DOI:10.28974/idojaras.2025.3.4

IDŐJÁRÁS

Quarterly Journal of the HungaroMet Hungarian Meteorological Service
Vol. 129, No. 3, July – September, 2025, pp. 307–337

Bioclimate conditions in the Mura-Drava-Danube Transboundary Biosphere Reserve – case study from Serbia

Jelena Dunjić [1], **Vladimir Stojanović** [1], **Dragan Milošević** [2], **Milana Pantelić** [1,*], **Sanja Obradović** [3], and **Milica Vasić** [3]

[1] *University of Novi Sad, Faculty of Sciences, Chair of Geoecology*
Trg Dositeja Obradovića 3, Novi Sad, Serbia

[2] *Wageningen University and Research, Meteorology and Air Quality Group*
6705 Wageningen, Netherlands

[3] *University of Novi Sad, Faculty of Sciences, Department of Geography, Tourism and Hotel Management;*
Trg Dositeja Obradovića 3, Novi Sad, Serbia

**Corresponding Author e-mail: milanap@dgt.uns.ac.rs*

(Manuscript received in final form September 17, 2024)

Abstract—The territory of the Mura-Drava-Danube Transboundary Biosphere Reserve is large and includes natural and built-up areas that local communities and tourists use during their outdoor work-related or recreational activities. These activities are affected by the outdoor thermal conditions, especially in the age of changing climate. In this paper we investigate micrometeorological and outdoor thermal comfort conditions in different natural and built-up environments at the area of the Bačko Podunavlje Biosphere Reserve. We chose one clear and calm day every month from October 2020 to June 2021, and performed measurements simultaneously at three different locations: settlement, riverside, and lake at midday hours. The results showed that thermal conditions differ between the different built-up and natural areas, and built-up areas tend to experience up to 7% less cold stress during the colder period than the other two sites according to the physiological equivalent temperature (PET) index. On the other hand, built-up area experiences more frequent strong and extreme heat stress during the warmer months. These and more detailed results presented in the paper indicate the most comfortable periods for outdoor activities in different natural or built-up environments.

Key-words: Mura-Drava-Danube Transboundary Biosphere Reserve, micrometeorological measurements, thermal comfort, physiological equivalent temperature (PET), modified physiological equivalent temperature (mPET)

1. Introduction

Biosphere reserves are *'learning places for sustainable development'*. They serve as testing grounds for interdisciplinary approaches to understanding and dealing with changes and interactions between social and ecological systems, in addition to conflict prevention and management of biodiversity. They are places that tackle global challenges by providing local solutions. The main idea that is promoted by establishing biosphere reserves is to offer solutions reconciling the conservation of biodiversity with its sustainable use. There are currently 738 biosphere reserves in 134 countries, including 22 transboundary sites (*https://en.unesco.org*).

According to *Pool-Stanvliet* and *Coetzer* (2020), biosphere reserves have a responsibility to promote and support interdisciplinary and transdisciplinary research that is relevant to society. The complex interaction between people and the natural environment is embedded in biosphere reserves, and it is this interconnectedness that drives sustainability science. Their aim is to conserve biodiversity, demonstrate sustainable development, undertake research and monitoring, and educate and train at the local level.

In the large area of Bačko Podunavlje Biosphere Reserve (BPBR), there are both natural areas and built-up areas - settlements whose population lives and works inside the biosphere reserve area. Built-up areas mainly consist of mid-rise family houses, which are not very densely built. Natural areas inside the BPBR are complex and different in terms of vegetation types, species, and presence of water bodies (see details in Section 2.1). Along with the global climate change issues, various types of land use and land cover influence the microclimatological conditions and thermal characteristics in different areas of the biosphere reserve. Climate change impacts land use by altering vegetation patterns, affecting agricultural practices, and shifting biodiversity, and can lead to both challenges, such as increased extreme weather events and water scarcity, and opportunities, such as extended growing seasons and new agricultural prospects. The area of BPBR is large with multiple types of human activities, such as agriculture, forestry, fishing, tourism, etc. Tourism activities in biosphere reserves are encouraged as a part of their sustainable development strategy (*Mondino* and *Beery,* 2019). As stated by *Jamaliah* and *Powell* (2017), ecotourism development in biosphere reserves require further adaptation planning and policies, to ensure robust and proactive measures that are capable of responding to climate change threats. Nature based touristic activities, such as activities in biosphere reserves are mostly performed outdoors, so they require fine weather and comfortable thermal conditions (*Milošević et al.,* 2020). Impacts on these biological systems are driven by natural processes, such as climate change and human development. Therefore, knowledge about climate and biometeorological conditions in specific areas is important for adequate planning of human activities and sustainable development of the area. Analyses of the instrumental records represent the best available means to document recent climate change (*Hamilton et al.,* 2020).

In this study we analyzed the 10-year data from the nearby Sombor official meteorological station. The data from Sombor official station included morning, midday, and evening records (0700, 1400, 2100 CET). Based on that data we selected midday hours as the hours when most human activities take place. Additionally, we performed a series of micrometeorological measurements in three different sites inside the Bačko Podunavlje Biosphere Reserve (BPBR). The sites represent different types of environments, one built-up, and two natural sites: blue and green. These sites were selected because of their specific natural conditions, but also because of the activities of the local population that live and work in this area, and visitors who often come to the riverside and lake for recreation.

Site specific micrometeorological studies were already used in various studies and areas. Some of them examined the impact of different level of built-up areas and the presence of green and blue areas (e.g., *Milošević et al.* 2022a, 2022b; *Vasić et al.,* 2022), or effects of artificial and natural shade including the efficiency of different types and location of the vegetation (e.g., *Colter et al.* 2019; *Milošević et al.* 2017), or the effects of different cooling strategies (e.g., *Vanos et al.,* 2020; *Anderson et al.,* 2022). These studies indicate that there are differences in thermal conditions even if they are located at a close distance from each other. However, most of the studies that are dealing with natural and protected areas rely on the data obtained from the official weather stations, without assessment of site-specific thermal conditions (*Bleta et al.,* 2014; *Brosy et al.* 2014; *Basarin et al.,* 2014, 2018; *Pecelj et al.,* 2017; *Błażejczyk et al.,* 2021a). Consequently, usually the analyses were done using the average monthly or daily data. As stated in *Basarin et al.* (2014), daily and hourly values of air temperature, relative humidity, wind speed, precipitation, and cloud cover would be beneficial for better understanding different bioclimatic conditions of the area. These are the gaps that present study fills. Even though previous studies do not provide site specific data, they provide very useful insight into long-term conditions.

There are fewer studies dealing with bioclimatic conditions of non-urban areas compared to the studies that assess urban bioclimatic conditions. However, the ones that do bioclimatic analysis of the non-urban areas, usually use indices such as physiological equivalent temperature (PET) (*Farajzadeh* and *Matzarakis,* 2012; *Basarin et al.,* 2014; *Milošević et al.,* 2020), or universal thermal climate index (UTCI) (*Basarin et al.*, 2017; *Pecelj et al.*, 2017; *Błażejczyk et al.,* 2021b). It is found that these indices are suitable for bioclimatic assessment, because they are easy to understand and use ºC as a unit which is familiar for majority of people.

The aim of this study is to evaluate the impact of different surroundings (built-up area, green-blue area, and blue area) of a protected area on human bioclimatic conditions, using the measured data from specific micro-locations. Such measurements give insight into the specific microclimatological conditions of the area, that have an impact on human outdoor activities. The main objective of measurements was to identify the most convenient environments in midday hours during the different seasons (autumn, winter and summer). The study of *Błażejczyk et al.* (2021a) shows that for active forms of recreation in natural environments, autumn, winter, and spring months are more convenient than summer months due to very oppressive weather in summer months, especially in south (Serbia, southern Ukraine). Due to the fact that weather/climate influences and affects people during their activities, it is useful to examine the bioclimatic conditions, and to apply a classification and assessment (*Matzarakis,* 2006, 2010). Micrometeorological measurements of this kind provide valuable information for human activities planning according to the most comfortable hours of the day, which contributes to sustainable development of the area (*Milošević et al.,* 2020). Investigating bioclimatic conditions in these sites contributes to planning mentioned activities and sustainable management of the area.

2. Study area, data, and methods

2.1. Study area

The Bačko Podunavlje Biosphere Reserve (BPBR) is situated on the peripheral northwestern part of Serbia, western part of the Autonomous Province of Vojvodina, that is in the west of its geographical-historical unit – Bačka. Towards the inner part of Serbia, the border of the biosphere reserve is drawn towards the borders of cadastral municipalities of numerous settlements. Biosphere reserve covers an area of 176,635 ha, within which there are three zones: a core (11,242 ha), a buffer zone (45,744 ha), and a transition zone (119,649 ha). Since 2021, the Bačko Podunavlje Biosphere Reserve has been an integral part of the the first transboundary UNESCO Biosphere Reserve (Mura-Drava-Danube Biosphere Reserve), that stretches across five countries Austria, Slovenia, Croatia, Hungary, and Serbia (*UNESCO,* 2022). The population of the biosphere reserve is estimated at 147, 405 inhabitants. They live in 26 settlements (according to the results of the latest census in 2011), in the town of Sombor and municipalities Odžaci, Bač, and Bačka Palanka (*Obradović et al.,* 2021).

Natural and cultural values of the Bačko Podunavlje Biosphere Reserve are, through the territories of the neighboring countries, connected with 700 kilometers long ecological corridor along the Mura, Drava, and Danube rivers. The Mura-Drava-Danube Biosphere reserve is also known by the informal name "European Amazon" (*Stojanović,* 2018). The area of the Bačko Podunavlje Biosphere Reserve is the largest conserved floodplain complex in the upper course of the Danube River in Serbia, and one of the largest floodplains along the middle section of the Danube. The area has a specific combination of ecological conditions: it is situated in the contact zone between the central and southeastern European forest zone with steppes, and it has characteristic hydrological dynamics. The primary habitats are: alluvial forests, Pannonian salt steppes and salt marshes, mesotrophic standing waters, natural eutrophic lakes, muddy river shores, alluvial wetlands, wet meadows, sand deposits, river islets, sand shores, floodplains, oxbows, abandoned river beds, meanders (*UNESCO,* 2016). The floodplain complex along the Danube has rich fauna, in particular: Bechstein's bat (*Myotis bechsteinii*), otter (*Lutra lutra*), and red dear (*Cervus elaphus*). A prime butterfly area (PBA) called "Gornje Podunavlje"exists in Bačko Podunavlje Biosphere Reserve: In total, 156 taxa of butterflies have been recorded in this area. The floodplain is also very important as a fish spawning site (*UNESCO,* 2022). The area of the BPBR includes five protected areas: the Gornje Podunavlje Special Nature Reserve, the Karađorđevo Special Nature Reserve, the Tikvara Nature Park, the Šuma Junaković Nature Heritage Site, and the Bukinski Hrastik Regional Nature Park (*Tucakov,* 2018).

According to the Köppen-Geiger climate classification, this region has a Cfb climate (temperate climate, fully humid, and warm summers, with at least four Tmon ≥ + 10 °C) (*Kottek et al.*, 2006). The mean monthly air temperature ranges from −0.1 °C in January to 21.9 °C in July. The mean annual precipitation is 612 mm. Average wind speeds are from 1.7 m/s for SSW direction to 3.1 m/s for N direction (*Milošević et al.,* 2020).

2.2. Data and methods

In this study we used two datasets:

1. For background information we used long-term data from Sombor meteorological station, for the period 2010–2019.
2. For the specific bioclimatic assessment in three particular sites, monthly series of micrometeorological measurements (from October 2020 to June 2021) was performed using Kestrel 5400 Heat Stress Meter.

