCS (moderate cold stress). However, as the years go by, the number of days in the categories belonging to

cold stress decreases, while the number of days with higher values of thermal stress increases (Figure 5). This applies to all 6 sub-indices (UTCI07h, UTCI14h, UTCI21h, UTCIsr (average), UTCImax, and UTCImin). If we look at the percentage participation, days without thermal stress dominate (NTS, green color, Figure 5). Regarding the UTCI14h and UTCImax sub-indexes, during the last decade of the researched period, an increase in days belonging to the VSHS category was recorded. This indicates an increase in UTCI values during the autumn months.

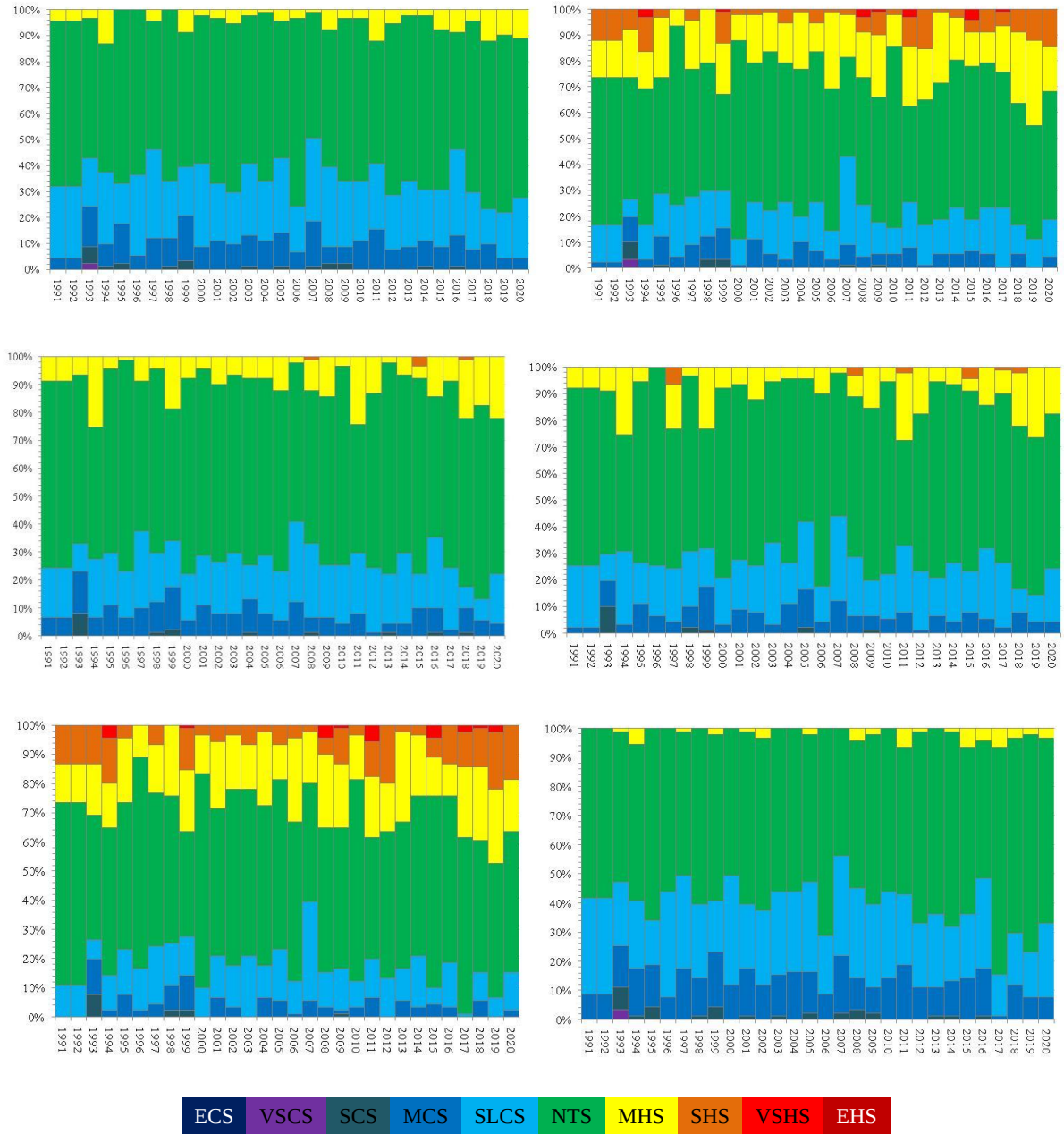


Figure 5. Frequencies of different cold and heat stress in Belgrade center; UTCI 07h, UTCI 14h, UTCI 21h, UTCIsr (average), UTCImax, and UTCImin during autumn, over a period of 30 (1991-2020)