General long-term climate characteristics of the BPBR area are assessed with data from the official meteorological station of Sombor (45° 46' N 19° 09' E, 88 m a.s.l.). This station is operated by the Republic Hydrometeorological Service of Serbia and is closest to the area of interest (63–66 km away from all three locations). Sombor meteorological station is located in natural surroundings bordering the suburban area (*Milošević et al.,* 2020). Since the distance of the Sombor official station from the areas of interest is quite large, micrometeorological campaign was performed monthly from October 2020 to June 2021. The measurement sites are located at a short distance from each other inside the Bačko Podunavlje Biosphere Reserve, but they are different in terms of vegetation types, presence of water bodies, and a level of build-up area. These locations include village Vajska (built-up area), lake Provala (blue area), and Berava as southern part of small river Živa, in the past meander of the Danube (blue and green area) (*Fig. 1*).

The measurement campaigns were planned and conducted in the following manner. We chose one clear and calm day every month from October 2020 to June 2021, and performed measurements simultaneously at three different locations: settlement Vajska (grey/ built-up area), riverside Berava (green-blue area), and lake Provala (blue area). Measurements were performed from 12:00 to 15:00 p.m. (Central European Time CET). Midday hours were selected for measurements, because during these hours wind speeds and cloud cover are low. Measurement data for November 2020 and March 2021 were not presented due to the high percent of missing values (>5%) for globe temperature (T_g), which affect the calculation of mean radiant temperature (T_{mrt}) and consequently the PET and mPET outcome. The analysis of the results was done by splitting the results in colder (October, December, January, February) and warmer (April, May, June) months.

We used three mobile Kestrel 5400 Heat Stress Trackers (*Fig. 1*) to measure air temperature (T_a in °C), relative humidity (*RH* in %), wind speed (v in m^{-1}), and globe temperature (T_g in °C) with one-minute temporal resolution. 1-minute values were later averaged to 15-minute values for the analysis. The measurements were performed at approximately 1.1 m height representing the center of gravity of the human body for standing subjects (ISO 7726*,* 1998). The Kestrel Heat Stress Trackers were deployed at least 10 minutes before the start of the measurement time to allow sensors to adjust to the atmospheric conditions at the site. The instruments were calibrated according to the manufacturers specifications, and their accuracy complies with ISO 7726 (1998) standards for sensor measurement range and accuracy (*Table 1*). Similar measurement settings were already used in previous studies (*Milošević et al.,* 2020*,* 2022).

Fig. 1. Study area and measurement instruments in three different sites: 1) blue-green area – riverside Berava; 2) blue area – lake Provala and 3) built-up area – settlement Vajska (Source: photos by authors; *figure by Stojanović* and *Savić,* 2013)

Table 1. Accuracy, resolution, and range of Kestrel 5400 Heat Stress Tracker sensors

Sensor	Accuracy (+/-)	Resolution	Range
Air temperature	0.5 ºC	0.1 ºC	-29.0 to 70.0 ºC
Relative humidity	±2% RH	0.1% RH	10 to 90 % 25 ºC non-condensing
Wind speed	Larger than 3% of reading, least significant digit of 20 ft/min	0.1 m/s	0.6 to 40.0 m/s
Globe temperature	1.4 ºC	0.1 ºC	-29.0 to 60.0 ºC

For the bioclimatic analysis and outdoor thermal comfort assessment, mean radiant temperature (T_{mrt}), physiologically equivalent temperature (PET) and modified physiologically equivalent temperature (mPET) were selected. T_{mrt} is calculated using the formula from *Thorsson et al.,* (2007):

$$Tmrt = \left[(Tg + 273.15)^4 + \frac{1.1 \cdot 10^8 \cdot v^{0.6}}{\varepsilon \cdot D^{0.4}} \cdot (Tg - Ta) \right]^{1/4}$$

where air temperature, T_a, globe temperature, T_g, and wind speed, v were obtained from in situ measurements, D represents the globe diameter (mm), and ε is the globe emissivity.

With the calculated T_{mrt}, and measured values for T_a, RH, and v, including default values for personal characteristics (age, height, weight, clothing, and work metabolism), we calculated PET and mPET values for each of the measurement sites. The physiologically equivalent temperature (PET) index is one of the most commonly used thermal indices in temperate climates (*Pecelj et al.,* 2021; *Coccolo,* 2016), and it uses widely known unit (°C), which makes the interpretation of the results easier for people less familiar with human biometeorology (*Brosy et al.,* 2014). According to *Höppe* (1999), PET represents "the air temperature at which, in a typical indoor setting (without wind and solar radiation), the energy budget of the human body is balanced with the same core and skin temperature as under the complex outdoor conditions to be assessed". PET index is based on a two-node thermo-physiological heat-balance model (Munich Energy-balance Model for Individuals (MEMI)), and the mean radiant temperature (T_{mrt}) (*Höppe,* 1999).

The modified physiologically equivalent temperature (mPET) is developed by *Chen* and *Matzarakis* (2018). It uses a multi-node heat transport model equal to the Fiala model (*Fiala et al.,* 2001), and a self-adapting multi-layer clothing model, which simulates water vapor resistance. Due to the integration of clothing variability according to the thermal conditions, mPET gives improved, more realistic representation of human thermal comfort (*Chen* and *Matzarakis,* 2018). The calculations of both PET and mPET indices were performed using the RayMan model (*Matzarakis et al.*, 2007, 2010b). PET classes are categorized according to thermal sensation and physiological stress level of humans (*Matzarakis* and *Mayer,* 1996) and are presented in the *Table 2*. mPET uses the same classification scale.

Table 2. PET index threshold values for the thermal sensation and the physiological stress level of humans (after *Matzarakis* and *Mayer,* 1996).

PET (ºC)	Thermal sensation	Physiological stress level
<4.1	Very cold	Extreme cold stress
4.1–8.0	Cold	Strong cold stress
8.1–13.0	Cool	Moderate cold stress
13.1–18.0	Slightly cool	Slight cold stress
18.1–23.0	Comfortable	No thermal stress
23.1–29.0	Slightly warm	Slight heat stress
29.1–35.0	Warm	Moderate heat stress
35.1–41.0	Hot	Strong heat stress
>41.0	Very hot	Extreme heat stress

3. Results

3.1. Background information

The data for background information on weather conditions in the study area are obtained from the official weather station in Sombor. This weather station records the values of meteorological conditions at 7:00, 14:00, and 21:00 (CET). *Fig. 2* shows average values of air temperature and relative humidity for the period 2010–2019.

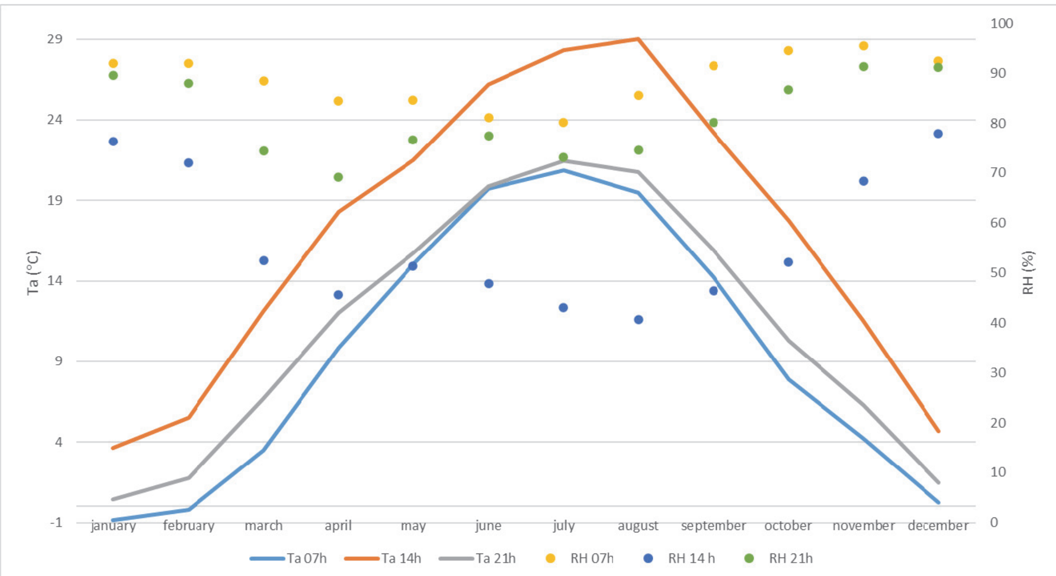

Fig. 2. Climate data obtained from Sombor official meteorological station (average values of T_a and *RH*) for the period 2010-2019 at 7:00, 14:00 and 21:00 (CET).

The results show that the temperatures are positive most of the time, except for the early morning temperatures in January and February. As expected, the highest T_a and the lowest *RH* are observed in the midday hours (14:00). It can also be noticed that the dynamics of *RH* values are showing direct inverse relationship to air temperature, which has already been reported in previous studies (e.g., *Yang et al.,* 2020; *Dunjić et al.,* 2021).

If we compare 10-year (2010-2019) average monthly midday hour (14:00) T_a and *RH* values from the official weather station (in Sombor) with the average measured T_a and *RH* values in the three selected sites: 1) blue-green area – riverside Berava; 2) blue area – lake Provala, and 3) built-up area – settlement Vajska, we can notice that the values are slightly different (*Table 3*).

Table 3. 10-year average monthly midday (14:00) T_a and *RH* values (official weather station Sombor) and average measured T_a valuesin three selected sites in the biosphere reserve

Site	**October**	**December**	**January**	**February**	**April**	**May**	**June**
Sombor	17.7	4.7	3.6	5.5	18.3	21.5	26.2
Site 1-R	20.5	4.8	4.8	14.5	22.6	25.9	30.7
Site 2-L	19.4	4.7	5.6	13.5	22.0	25.6	31.4
Site 3-S	20.0	5.0	5.4	13.1	23.9	26.5	30.8

Higher air temperatures in the specific sites in the biospehere reserve during the measurement days compared to the 10-year monthly average from the official weather station is observed in almost all months except for the winter months, December and January. This is due to the selection of the micrometeorological measurement days, where calm and clear days were chosen. Data from the official weather station in Sombor represent averaged monthly data at 14:00 (CET), from the 10-year period, which included clear and cloudy days. When it comes to micrometeorological measurements, calm and clear days are usually selected, because they secure minimal wind interference, stable atmospheric conditions, accurate solar radiation measurements, and reduced possibilities for errors by the device. Stable conditions provide that measurements are representative to the selected micro-location, because many instruments tend to be sensitive to rapid changes in environmental conditions (strong winds, precipitation, cloud cover that block or diffuse solar radiation, etc.), which can cause errors or require frequent recalibration (*Arya*, 2001; *Oke*, 1987). Other reason for this difference is that official weather station is located not very close to the measurement sites, but that is the closest that exists. The official weather station in Sombor is approximately 65 km away from the measurement locations, so T_a and *RH* data obtained from this station served as the background referent dataset but cannot be representative for the microclimatological conditions at the certain sites. Therefore, we performed a series of micrometeorological measurements, to provide more detailed assessment of bioclimatic conditions inside the biosphere reserve.

3.2. Micrometeorological measurements

3.2.1. Air temperature

In the colder period (October, December 2020, and January, February 2021), the highest average air temperature was observed at the riverside (T_{aver}=11.15 ºC). In the other two locations (settlement and lake), the average air temperatures in the colder period were slightly lower (T_{aver}=10.9 ºC and 10.77 ºC respectively). The maximum average air temperature was also recorded at the riverside (T_{max}=23.4 ºC), while lower average maximum temperatures were observed at the lake Provala (T_{max}=21.90 ºC), and settlement Vajska (T_{max}=20.95 ºC). At the settlement measurement site, the highest minimum temperatures were recorded (T_{min}=2.90 ºC). The largest temperature range (20.80 ºC) and standard deviation (6.80) were observed at the riverside measurement location (*Table 4*).

In the warmer period, however, the highest average air temperature was observed in the settlement (T_{aver}=27.11 ºC), while at the other two locations average air temperatures were lower and quite similar (T_{aver}=26.42 ºC at the riverside, and 26.37 ºC at the lake). The highest extreme air temperatures (maximum and minimum) were also observed in the settlement (T_{max}=33.25 ºC, and T_{min}=22.55 ºC), while slightly lower maximum and minimum air temperatures were observed at other locations. The lake measurement site had the largest temperature range (12.99 ºC). Standard deviations were lower in warmer period compared to the colder period, and their values ranged from 3.07 (settlement) to 4.08 (lake).