As with the previous two seasons, very similar results are recorded when it comes to autumn. UTCImin records the highest positive trend again (0.141°C/year). During the autumn months, there is an increase in all UTCI values, especially in the morning hours (UTCI07h, trend is 0.108°C/year).

Next is UTCImax, with the rising trend of 0.104°C/year. The maximum autumn UTCI value was registered in 2019 (UTCImax = 23.54°C), Figure 6.

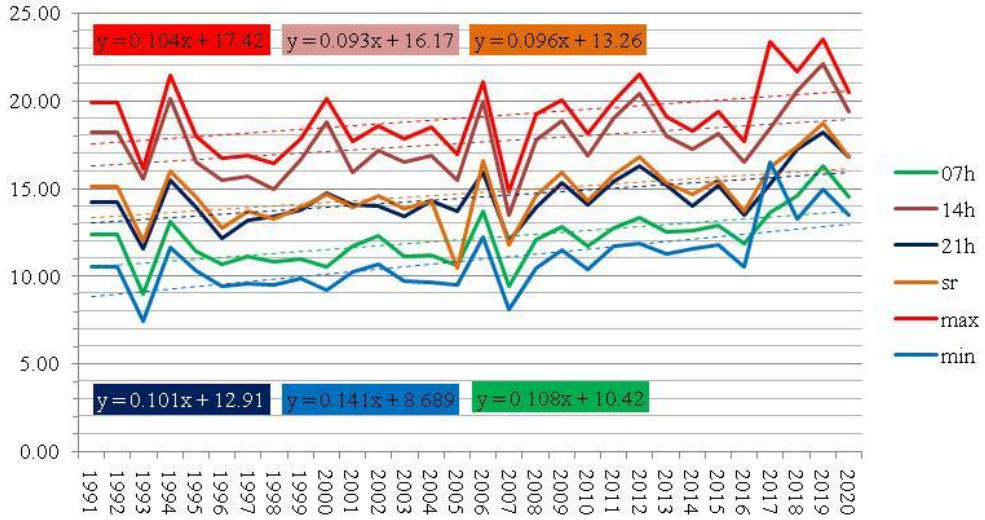
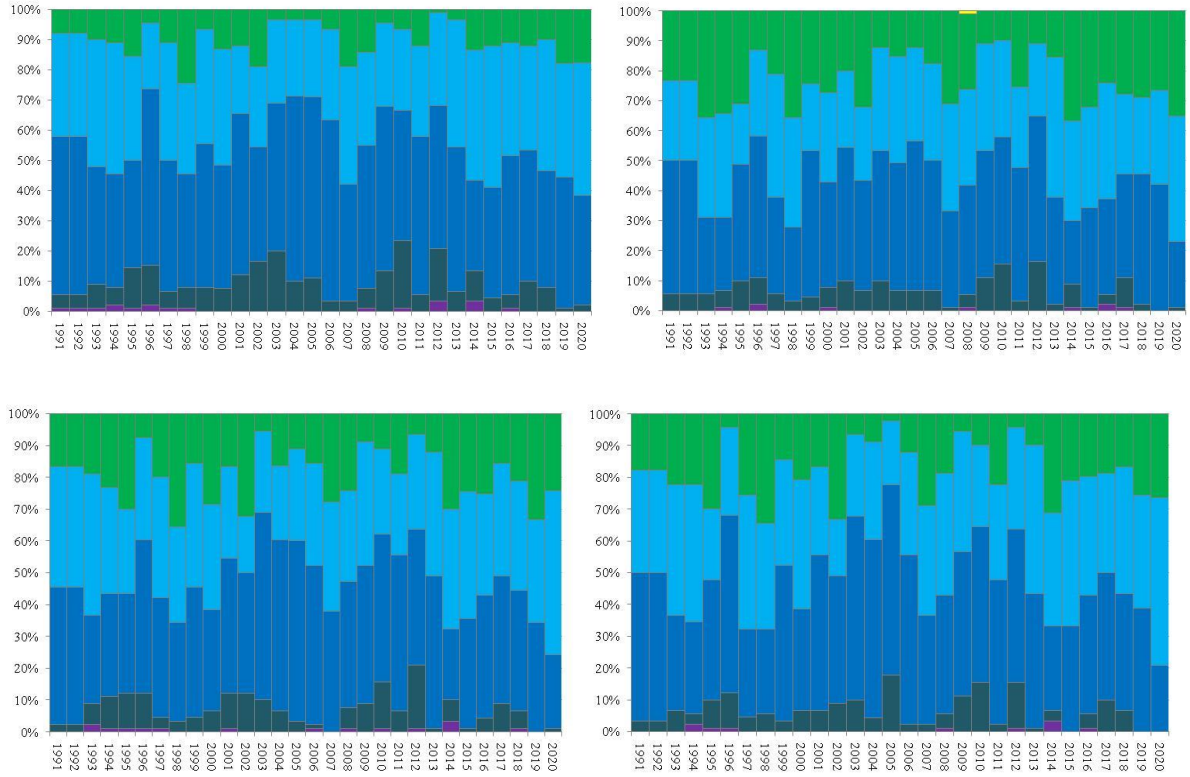


Figure 6. Average autumn UTCI at: 7h, 14h, 21h CET, average daily value UTCI (sr), minimum UTCI (min) and maximum UTCI (max), Belgrade 1991-2020

Thermal comfort in Belgrade: winter 1991-2020

If we carefully look at Figure 7, we can see that the winter in Belgrade is getting milder and warmer. The average winter air temperature in Belgrade grows at the rate of 1.95°C/100 years [27]. It directly affects the growth of UTCI values and changes in outdoor thermal comfort. When we consider OTC in the central areas of Belgrade, on Figure 8. we can clearly see that the most significant changes in this thirty-year period took place precisely during the winter months. A positive trend is noticeable in all winter UTCIs. This is especially noticeable after the winter of 2012/13. Winter UTCImin records the highest positive trend (0.070°C/year). The winter of 2019/20 proved to be the warmest (regarding OTC) in this period (1991-2020) when the highest values of almost all UTCI were measured. The maximum winter UTCI value was registered during winter 2019/20 (UTCImax = 8.40°C).



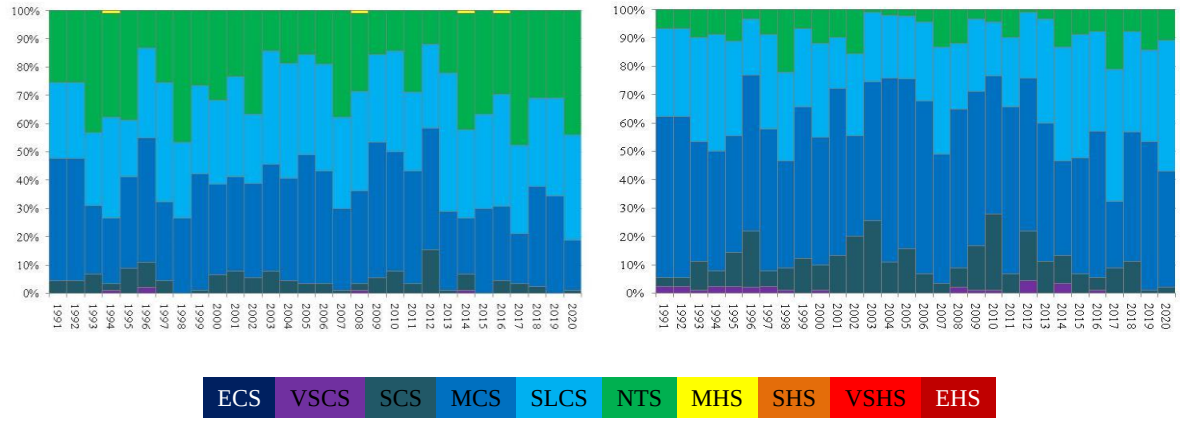


Figure 7. Frequencies of different cold and heat stress in Belgrade center; UTCI 07h, UTCI 14h, UTCI 21h, UTCIsr (average), UTCImax, and UTCImin during **winter**, over a period of 30 (1991-2020)