Table 4. Main statistical characteristics of air temperature (T_a), globe temperature (T_g), relative humidity (*RH*), wind speed (*v*), Mean Radiant Temperature (T_{mrt}), physiologically equivalent temperature (PET) and modified physiologically equivalent temperature (mPET) in diverse urban environments of the Bačko Podunavlje Biosphere Reserve in the colder period (measurement period October, December, January, February; 12-15 CEST), and in the warmer period (measurement period April, May, June; 12–15 CEST).

	Ta			Tg			RH			v			Tmrt			PET			mPET		
Envir.	**S**	**R**	**L**	**S**	**R**	**L**	**S**	**R**	**L**	**S**	**R**	**L**	**S**	**R**	**L**	**S**	**R**	**L**	**S**	**R**	**L**
Colder period (October, December, January, February; 12-15 p.m. CEST)																					
Aver.	10.90	11.15	10.77	19.95	18.05	17.92	56.67	57.81	58.08	0.97	1.24	1.29	39.41	34.67	36.17	18.14	15.49	15.60	19.50	17.17	17.29
max	20.95	23.40	21.90	34.32	33.20	31.75	79.20	81.40	82.10	1.57	2.18	2.43	64.88	59.77	68.48	35.40	33.70	32.10	32.70	31.50	30.40
min	2.90	2.60	3.67	6.44	3.87	4.90	36.95	39.60	39.85	0.41	0.00	0.00	9.88	3.14	7.06	3.90	-0.30	0.90	7.80	3.90	5.10
range	18.05	20.80	18.23	27.88	29.33	26.85	42.25	41.80	42.25	1.15	2.18	2.43	55.00	56.63	61.42	31.50	34.00	31.20	24.90	27.60	25.30
stdev	6.24	6.80	6.17	9.59	9.54	8.81	13.14	14.22	13.58	0.29	0.46	0.59	17.57	16.34	18.51	10.88	11.04	10.32	8.62	8.91	8.29
Warmer period (April, May, June; 12-15p.m. CEST)																					
Aver.	27.11	26.42	26.37	40.15	39.44	39.59	40.52	42.10	42.09	0.72	0.93	1.07	59.49	61.98	63.60	41.37	41.07	41.38	37.72	37.45	37.76
max	33.25	32.45	32.79	49.75	51.25	49.90	57.13	68.80	64.71	1.27	2.00	2.11	75.39	78.68	87.32	52.60	54.90	55.70	46.30	48.20	49.00
min	22.55	19.70	19.80	28.30	27.80	28.52	29.76	29.69	28.25	0.00	0.00	0.17	28.30	27.80	33.86	27.60	26.80	27.60	26.50	26.90	26.90
range	10.70	12.75	12.99	21.45	23.45	21.38	27.37	39.11	36.46	1.27	2.00	1.94	47.09	50.88	53.45	25.00	28.10	28.10	19.80	21.30	22.10
stdev	3.07	3.59	4.08	5.16	6.60	6.71	8.81	10.41	10.25	0.23	0.45	0.55	9.51	12.92	14.35	6.00	7.44	8.48	4.58	5.72	6.59

Note: Abbreviations of measurement locations are as follows: S - settlement, R - riverside, L - lake

More detailed insight into temporal variability of air temperature at the three measurement locations is presented in *Figs. 3* and *4,* where the differences between the air temperatures between measurement sites are presented. In the colder period, air temperature differences recorded in December were quite similar at all locations, and their variability was low (between -1 °C and 1 °C) during the measurement hours. Similar results were observed in the January measurement campaign, but with a higher temperature range (between -2 °C, in the early afternoon, and 1.5 °C). In October, the air temperatures, in general, were higher than in other months from the colder period. Therefore, the air temperature differences were higher and more dynamic than in other colder months. The greatest differences were observed between the riverside and lake (~10 °C), where the air temperature was higher by the lake, in the early afternoon hours, but later in the midafternoon, the air temperature was higher by the riverside. Similar dynamics but with a lower temperature range were observed between the settlement and the lake. Inverse dynamics was observed between the settlement and river, where in the early afternoon, air temperatures were higher in the settlement than by the riverside, but lower in the settlement than by the riverside in the later afternoon. In February, the most intensive differences were observed in temperature differences between the riverside and lake (up to almost 9 °C). Similar dynamics, but with a lower temperature range were noticed when observing the differences between the other two locations. The observed differences in air temperature between the locations can be attributed to different topoclimatic conditions, but also to local weather patterns. Different topoclimatic conditions at each site contribute to diffeences in air temperature and its variability. For example, the lake site has a moderating effect on temperature, leading to higher temperatures in its surroundings during the early afternoon as the water absorbs and slowly releases heat. On the other hand, the riverside experiences more dynamic temperature changes due to the moving water, which may cool the surrounding area in the early afternoon but can warm up quickly later in the day as solar radiation increases. The differences observed between the settlement and the riverside and lake sites can also be linked to topoclimatic influences, such as urban heat retention in the settlement due to built-up structures and slightly reduced vegetation. The inverse dynamics observed between the settlement and the riverside sites likely result from the differences in heat retention. Local weather patterns such as varying cloud cover, wind patterns, or humidity levels could enhance or mitigate the temperature differences at specific times of day. Additionally, the influence of the broader climate conditions cannot be neglected, as it sets the overall context, within which these topoclimatic and weather-related effects occur.

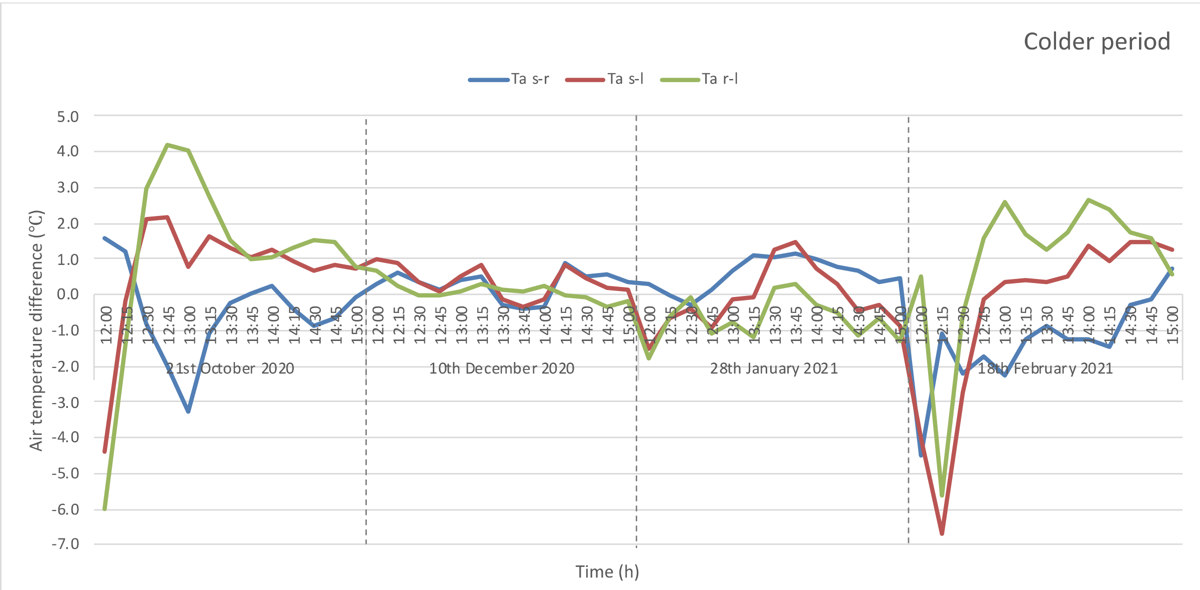

Fig. 3. Temporal variability of differences in air temperature at the three measurement locations in the colder period.

In the warmer period (*Fig. 4*), the dynamics between temperature differences were also observed but with the lower ranges than in the colder months. The highest temperature differences were observed in May 2021, between the riverside and lake measurement locations (up to 8 °C). In April 2021 and June 2021, the most intensive differences (up to 4 °C and 5 °C, respectively) occurred between settlement and riverside, in the early afternoon.

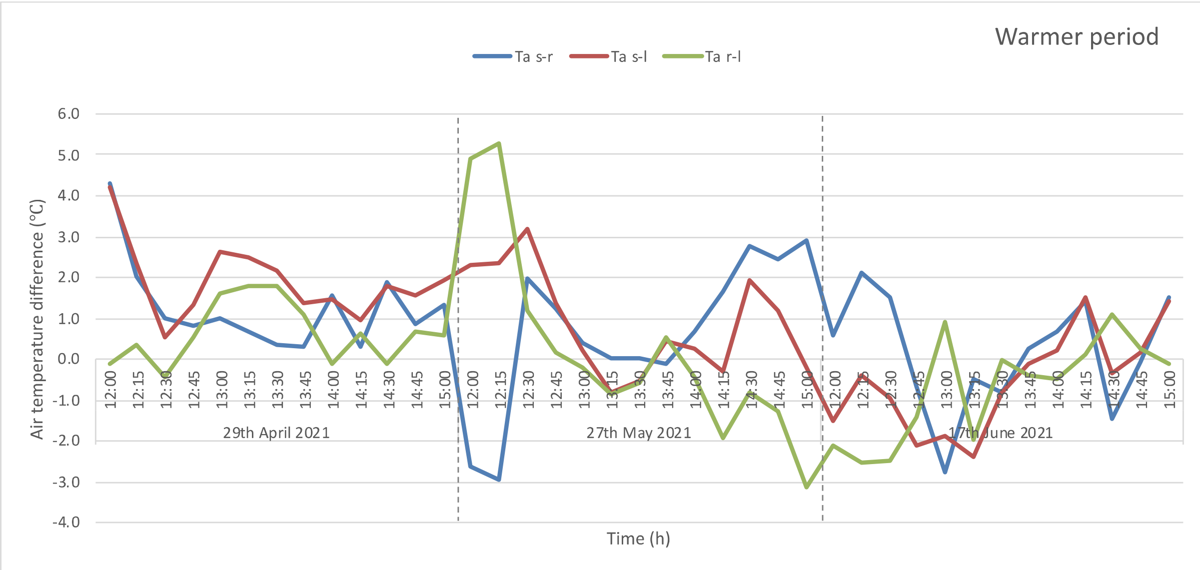

Fig. 4. Temporal variability of differences in air temperature at the three measurement locations in the warmer period.

3.2.2. Relative humidity

In the colder period (October, December, 2020 and January, February, 2021), average relative humidity values were the same at the lake and riverside measurement sites (RH_{aver}=58%), and slightly lower in the settlement (57%). Similarly, the highest maximum and minimum relative humidity values were observed at the lake measurement site, followed by the riverside and the settlement site (*Table 3*).

In the warmer period (April, May, and June 2021), the average relative humidity values at the riverside and lake sites were the same (42% and 42%), while at the settlement site, a slightly lower value of average relative humidity was observed (41%). The values of maximum and minimum *RH* were observed at the riverside site, and this site showed a larger range than the other two locations (*Table 3*).

Temporal dynamics of *RH* in colder period (Fig. 5) show the greatest differences between the riverside and lake measurement sites in the earlier hours (around noon). In February the differences between the two sites go up to ~14%, and higher levels are observed at the lake site. The lowest differences occur between the settlement and riverside sites (up to ~7% higher *RH* in settlement earlier hours). In the colder period, it is possible that at some sites *RH* values are different than expected. For example, at the settlement site in the early afternoon hours *RH* is higher than at the riverside site. This is likely to happen when the temperature in settlement is higher during the night hours, which causes higher overnight moisture retention in the air, and the moisture is not fully evaporated by noon which leads to higher *RH* values in the settlement site. Additionally, built-up structures in the settlement act as barriers that reduce wind speed and affect mixing of the air. With less wind, moisture tends to stay trapped near the surface of the settlement area which can cause higher *RH* values.