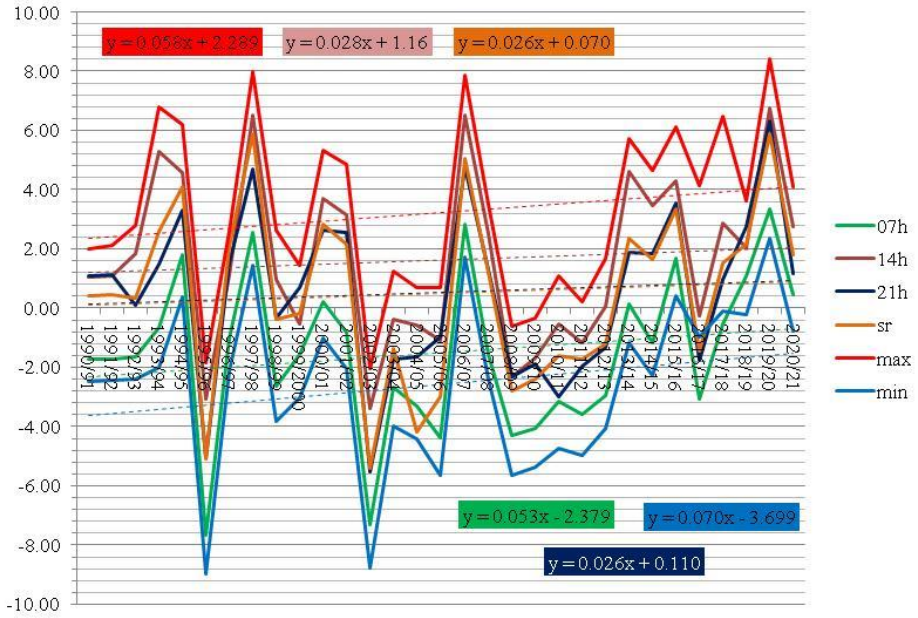


Figure 8. Average winter UTCI at: 7h, 14h, 21h CET, average daily value UTCI (sr), minimum UTCI (min) and maximum UTCI (max), Belgrade 1991-2020

Thermal comfort in Belgrade: annual analysis

Table 2. presents the average annual values of the bioclimatic index UTCI in Belgrade during the period 1991-2020. The values for each of the considered UTCIs in this study are extracted for this purpose. In this way, we get a precise insight into the mean annual values for each UTCI. We can also see when the maximum values were recorded. It is clearly observed that the highest values are recorded at the end of the third decade of the researched period, i.e. in the period 2017-2020. The highest record values were recorded in 2019 and 2017. The continuous increase in air temperature in Belgrade, which is accompanied by the increase in the UTCI value, indicates that we can expect such trends in the coming years as well.

Table 2. Average annual values UTCIs in Belgrade, 1991-2020
(five highest recorded avg. annual values are highlighted in red)

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
07h	11.89	12.00	11.60	13.62	12.15	9.75	11.53	13.04	12.34	12.35
14h	16.90	17.25	17.39	19.12	16.44	14.20	15.24	17.25	16.52	17.62
21h	14.01	14.76	13.86	15.56	14.21	11.69	13.75	15.65	14.58	15.25

avg.	14.22	14.85	14.15	16.32	14.66	12.01	13.51	15.46	14.63	15.18
max	17.91	18.47	18.00	20.53	17.93	15.54	16.66	18.73	18.04	19.05
min	9.98	10.32	9.69	11.74	10.34	7.92	9.63	11.19	10.55	10.34
Year	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
07h	11.33	12.11	11.41	10.54	10.17	11.78	13.06	12.56	11.84	11.21
14h	15.62	17.21	16.66	15.19	14.20	16.26	17.65	17.22	16.53	15.06
21h	14.01	14.73	13.77	13.14	12.88	14.00	15.32	14.69	14.51	13.26
avg.	13.81	14.84	14.12	13.06	9.56	14.14	15.46	14.86	14.35	13.32
max	17.33	18.61	18.02	16.64	15.75	17.62	18.93	18.70	18.03	16.44
min	9.40	10.23	9.55	8.76	8.40	9.99	11.12	10.65	10.03	9.37
Year	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
07h	12.26	12.72	12.22	12.61	13.39	13.10	13.81	14.15	14.94	14.39
14h	17.09	17.74	17.12	17.21	18.14	16.86	18.29	18.79	19.52	18.64
21h	14.68	14.83	14.67	14.47	15.54	14.93	15.10	16.29	17.37	16.64
avg.	14.93	15.23	14.78	14.75	15.84	14.91	16.05	16.44	17.26	16.59
max	18.43	19.05	18.43	18.45	19.46	18.39	23.30	20.20	20.94	20.12
min	10.51	10.88	10.44	10.99	11.75	11.36	15.75	12.54	13.20	12.81