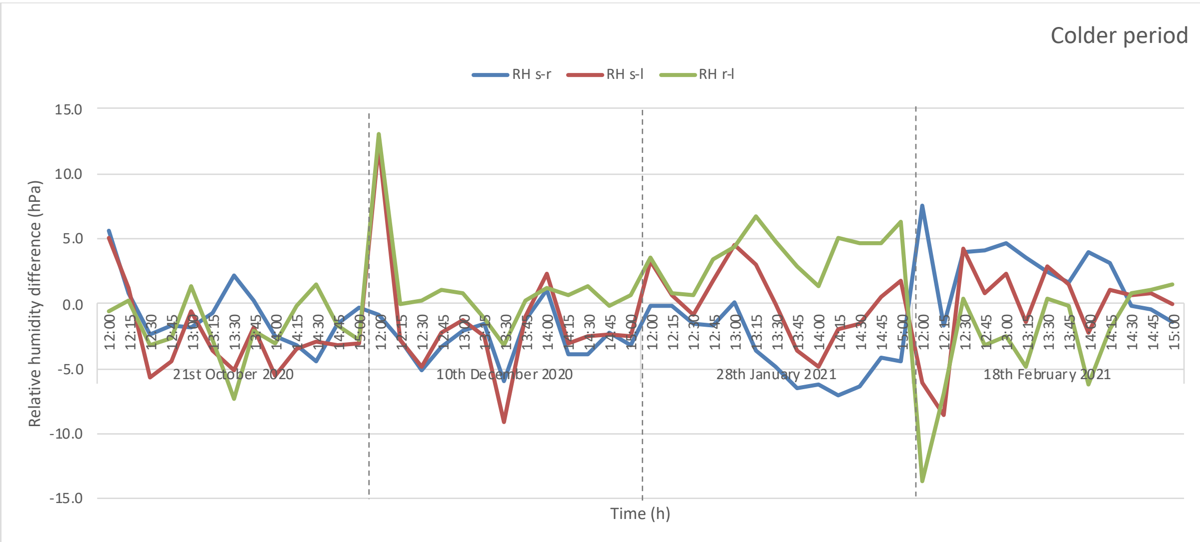

Fig. 5. Temporal variability of differences in relative humidity at the three measurement locations in the colder period.

Temporal dynamics of *RH* in the warmer period (Fig. 6) is similar as in the colder period. The greatest differences are observed between the settlement and riverside sites in April, when *RH* was up to 14% higher at the riverside than in the settlement.

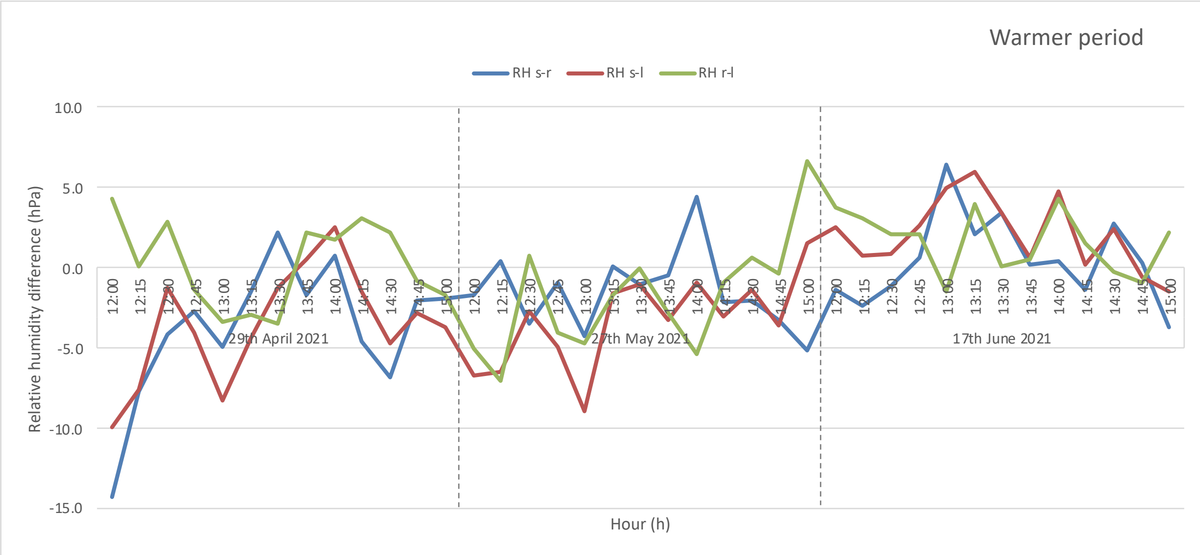

Fig. 6. Temporal variability of differences in relative humidity at the three measurement locations in the warmer period.

3.2.3. Globe temperature

In the colder period, on average, T_g was up to 2 °C higher in the settlement than in the other two locations (*Table 3*). Maximum and minimum T_g values are also observed in settlement. However, in the warmer period, the average difference between the measurement sites was lower (less than 1 °C). It is nteresting that maximum and minimum T_g values were observed at the riverside site. However, the differences are very low (less than 1 °C). More detailed temporal dynamics of T_g is showed in *Figs. 7* and *8*.

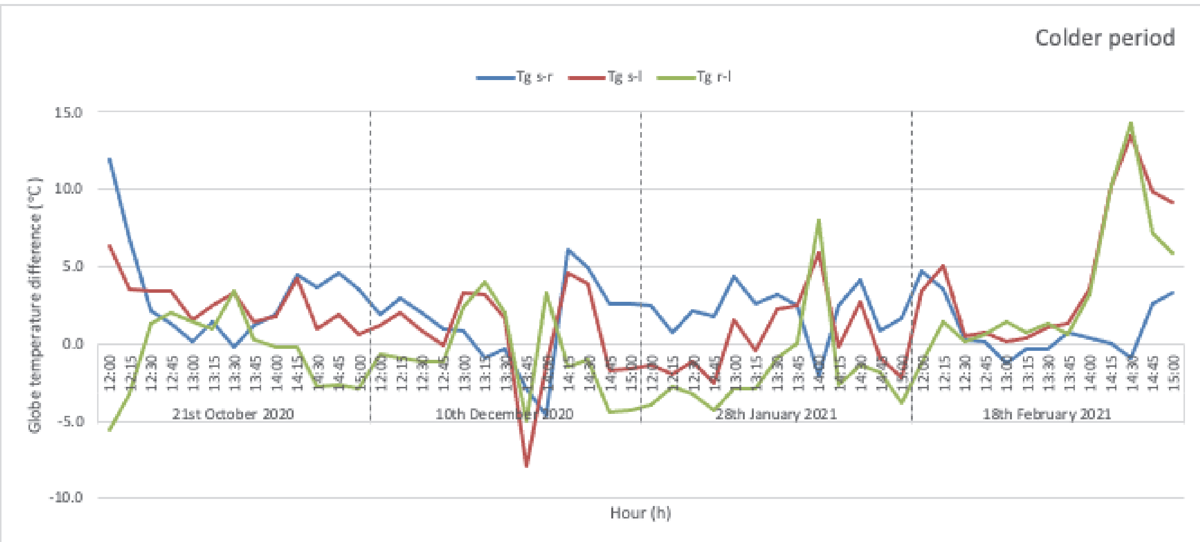

Fig. 7. Temporal variability of differences in globe temperature at the three measurement locations in the colder period.

Temporal dynamics in the colder period shows that larger differences between the sites occurred in the later measurement hours. The largest difference in T_g (~14 ºC) was observed between the riverside and lake site in February in the later measurement hours (*Fig. 7*). This could be due to the temporal cloud cover presence at the lake site that reduced the impact of solar radiation, which affected globe temperature that absorbs radiant heat from all directions, allowing the thermometer to give an integrated measure of the thermal environment (ASHRAE, 2017).

In the warmer period, the largest differences were observed in June around noon, when T_g was 21 ºC higher by the lake than by the riverside. In the earlier warmer months, T_g showed low differences among the measurement sites (*Fig.* 8).

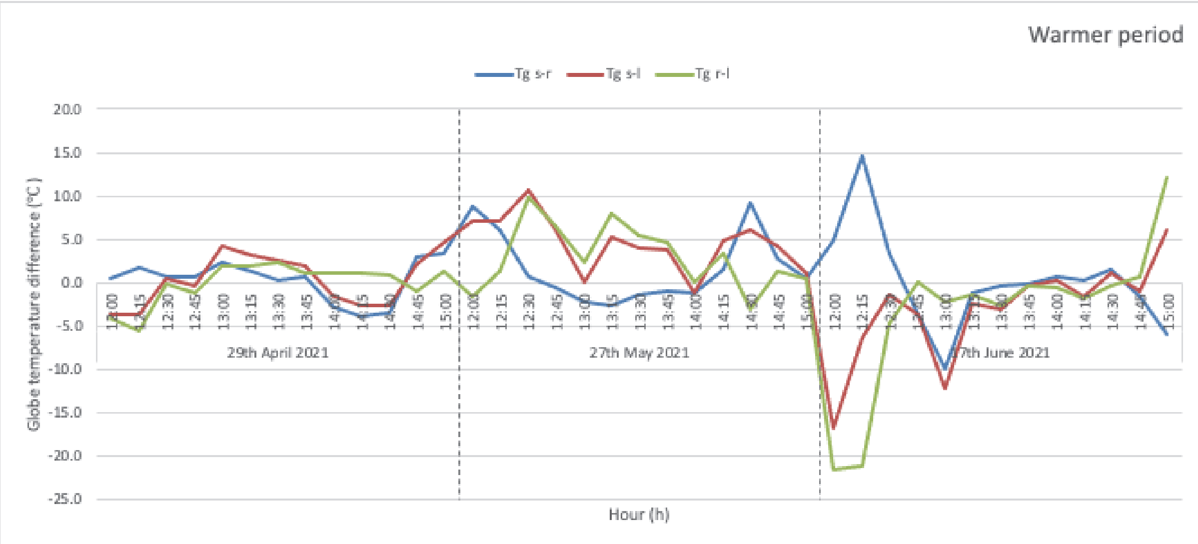

Fig. 8. Temporal variability of differences in globe temperature at the three measurement locations in the warmer period.

3.2.4. Wind speed

In this type of microclimate measurements, usually calm and clear days are selected (e.g. *Milošević et al.,* 2020*,* 2022a, 2022b). Therefore, we selected calm days with lower wind speeds for this measurement campaign. As it is shown in *Table 3*, the higher average and maximum wind speeds in both colder and warmer periods were observed by the lake (v_{aver}=1.29 m/s), followed by the riverside site (v_{aver}=1.24 m/s). In the settlement the average windspeeds were the lowest (v_{aver}=0.97 m/s). This is due to the nature of the measurement sites, and slight differences in the presence of natural and built barriers (vegetation, buildings). The differences did not show any regular pattern between the sites, so a detailed temporal analysis is not provided.

3.3. Bioclimatological parameters

3.3.1. Mean radiant temperature

The highest average values of T_{mrt} in the colder period are observed in the settlement ($T_{mrt\ aver}$ = 39.41 ºC), followed by the lake site ($T_{mrt\ aver}$ = 36.17 ºC), and slightly lower values are observed at the riverside site ($T_{mrt\ aver}$ = 34.67 ºC). Maximum values, however, are calculated at the lake site ($T_{mrt\ max}$ = 68.48 ºC), followed by the settlement site ($T_{mrt\ max}$ = 64.88 ºC), and the riverside site ($T_{mrt\ max}$ = 59.77 ºC). In the settlement, the highest minimum values are recorded ($T_{mrt\ min}$ = 09.88 ºC), followed by the lake site ($T_{mrt\ min}$ = 07.06 ºC), and the riverside site ($T_{mrt\ min}$ = 03.14 ºC) in the colder period (*Table 3*).

In the warmer period, the highest average T_{mrt} is calculated for the lake site ($T_{mrt\ aver}$ = 63.60 ºC), followed by the riverside site ($T_{mrt\ aver}$ = 61.98 ºC) and the settlement ($T_{mrt\ aver}$ = 59.49 ºC) (*Table 3*).

Temporal analysis of T_{mrt} in colder period indicates that in most colder months the settlement had higher T_{mrt} values compared to two other sites. It also shows that the greatest differences occurred in later measurement hours. However, the largest difference is observed between riverside and lake in February afternoon, and the measured difference was 44.6 ºC (*Fig. 9*). The lake site is likely to have lower T_{mrt} due to the cooling effect of larger water body, that can absorb significant thermal mass and release it slower than vegetated areas, and built-up areas. On the other hand, settlement site experiences higher T_{mrt} due to the presence of buildings and roads, that can absorb and re-emit the heat faster.

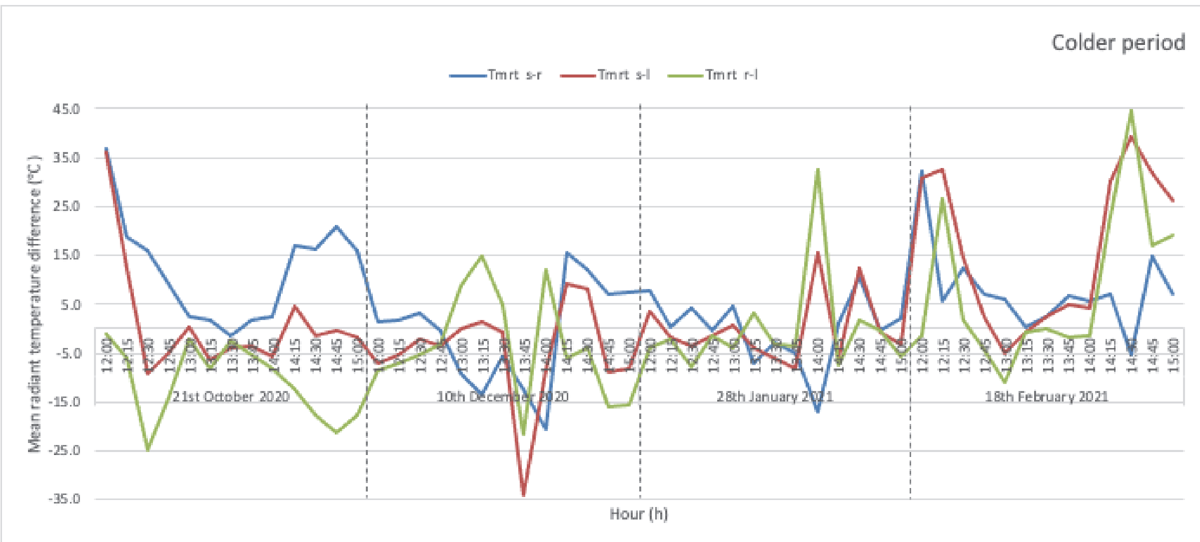

Fig. 9. Temporal variability of differences in mean radiant temperature at the three measurement locations in the colder period.

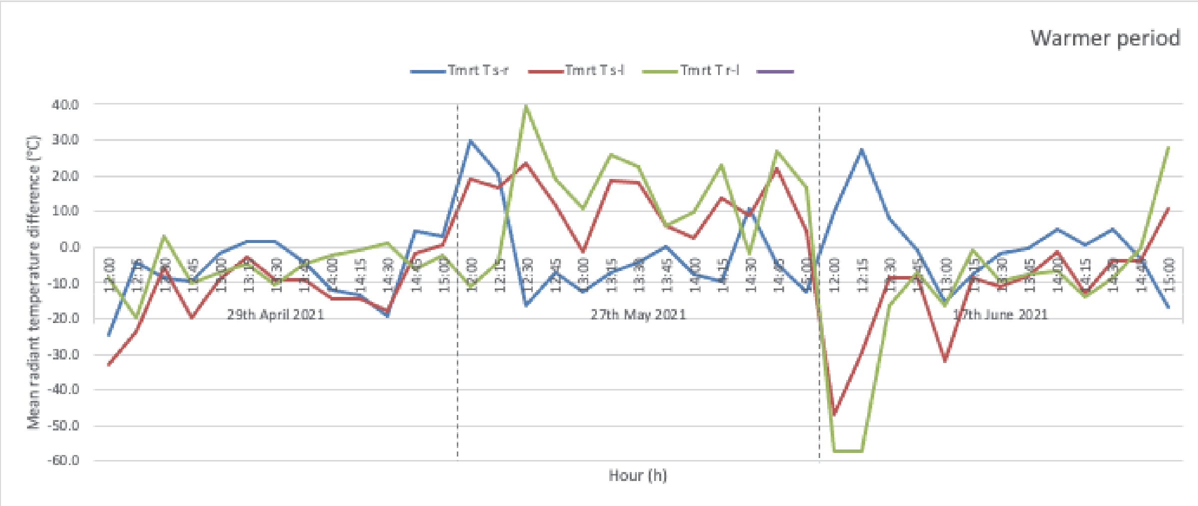

Fig. 10. Temporal variability of differences in mean radiant temperature at the three measurement locations in the warmer period.

Temporal analysis in the warmer period (Fig. 10) shows that the dynamics of T_{mrt} differences among the sites is lower than in the colder period, especially in April. In May, the highest differences between the riverside site and the lake site are observed (up to 40 ºC). In June, the difference in T_{mrt} between the riverside and lake site peaked, but in opposite direction, which means that the values of T_{mrt} at the lake site were 57 ºC higher than at the riverside site around noon. By the end of the measurements, the differences between the sites were lower. In all three warmer months, the most prominent differences occurred in the early measurement hours, around noon. That indicated the influence of the different shading effects on T_{mrt} on each site (*Milošević et al.,* 2022b) in times of high exposure to solar radiation (*Aminipouri et al.,* 2019).

3.3.2. PET and mPET – colder period

Table 3 shows that in the colder period, the highest average PET and mPET values are recorded at the settlement site (PET_{aver} = 18.14 ºC; $mPET_{aver}$ = 19.50 ºC) followed by the lake and riverside site where very similar average PET values are calculated (PET_{aver} = 15.60 ºC and PET_{aver} = 15.49 ºC, respectively). Similar results are observed for the mPET index values for the lake and riverside site ($mPET_{aver}$ = 17.29 ºC and $mPET_{aver}$ = 17.17 ºC, respectively). This means that on average, settlement is under no thermal stress, while lake and riverside site are under slight cold stress (13-18ºC), in colder months. The highest maximum PET values are also recorded in the settlement site (PET_{max}=35.4 ºC), which indicates that strong heat stress occasionally happens in the colder months in the settlement site. However, maximum mPET value is lower in settlement ($mPET_{max}$=32.7 ºC), indicating the presence of moderate heat stress. In other sites, there is occasional moderate heat stress, when maximum PET and mPET values are recorded. Minimum PET values (<4.1 ºC) show that there is extreme cold stress observed in all three sites during the colder period (*Table 3*). Minimum mPET values indicate the presence of an occasional extreme cold stress only at riverside site, while at the settlement site and lake sites, minimum mPET values indicate the occurrence of strong cold stress (*Table 3*). These results of short term, location-specific micro-measurements are in good accordance with the previous study by *Basarin et al.* (2014) that examined PET in the broader area of Gornje Podunavlje Special Nature Reserve, using the long-term data from the official Sombor meteorological station. They reported the occurrence of extreme cold stress (PET_{aver}<4 °C) in the period from December to February.

Temporal analysis of PET in the colder period is shown in *Fig. 11a*. In October, the differences between the measurement sites were larger in the beginning of the measurement hours, around noon. The greatest difference was recorded between the settlement site and riverside site (peak $PET_{diff\ s\text{-}r}$=14.6ºC). In the other three months (December, January, and February), the greatest differences occurred in the afternoon, around 2 p.m. During most of the measurement time, settlement site showed higher PET values comparing to both the riverside site and lake site. However, riverside site and lake site PET values did not show regular pattern in the colder period, but the PET values difference between them was the largest ($PET_{diff\ r\text{-}l}$=16.6ºC). These results are in good accordance with the T_{mrt} results.

Fig. 11b shows temporal variation of mPET values during the measurement hours. An almost identical trend as with PET values can be observed. The difference between the PET and mPET index values is that mPET values are slightly lower compared to the PET values.

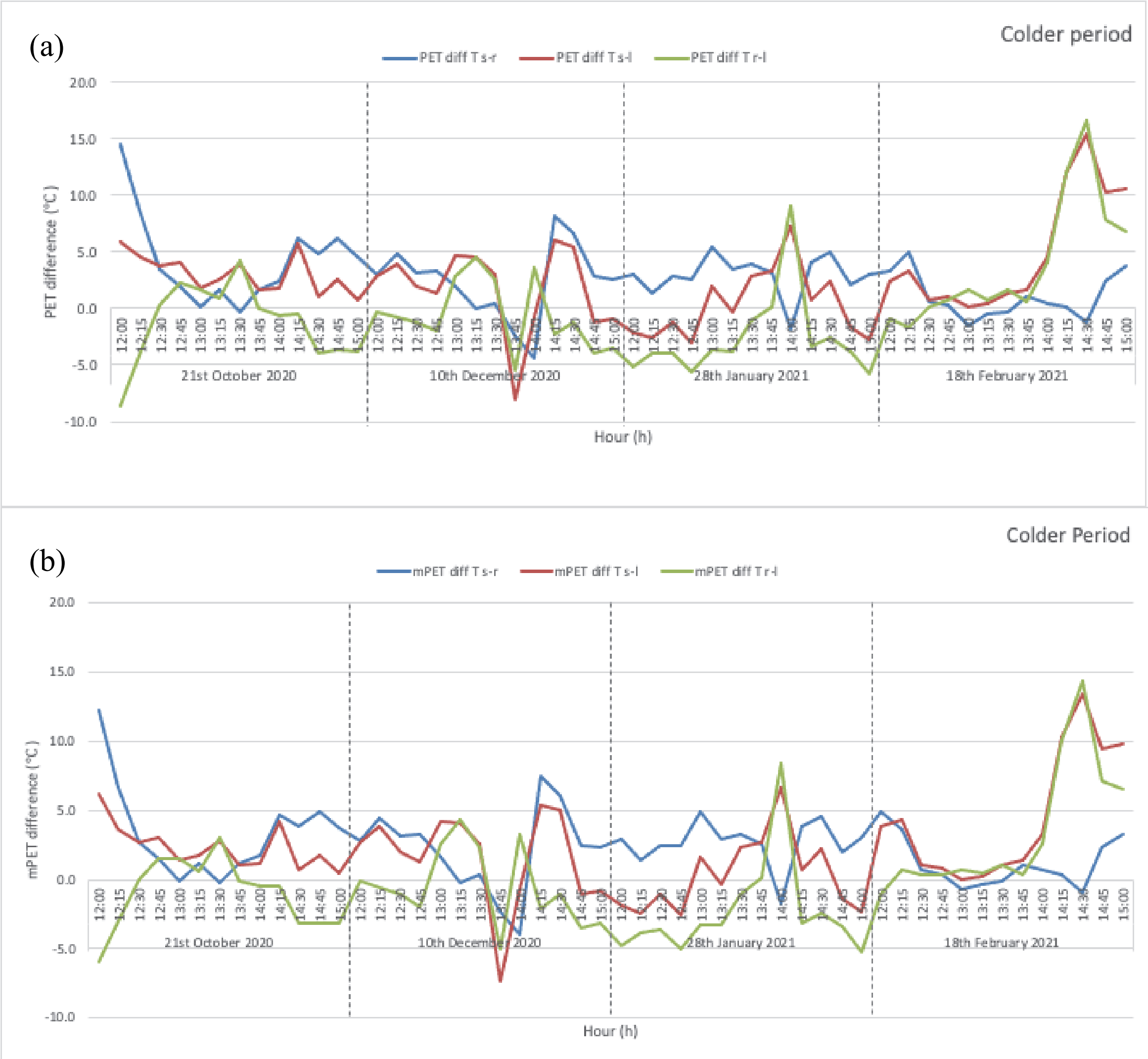

Fig. 11. Temporal variability of differences in PET (a) and mPET (b) values at the three measurement locations in the colder period.