Figure 9. shows the annual trend for each UTCI and each year of the researched period (1991-2020). As expected, the highest positive trend was recorded with the UTCImin index (trend is 0.099°C/year). Next is UTCImax with a positive trend of 0.081°C/year, followed by UTCI07h (0.073°C/year). The lowest rising rate (but still not negligible) amounts to 0.054°C/year for UTCI14h.

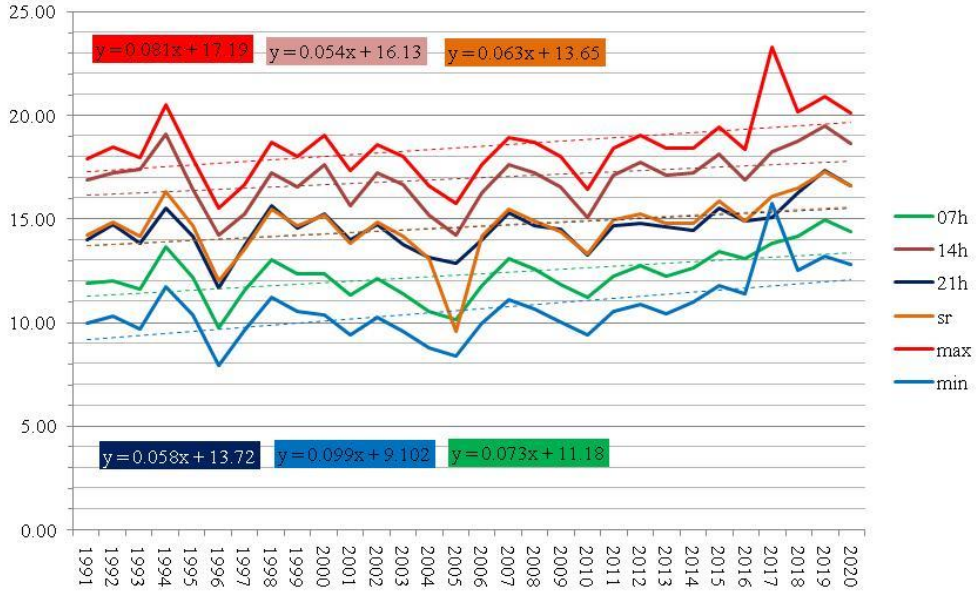


Figure 9. Average **annual** UTCI at: 7h, 14h, 21h CET, average daily value UTCI (sr), minimum UTCI (min) and maximum UTCI (max), Belgrade, 1991-2020

CONCLUSION

The aim of this research was to analyze thermal comfort outdoors in the central area of Belgrade, over a period of 30 years (1991-2020). The obtained results were considered on a seasonal and annual level, and the UTCI bioclimatic index was used for the analysis, which proved to be one of the most optimal and most frequently used in modern scientific research.

Belgrade has changed tremendously in recent decades. Urbanization is pronounced, and the morphological structure of the city has taken on entirely new contours. At the same time, due to the reduced share of green areas (only 2.83% of public green areas in the central part of the city), and the increasing dominance of artificial materials used in construction (concrete, asphalt, steel), Belgrade's urban heat island is becoming more pronounced. Parallel, the impact of climate change as a global phenomenon on the microclimate of the city is obvious. Average summer temperature in Belgrade increases at the rate of 0.1316◦C/year, while the average winter air temperature grows at the rate of 1.95°C/100 years. In such changed conditions, it is highly important to take OTC into account when planning the city. The results of this research show that changes are present and constant, and everything indicates that they will continue in the same direction.