Fig. 12a shows frequency analysis (%) of physiological stress according to the PET index in all three measurement sites. The results show that at the majority of the time, all three sites experience some level of cold stress, 58%, 56%, and 51%, at the lake, riverside, and settlement, respectively. Riverside site experiences extreme cold stress 23% of the time, while settlement site experiences moderate cold stress 29% of the time. However, there is a significant percent of heat stress for all three sites as well (46% at the settlement, 48% at the riverside, and 36% at the lake site) even though this is defined as colder period.

Fig. 12b shows the frequency of different levels of thermal stress according to the mPET index. According to the mPET values, all sites experience cold stress at almost half of the measurement time (53%, 49%, and 58% at the riverside, settlement, and lake site, respectively). Extreme cold stress occurs only at the riverside site very rarely (4%). Similarly to the PET values, mPET values show significant percent of heat stress, 39%, 46%, and 35% for the riverside, settlement, and lake site, respectively. High percent of the heat stress at the measurement sites occur because October is included in the colder period, and the thermal conditions were not as cold as in the other colder months (*Fig. 12*).

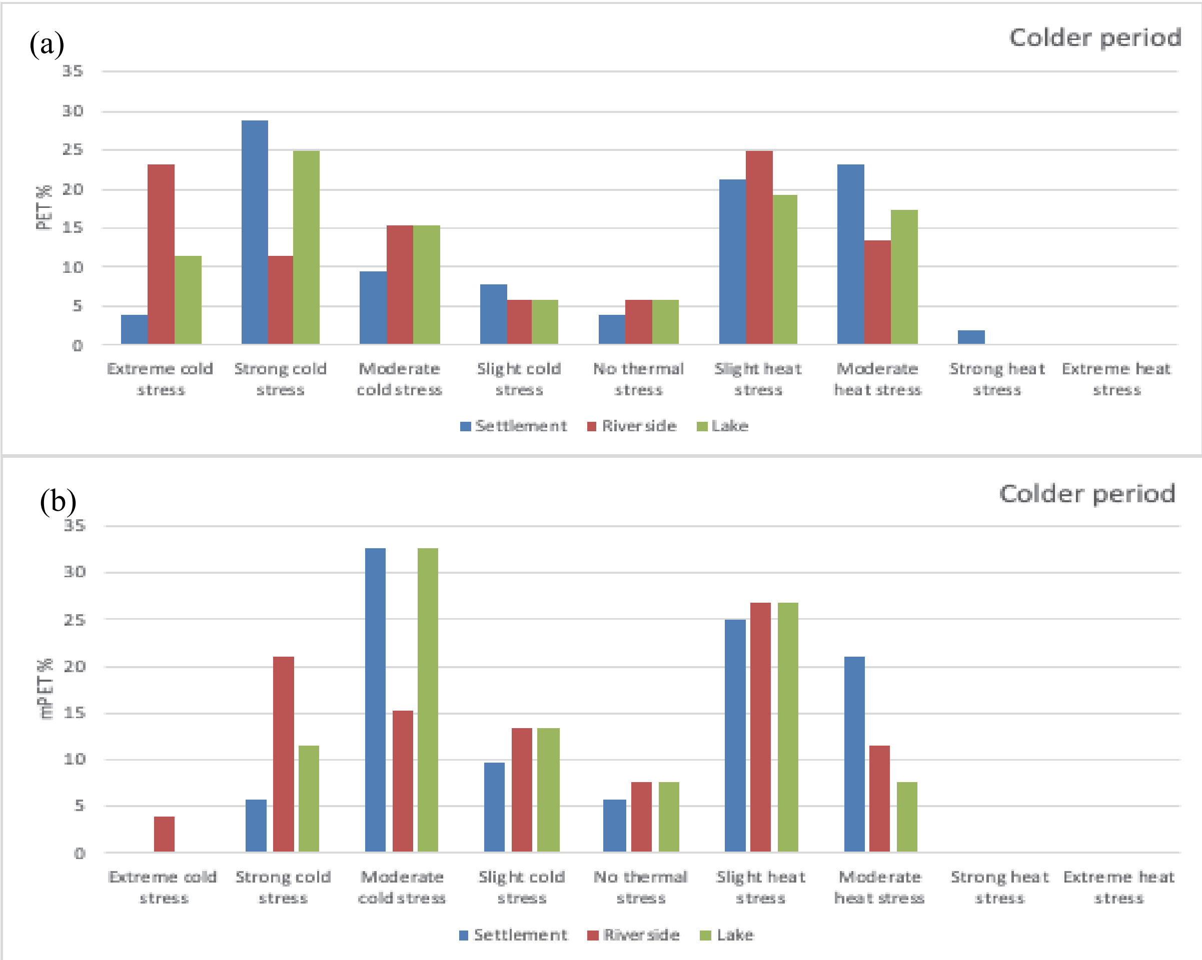

Fig. 12. Frequency analysis (%) of physiological stress according to PET (a) and mPET (b) indices at three measurement locations in colder period.

3.3.3. PET and mPET – Warmer period

In the warmer period, average PET values are quite similar for all of the three sites, with the differences less than 1 ºC. All three sites experience extreme heat stress during the warmer months in the midday hours (PET_{aver} = 41.37 ºC -

settlement, $PET_{aver} = 41.07$ ºC - riverside, $PET_{aver} = 41.38$ ºC -lake). Maximum PET values are recorded at the lake site ($PET_{max} = 55.7$ ºC) followed by the riverside site ($PET_{max} = 54.9$ ºC), and the settlemet site ($PET_{max} = 52.6$). Minimum PET values are similar for all three sites (differences less than 1 ºC), and it means that even when taking minimum PET values for all three sites in the warmer period during the midday hours, there is slight heat stress (*Table 3*).

mPET values for the warmer period show strong heat stress for all three sites, and the differences between the sites are also less than 1ºC ($mPET_{aver} = =37.72$ ºC - settlement, $mPET_{aver} = 37.45$ ºC - riverside, $mPET_{aver} = 37.76$ ºC - lake). Maximum mPET values for all three sites also indicate extreme heat stress, and similarly to the PET values, mPET values are the greatest at the lake site ($mPET_{max} = 49$ ºC), followed by the riverside site ($mPET_{max} = 48.2$ ºC), and settlement site ($mPET_{max} = 46.3$ ºC). Also, minimum mPET values are rather similar at all three sites, and also indicate the presence of the slight heat stress (*Table 3*).

Temporal analysis of PET values in the warmer period (*Fig. 13a*) shows that the dynamics of PET differences among the sites is lower than in the colder period, especially in April. In May, the differences between the measurement sites were slightly larger (up to 13.8 ºC between the riverside and lake sites). In June, the difference in PET values between the riverside and lake site peaked in opposite direction, meaning that the values of PET at the lake site were 26 ºC higher than at the riverside site around noon. By the end of the measurements, the differences between the sites were lower. The results are in good accordance with the results of the T_{mrt} analysis.

Fig. 13b shows temporal variation of mPET values during the warmer period. Almost identical trend as with PET values is recorded. The difference between the PET and mPET index values is that mPET values are slightly lower compared to the PET values. This trend is also noticed at the analysis of the colder period values of PET and mPET.

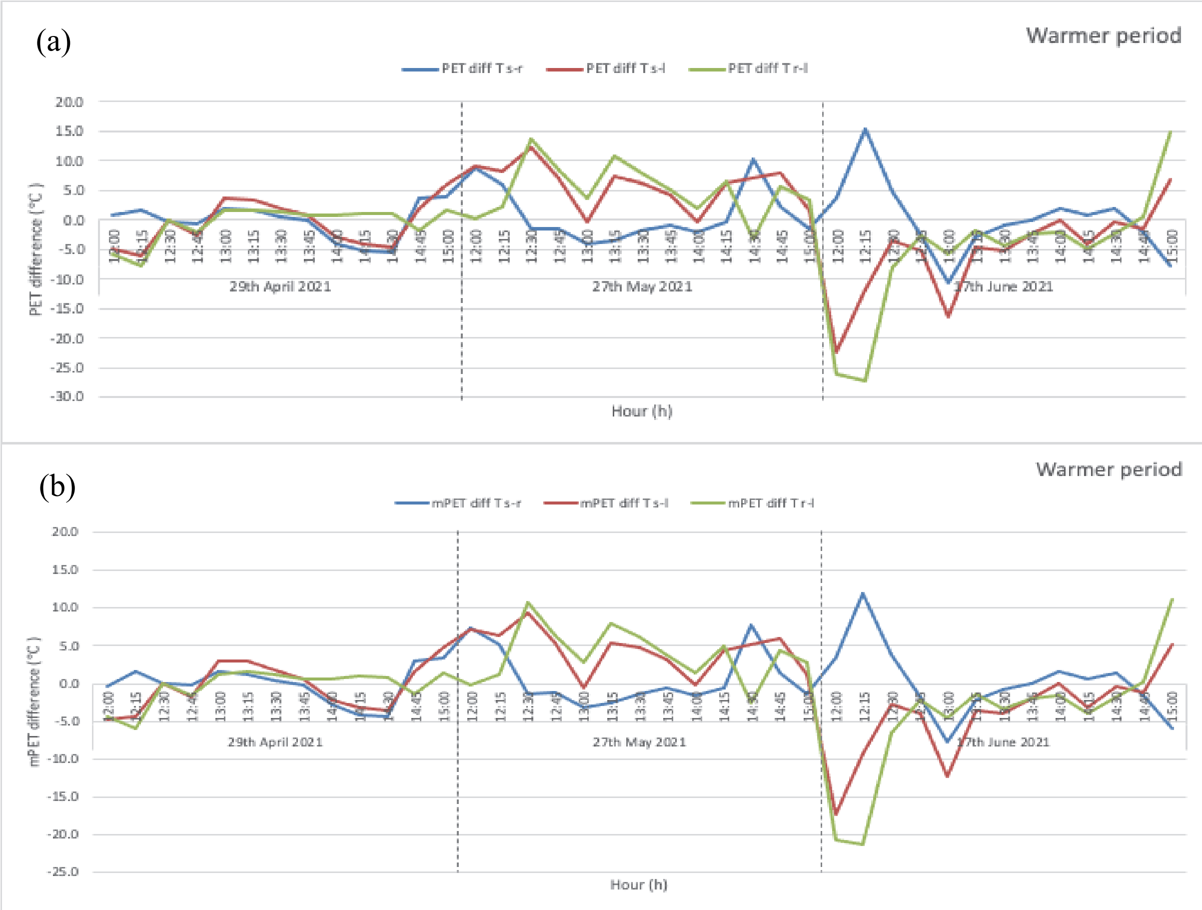

Fig. 13. Temporal variability of differences in PET (a) and mPET (b) values of the three measurement locations in the warmer period.

Frequency analysis of the PET values (*Fig. 14a*) in the warmer period show that all the measurement sites experienced some level of heat stress during the measurement campaigns in the warmer months. The settlement and riverside sites experienced extreme heat stress almost at 50% of the measured period. At the lake measurement site, strong heat stress was the most frequent thermal sensation. Slight and moderate heat stresses were noticed at about 10% of the measurement period. This means that all three sites experienced most frequently strong and extreme strong heat stress during the warmer months and during the midday hours (12–15h).

Frequency analysis of the mPET index (*Fig. 14b*) shows also that in the warmer period all sites are under some level of heat stress. The interesting thing is that the lake site according to the mPET index experiences moderate, strong, and extreme heat stress almost equally frequent. On the other hand, the settlement and riverside sites are under strong and extreme heat stress is more than 70% of the time in the midday hours.

It can be concluded that the lake site has more comfortable conditions compared to the settlement and riverside sites, due to the less frequent exposure to extreme heat stress. However, strong heat stress is often present at the lake site as well.

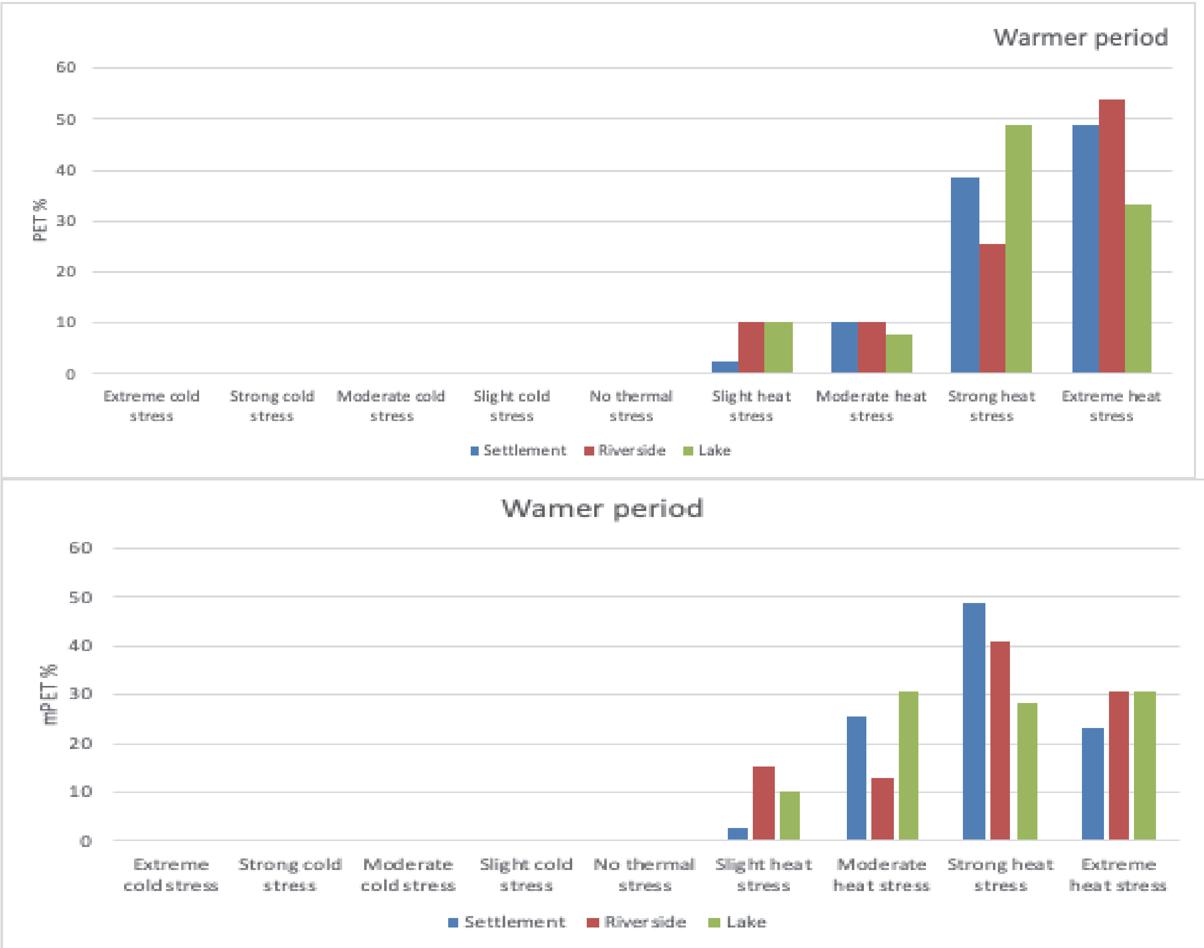

Fig. 14. Frequency analysis (%) of physiological stress according to PET (a) and mPET (b) indices at the three measurement locations in the warmer period.

4. Discussion

Natural areas such as the Mura-Drava-Danube Biosphere Reserve represent the corridor formed by the Danube and its tributaries, the Mura and Drava rivers, that forms a unique biotope network that is the habitat for many rare animal and plant species, and thus represents the most valuable continuous river landscape in Central Europe (*Mohl et al.,* 2020). At the same time, the definition of biosphere reserve states the importance of providing space for human activities as well. Therefore, it is important to analyze climate and bioclimate characteristics of the area, with respect to the natural and built-up environment and land use types at the specific sites. In our study, we selected two different natural sites and one built-up site to perform bioclimatic analysis using human thermal comfort indices PET and mPET. The results show that thermal conditions between them are different in different parts of the year. The observed differences in bioclimatic parameters across the sites, although not always following a regular pattern, highlight the complexity of microclimatic interactions within the biosphere reserve. These differences suggest that local factors such as vegetation cover, water proximity, and human activities play significant roles in shaping the bioclimatic conditions.

Bioclimatic analysis of physiological stress according to PET index in all three measurement sites show at that majority of the time, all three sites experience some level of cold stress, 58%, 56%, and 51%, at the lake, riverside and settlement sites, respectively. The settlement site experiences up to 7% less cold stress than the riverside and lake sites. However, there is a significant percentage of heat stress for all three sites as well (46% at the settlement, 48% at the riverside, and 36% at the lake site), even though this is defined as colder period. This could be explained by the fact that October was included in the colder period for the analysis, and temperatures in October are higher than in the rest of the colder months.

Bioclimatic analysis in the warmer period shows that all the measurement sites experienced some level of heat stress during the measurement campaigns in the warmer months. The settlement and riverside sites experience extreme heat stress almost at 50% of the measured period. At the lake measurement site, strong heat stress was the most frequent thermal sensation. Slight and moderate heat stresses were noticed at about 10% of the measurement period. This means that all three sites experience most frequently strong and extremely strong heat stress during the warmer months and during the midday hours (12–15h), but the settlement site experiences up to 7% more strong and extreme heat stress categories than the other two sites.

Bioclimatic analysis in this article is done using micrometeorological data, which is obtained by measurements in clear and calm days. It can vary in the circumstances when stronger wind, cloud cover, and precipitation are present. 10-year background data from the official weather station in Sombor show that the cloud cover is the lowest in summer months, and the highest in winter months, and the average cloud cover during the year is 5.3/10.

Previous studies (*Farajzadeh* and *Matzarakis,* 2012; *Basarin et al.,* 2014; *Milošević et al.,* 2020) have also used the PET index to investigate bioclimatic conditions of different natural areas enable the comparison with the present study. For example, *Basarin et al.* (2014) assessed long-term bioclimatic conditions in the Special Nature Reserve „Gornje Podnavlje“, which is part of the Mura-Drava-Danube Biosphere Reserve. They reported that the most comfortable thermal conditions for outdoor ativities occur in the autumn and spring months of the year. During the period from November until February, cold stress occurs in the reserve in more than 60% of the time (*Basarin et al.,* 2014). These results are in good accordance with the results from the present study, that also reports certain amount of cold stress in the colder part of the year (October to February) in both natural sites, and comfortable conditions only in the settlement site (according to PET_{aver}). *Basarin et al.* (2014) reported the highest amounts of heat stress during the meteorological summer season (June, July, and August), however, when analyzing the PET values of the midday hours (14h), they reported that heat stress occurs from May to September, and the periods with no thermal stress are observed in October and April. These results are confirmed in this study for the warmer period (April, May and June). In the study by *Milošević et al.* (2020) it is shown, that there are differences in thermal sensation and comfort at the same site but in different vegetation structures. They reported that there are differences in microclimatic conditions between the sites at even smaller distances in autumn (October 2019), where the most comfortable conditions during the midday hours are in the areas with the higher vegetation (forests), while in the more open areas, there is slight discomfort observed. In the present study, the differences between the different natural and built-up environments are emphasized.

Bioclimatic analysis provides us with very useful information about the differences in human thermal sensations that occur between the sites at different periods of the year. This is the first study that analyzed thermal conditions of the specific sites inside the large area of the transnational biosphere reserve, that are often used by local population and visitors. The information obtained indicates that the activities in the investigated sights should be organized according to the most comfortable period (*Milošević et al.,* 2020) of the year. For example, in the colder period of the year, tourists' activity should be encouraged in the more urbanized areas, promoting cultural heritage and social diversity of the BPBR. On the other hand, in the summer months, thermal conditions are more favorable at the lake site. Given the recreational function of the site, this is a reasonable choice. Local communities that perform other activities in the area, could also use this information to organize their work activities, if possible, in such manner that they avoid longer exposure in the midday hours in warmer months to prevent themselves from the heat stress related health issues.

Micrometeorological measurements of this kind provide valuable information for tourism zoning and visitors distribution according to the most comfortable periods of the year, which contributes to sustainable management of tourism activities (*Milošević et al.,* 2020). Though this study is the first micrometeorological field measurement conducted in this region, it gave important insights into micrometeorological differences between different natural and built-up environments. In order to contribute to long-term strategic planning of the activities and their sustainable management, longer measurements campaigns, more measurement sites in Serbian part, but also in parts of the reserve that belongs to other countries would be beneficial.

5. Conclusion

The area of BPBR is large and it belongs to an even larger area of the Drava-Mura-Danube Transboundary Biosphere Reserve. In the large area of the biosphere reserve, people are involved in all kinds of activities that require certain thermal conditions. In this study we gave the overview of the bioclimate conditions, in the colder and warmer parts of the year for specific, but different sites, to provide comprehensive results for all the users of the biosphere reserve area, including local population and visitors.

However, the study has its limitations, simultaneously the recommendations for future investigation.

- Measurement hours could be prolonged in order to identify the most comfortable time of the day for each location in different seasons. This implies that measurements should be done in all months of the year. Additionally, measurements in different weather types and climates could be performed.
- It would be useful to do similar studies in other countries that are part of the Mura-Drava-Danube Transboundary Biosphere Reserve and to compare the results.
- Bioclimatic questionnaire survey that accompanies the measurements would give more complete information about the thermal sensation of the locals and visitors the reserve.

The fact that the area selected for this study is a part of the first transnational park, the Mura-Drava-Danube Transboundary Biosphere Reserve indicates, that there is a significant potential that it becomes more popular for visits. Investigating climate conditions in the Bačko Podunavlje Biosphere Reserve (BPBR) might be the basis for planning human activities in order to preserve diverse natural and built-up areas in the BPBR in the age of climate change, as well as for sustainable use of natural resources of these fragile ecosystems. Extreme bioclimate conditions that occur in this area at certain hours can be considered as unsuitable for the activities of visitors and local population, while hours of lower levels of thermal stress or no thermal stress can be considered as good bioclimate conditions. Recognizing the variations in bioclimatic conditions is crucial for effective management of the protected area, as it emphasizes the need for tailored strategies that consider the unique microclimates of different zones within the reserve. The importance of these differences lies in their potential to influence decision-making processes related to habitat management, species conservation, and visitor activities. Integrating bioclimatic considerations into management plans can enhance the sustainability and usability of the biosphere reserve, aligning with the broader goals of conservation and sustainable development.

Acknowledgment: This research was supported by the Provincial Secretariat for Higher Education and Scientific Research, Autonomous Province of Vojvodina (Project 142-451-3485/2023-01/01). The authors gratefully acknowledge the financial support of the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Grants No. 451-03-66/2024-03/ 200125 & 451-03-65/2024-03/200125). The authors also acknowledge the financial support of the Ministry of Education, Science and Technological Development of the Republic of Serbia (Grant No. 451-03-9/2021-14/ 200125).