All six considered sub-indices show a positive rising trend. On an annual level, UTCImin has rising trend of 0.099°C/year, while UTCImax has trend of 0.081°C/year. For spring 1991-2020, the most pronounced positive trend has UTCImin (0.101°C/year) and UTCImax (0.083°C/year). For summer 1991-2020, the most pronounced positive trend has UTCImin (0.081°C/year) and UTCImax (0.068°C/year). The biggest changes were recorded during the autumn months. Autumn UTCImin records the highest positive trend of all: 0.141°C/year, which is actually the highest rate of growth in this thirty-year period. Winter in Belgrade is getting milder and warmer, and the winter of 2019/20 proved to be the warmest (regarding OTC) during the period 1991-2020. Four of five years with the highest average UTCIs were recorded in the last decade of the survey, more precisely in the period 2015-2020 (especially 2017, 2018, 2019 and 2020).

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LITERATURE

[1] Mitić-Radulović, A., Lukić, M., Simić, A. (2022a). Ecological index as an instrument of Belgrade's adaptation to climate change. Collection of works "Local self-government in planning and arrangement of space and settlement". Belgrade: Association of Spatial Planners of Serbia, Faculty of Geography, p. 123-130. *[Serbian language]*

[2] Mitić-Radulović, A., Simić, A., Ljubić, S. (2022b). Possibilities of applying the ecological index in the planning of Belgrade. Belgrade: Center for Expertise and Urban Studies - CEUS. *[Serbian language]*

[3] Lukić, M., Lukić, A. (2022). Outdoor thermal comfort as an indicator of the "Belgrade Green City" concept - advantages and applications. Proceedings of the 4th International Conference on Urban Planning – ICUP 2022. Niš: University of Niš - Faculty of Civil Engineering and Architecture, pp 173-180, ISBN 978-86-88601-74-0

[4] Madeco Alves, F. et al. (2022). The use of Envi-Met for the Assessment of Nature-Based Solutions' Potential Benefits in Industrial Parks - A Case Study of Argales Industrial Park (Valladolid, Spain). Infrastructures 7, 85, https://doi.org/10.3390/infrastructures7060085

[5] Rui, L., Buccolieri, R., Gao, Z. et al. (2019). Study of the effect of green quantity and structure on thermal comfort and air quality in an urban-like residential district by ENVI-met modelling. Build. Simul, 12, pp 183–194, https://doi.org/10.1007/s12273-018-0498-9

[6] Carfan, A. Galvani, E., Nery J. (2012). Study of thermal comfort in the City of São Paulo using ENVI - met model. Investigaciones geográficas, 78.

[7] Fahmy, M., Sharples, S. (2009). On the development of an urban passive thermal comfort system in Cairo, Egypt. Building and Environment, 44(9), pp 1907-1916, https://doi.org/10.1016/j.buildenv.2009.01.010

[8] Forouzandeh, A. (2021). Prediction of surface temperature of building surrounding envelopes using holistic microclimate ENVI-met model. Sustainable Cities and Society, 70, 102878, https://doi.org/10.1016/j.scs.2021.102878

[9] Abdollahzadeh, N., Biloria, N. (2021). Outdoor thermal comfort: Analyzing the impact of urban configurations on the thermal performance of street canyons in the humid subtropical climate of Sydney. Frontiers of Architectural Research, 10, pp 394–409, https://doi.org/10.1016/j.foar.2020.11.006

[10] Cetin, M. (2019). The effect of urban planning on urban formations determining bioclimatic comfort area's effect using satellitia imagines on air quality: a case study of Bursa city. Air Quality, Atmosphere & Health, 12, pp 1237–12, doi:10.26650/PB/PS12.2019.002.040

[11] Unkašević, M. Vujović, D., Tošić, I. (2005). Trends in extreme summer temperatures at Belgrade. Theor. Appl. Clim, 82, pp 199–205.