References

Aminipouri, M., Rayner, D., Lindberg, F., Thorsson, S., Knudby, A.J., Zickfeld, K., Middel, A. and *Krayenhoff, E.S.,* 2019: Urban tree planting to maintain outdoor thermal comfort under climate change: The case of Vancouver's local climate zones. *Build. Environ. 158*, 226–236. https://doi.org/10.1016/j.buildenv.2019.05.022

Anderson, V., Gough, W. A., Zgela, M., Milosevic, D., and *Dunjic, J.,* 2022: Lowering the Temperature to Increase Heat Equity: A Multi-Scale Evaluation of Nature-Based Solutions in Toronto, Ontario, Canada. *Atmosphere* 13(7), 1027. https://doi.org/10.3390/atmos13071027

Arya, S.P., 2001: Introduction to Micrometeorology (2nd ed.). Academic Press.

ASHRAE, 2017: *Handbook Fundamentals*. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).

Basarin, B., Kržič, A., Lazić, L., Lukić, T., Đorđević, J., Janićijević Petrović, B. Ćopić S., Matić D, Hrnjak I. and *Matzarakis, A.,* 2014: Evaluation of bioclimate conditions in two special nature reserves in Vojvodina (Northern Serbia). *Carpathian J. Earth Environ.Sci. 9* (4), 93–108. https://www.researchgate.net/publication/287307211_Evaluation_of_bioclimate_conditions_in_two_special_nature_reserves_in_Vojvodina_Northern_Serbia

Basarin, B., Lukić, T., Bjelajac, D., Micić, T., Stojićević, G., Stamenković, I., Đorđević J., Đorđević T. and *Matzarakis, A.,* 2018: Bioclimatic and climatic tourism conditions at Zlatibor Mountain (Western Serbia). *Időjárás 122*, 321–343. https://doi.org/10.28974/idojaras.2018.3.6

Błażejczyk, A., Pecelj, M., Błażejczyk, K. and *Skrynyk, O.,* 2021a: Weather suitability for outdoor tourism in three European regions in first decades of the twenty-first century. *Int. J. Biometeorol. 65*, 1339–1356. https://doi.org/10.1007/s00484-020-01984-z

Błażejczyk, K., Nejedlik, P., Skrynyk, O., Agnieszka, H., Skrynyk, O., Błażejczyk, A., and *Mikulova, K.,* 2021b: Influence of geographical factors on thermal stress in northern Carpathians. *Int. J. Biometeorol. 65*, 1553–1566. https://doi.org/10.1007/s00484-020-02011-x

Bleta, A., Nastos, P. T. and *Matzarakis, A.,* 2014: Assessment of bioclimatic conditions on Crete Island, Greece. *Reg. Environ. Change 14*, 1967–1981. https://doi.org/10.1007/s10113-013-0530-7

Brosy, C., Zaninovic, K., and *Matzarakis, A.,* 2014: Quantification of climate tourism potential of Croatia based on measured data and regional modeling *Int. J. Biometeorol. 58*, 1369–1381. https://doi.org/10.1007/s00484-013-0738-8

Chen, Y.C. and *Matzarakis, A.,* 2018: Modified physiologically equivalent temperature—Basics and applications for western European climate. *Theor. Appl. Climatol. 132*, 1275–1289. https://doi.org/10.1007/s00704-017-2158-x

Coccolo, S., Kämpf, J., Scartezzini, J.L. and *Pearlmutter, D.,* 2016: Outdoor human comfort and thermal stress: A comprehensive review on models and standards. *Urban Climate 18*, 33–57. https://doi.org/10.1016/j.uclim.2016.08.004

Colter, K.R., Middel, A. C. and *Martin, C.A.,* 2019: Effects of natural and artificial shade on human thermal comfort in residential neighborhood parks of Phoenix, Arizona, USA. *Urban Forestry Urban Green. 44*, 126429. https://doi.org/10.1016/j.ufug.2019.126429

Dunjić, J., Milošević, D., Kojić, M., Savić, S., Lužanin, Z., Šećerov, I. and *Arsenović, D.,* 2021: Air Humidity Characteristics in "Local Climate Zones" of Novi Sad (Serbia) Based on Long-Term Data. *ISPRS Int. J. Geo-inf. 10*(12), 810. https://doi.org/10.3390/ijgi10120810

Farajzadeh, H. and *Matzarakis, A.,* 2012: Evaluation of thermal comfort conditions in Ourmieh Lake, Iran. *Theor. Appl. Climatol. 107*(3), 451–459. https://doi.org/10.1007/s00704-011-0492-y

Fiala, D., Lomas, K., and *Stohrer, M.,* 2001: Computer prediction of human thermoregulatory and temperature responses to a wide range of environmental conditions. *Int. J. Biometeorol. 45*, 143–159. https://doi.org/10.1007/s004840100099

Hamilton, J.P., Whitelaw, G.S., and *Fenech, A.,* 2001: Mean annual temperature and total annual precipitation trends at Canadian biosphere reserves. *Environ. Monitor. Assess. 67*(1), 239–275. https://doi.org/10.1023/a:1006490707949

Höppe, P., 1999: The physiological equivalent temperature–a universal index for the biometeorological assessment of the thermal environment. *Int. J. Biometeorol.* 43(2), 71–75.

ISO 7726, 1998: Ergonomics of the thermal environment—instruments for measuring physical quantities. International Standard, 2nd edn. International Organization for Standardization (ISO), Geneva.

Jamaliah, M.M. and *Powell, R.B.,* 2017: Ecotourism resilience to climate change in Dana Biosphere Reserve, Jordan. *J. Sustain. Tourism 26*(4), 519–536. https://doi.org/10.1080/09669582.2017.1360893

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

Matzarakis, A. and *Mayer, H.,* 1996: Another kind of environmental stress: thermal stress. *WHO newsletter* 18, 7–10.

Matzarakis A., 2006: Weather- and climate-related information for tourism. *Tour Hosp Plan Dev 3*, 99–115.

Matzarakis, A., Rutz, F. and *Mayer, H.,* 2007: Modelling radiation fluxes in simple and complex environments—application of the RayMan model. *Int. J. Biometeorol. 51*(4), 323–334. https://doi.org/10.1007/s00484-006-0061-8

Matzarakis A., 2010a: Climate change: temporal and spatial dimension of adaptation possibilities at regional and local scale. In: (ed. *Schott C*) Tourism and the implications of climate change: issues and actions, Emerald Group. *Bridging Tourism Theory Practice 3*, 237–259. https://doi.org/10.1108/S2042-1443(2010)0000003017

Matzarakis, A., Rutz, F. and *Mayer, H.,* 2010b: Modelling radiation fluxes in simple and complex environments: basics of the RayMan model. *Int. J. Biometeorol. 54*(2), 131–139. https://doi.org/10.1007/s00484-009-0261-0

Milošević, D. D., Bajšanski, I. V. and *Savić, S. M.,* 2017: Influence of changing trees locations on thermal comfort on street parking lot and footways. *Urban forest. Urban Green. 23*, 113–124. https://doi.org/10.1016/j.ufug.2017.03.011

Milosević, D., Dunjić, J., and *Stojanović, V.,* 2020: Investigating micrometeorological differences between saline steppe, forest-steppe and forest environments in northern Serbia during a clear and sunny autumn day. *Geographica Pannonica* 24 (3), 176–186. https://doi.org/10.5937/gp24-25885

Milošević, D., Middel, A., Savić, S., Dunjić, J., Lau, K. and *Stojsavljević, R.,* 2022a: Mask wearing behavior in hot urban spaces of Novi Sad during the COVID-19 pandemic. *Sci. Total Environ. 815*, 152782. https://doi.org/10.1016/j.scitotenv.2021.152782

Milošević, D., Trbić, G., Savić, S., Popov, T., Ivanišević, M., Marković, M., Ostojić M., Dunjić J., Fekete R. and *Garić, B.,* 2022b: Biometeorological conditions during hot summer days in diverse urban environments of Banja Luka (Bosnia and Herzegovina). *Geographica Pannonica 26*(1), 29–45. https://doi.org/10.5937/gp26-35456

Mohl, A., Korn-Varga, I. and *Györfi, E.,* 2020: The ecological corridor Mura-Drava-Danube and future five-country biosphere reserve. IUCN Guidelines for Conserving Connectivity through Ecological Networks and Corridors, Series 30, 104–106.

Mondino, E. and *Beery, T.,* 2019: Ecotourism as a learning tool for sustainable development. The case of Monviso Transboundary Biosphere Reserve, Italy. *J. Ecotourism 18*(2), 107–121. https://doi.org/10.1080/14724049.2018.1462371

Oke, T. R., 1987: Boundary Layer Climates (2nd ed.). Routledge.

Obradović, S., Stojanović, V., Kovačić, S., Jovanovic, T., Pantelić, M. and *Vujičić, M.,* 2021: Assessment of residents' attitudes toward sustainable tourism development-A case study of Bačko Podunavlje Biosphere Reserve, Serbia. *J. Outdoor Recreat. Tourism 35*, 100384. https://doi.org/10.1016/j.jort.2021.100384

Pecelj, M., Đorđević, A., Pecelj, M., Pecelj-Purković, J., Filipović, D. and *Šećerov, V.,* 2017: Biothermal conditions on Mt. Zlatibor based on thermophysiological indices. *Arch. Biol. Sciences 69*(3), 455–461. https://doi.org/10.2298/ABS151223120P

Pecelj, M., Matzarakis, A., Vujadinović, M., Radovanović, M., Vagić, N., Đurić, D. and *Cvetkovic, 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

Pool-Stanvliet, R., and *Coetzer, K.,* 2020: The scientific value of UNESCO biosphere reserves. *South African J. Sci. 116*(1-2), 1–4. https://doi.org/https://doi.org/10.17159/sajs.2020/7432

Stojanović, V. and *Savić, S.,* 2013: Management challenges in special nature reserve'Gornje Podunavlje'and preparations for its proclamation of biosphere reserve. *Geographica Pannonica 17*(4), 98–105. https://doi.org/10.5937/GeoPan1304098S

Stojanović, V., 2018: What we have and what we are proud of. In (Ed. *Zagorac*), Bačko Podunavlje Biosphere reserve – Nature with people. Novi Sad: Provincial secretariat for urban planning and environmental protection. Institute for nature conservation of Vojvodine Province.

Thorsson, S., Lindberg, F., Eliasson, I., and *Holmer, B.,* 2007: Different methods for estimating the mean radiant temperature in an outdoor urban setting. *Int. J. Climatol. 27*, 1983–1993. https://doi.org/10.1002/joc.1537

Tucakov, M., 2018: Functions of the Biosphere Reserve. In (Ed. *Zagorac*), Bačko Podunavlje Biosphere Reserve - Nature with people. Novi Sad: Provincial secretariat for urban planning and environmental protection. Institute for nature conservation of Vojvodine Province.

UNESCO, 2016: Bačko Podunavlje Biosphere Reserve Nomination Form. Man and the Biosphere (MAB) Programme – Biosphere reserve nomination form – January 2013 – June, 2016.

UNESCO, 2022: Bačko Podunavlje Biosphere Reserve, Serbia. Retrieved January 19, 2022, from https://en.unesco.org/biosphere/eu-na/backo-podunavlje

Vanos, J.K., Wright, M.K., Kaiser, A., Middel, A., Ambrose, H. and *Hondula, D.M.,* 2020: Evaporative misters for urban cooling and comfort: effectiveness and motivations for use. *Int. J. Biometeorol. 66*, 357–369. https://doi.org/10.1007/s00484-020-02056-y

Vasić, M., Milošević, D., Savić, S., Bjelajac, D., Arsenović, D., and *Dunjić, J.,* 2022: Micrometeorological measurements and biometeorological survey in different urban settings of Novi Sad (Serbia). *Bull. Serbian Geograph. Soc. 102*(2), 45–66. https://doi.org/10.2298/GSGD2202045V

Yang, X., Peng, L. L., Chen, Y., Yao, L., and *Wang, Q.,* 2020: Air humidity characteristics of local climate zones: A three-year observational study in Nanjing. *Build. Environ. 171*, 106661. https://doi.org/10.1016/j.buildenv.2020.106661