[12] Pecelj, M., Matzarakis, A., Vujadinović, M., Radovanović, M., Vagić, N.; Đurić, D., Cvetković, M. (2021). Temporal Analysis of Urban-Suburban PET, mPET and UTCI Indices in Belgrade (Serbia). Atmosphere, 12(7), 916, https://doi.org/10.3390/atmos12070916

[13] Lukić, M., Milovanović, J. (2020). UTCI based assessment of urban outdoor thermal comfort in Belgrade, Serbia. Proceedings of the SINTEZA 2020 - International Scientific Conference on Information Technology and Data Related Research. Belgrade: Singidunum University, pp 70-77, https://doi.org/10.15308/Sinteza-2020-70-77,ISBN 978-86-7912-735-8

[14] Lukić, M. (2019). An analysis of the influence of air temperature and humidity on outdoor thermal comfort in Belgrade (Serbia) using a simple heat index. Archives for Technical Sciences, No. 21 (1), pp 75-84, https://doi.org/10.7251/afts.2019.1121.075L

[15] Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F. (2006). World map of the Köppen–Geiger climate classification updated. Meteorol. Z., 15(3), 259–263, https://doi.org/10.1127/0941-2948/2006/0130

[16] Lukić, M., Filipović, D., Pecelj, M., Crnogorac, Lj., Lukić, B., Divjak, L., Lukić, A., Vučićević, A. (2021). Assessment of Outdoor Thermal Comfort in Serbia's Urban Environments during Different Seasons. Atmosphere, 12, 1084, ISSN: 2073-4433, https://doi.org/10.3390/atmos12081084

[17] Milovanović, B., Radovanović, M., Schneider, Ch. (2020). Seasonal distribution of urban heat island intensity in Belgrade (Serbia). J. Geogr. Inst. Jovan Cvijić SASA, 70 (2), 163-170, https://doi.org/10.2298/IJGI2002163M

[18] Tošić, I., Mladjan, D., Gavrilov, M., Živanović, S., Radaković, M., Putniković, S., Petrović, P., Krstić Mistridželović, I., Marković, S. (2019). Potential influence of meteorological variables on forest fire risk in Serbia during the period 2000-2017. Open Geosci., 11, 414-425, https://doi.org/10.1515/geo-2019-0033

[19] Bröde, P.; Krüger, L.E.; Fiala, D. UTCI: validation and practical application to the assessment of urban outdoor thermal comfort. Geog. Pol 2013, 86 (1), 11-20. http://dx.doi.org./10.7163/GPol.2013.2

[20] Błażejczyk, K., Jendritzky, G., Brode, P., Fiala, D., Havenith, G., Epstein, Y., Psikuta, A., Kampmann, B. (2013). An introduction to the Universal Thermal Climate Index. Geogr. Pol 2013, 86 (1), 5-10, http://dx.doi.org./10.7163/GPol.2013.1

[21] Bröde, P., Fiala, D., Błażejczyk., K., Holmér, I., Jendritzki, G., Kampmann, B., Tinz, B., Havenith, G. (2012). Deriving the operational procedure for the Universal Thermal Climte Index (UTCI) J. Biometeorol, 56 (3), 481-494. https://doi.org/10.1007/s00484-011-0454-1

[22] Błażejczyk, K., Kuchcik, M., Błażejczyk, A., Milewski, P., Szmyd, J. (2014). Assessment of urban thermal stress by UTCI – experimental and modelling studies: an example from Poland. Die Erde, 145 (1-2), 16-33, https://doi.org/10.12854/erde-145-3

[23] Blażejczyk, K., Epstein, Y., Jendritzky, G., Staiger, H., Tinz, B. (2012). Comparison of UTCI to selected thermal indices. Int. J. Biometeorol, 56 (3), 515-535, https://doi.org/10.1007/s00484-011-0453-2

[24] Pecelj, M., Lukić, M., Filipović, D., Protić, B., Bogdanović, U. (2020). Analysis of the Universal Thermal Climate Index during heat waves in Serbia. Nat. Hazards Earth Syst. Sci., 20, 2021–2036, https://doi.org/10.5194/nhess-20-2021-2020

[25] Institute of Geography and Spatial Organization Polish Academy of Science. Available online: https://www.igipz.pan.pl/Bioklima-zgik.html (accessed on 22nd February 2023)

[26] Republic Hydrometeorological Service of Serbia (RHSS). Available online: http://www.hidmet.gov.rs/latin/meteorologija/klimatologija_godisnjaci.php (accessed on 03rd February 2023).

[27] Đorđević, S. (2008). Temperature and Precipitation Trends in Belgrade and Indicators of Changing Extremes for Serbia. Geog. Pannon., 12(2), 62-68, https://doi.org/10.5937/GeoPan0802062D