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EFFECT OF VEGETATION STRUCTURE ON URBAN CLIMATE MITIGATION

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Vegetation formations are an important component in the urban structure, as they perform a wide range of ecosystem services there. The climate modification to improve the environmental and residential quality of the city is one of the important functions. The paper presents the results of the microclimate assessment in the chosen localities of Nitra town, Slovakia, with an emphasis on the stage and differences in air temperature and relative humidity. The climate elements were measured at 7 spatially different sites (sites A to G), each of them at two comparative sites, vegetation stand and open area. The largest average air temperature difference between the vegetation stand and the non-vegetation area was 1.2 °C at the locality D. The largest air temperature difference in the vegetation stands was measured between the street space (site E) and the city park (F), reaching 2.3–2.5 °C. The relative air humidity reached the highest differences between the park (locality F) and the street space (G) measured at 3:00–8:00. These reached 19.6% to 24.4% with higher relative humidity in the popular city park. The highest differences between the compared habitats were measured at locality G and averaged 9.6% at 04:00 – 07:00 in a preference to a tree canopy. The research results confirmed the importance of the vegetation structures in the process of mitigating the urban climate extremes and the environmental quality improving.

Keywords: urban vegetation structure, climate function assessment, mitigation effect

Currently, 50% of the world's population lives in cities, almost 73% in the European most urbanized regions, and is expected that by 2050 2/3 of the world's population will live in cities. The enormous growth of cities causes complex environmental problems. The environment of the city is influenced by global and local climate changes, pollution load from transport, industry and local heating sources. Current building materials and constructions such as concrete, iron, glass, asphalt, stone paving etc. have started modifying the atmospheric environment and mainly raising the city temperature (Kuttler, 2008).The urban planners, in accordance with the Athens Charter, applied the theory of dividing the urban settlements into functional zones, road traffic and pedestrian paths, together with involving large green areas of public parks and intra-block house vegetation in the urban structure (Supuka, 2002; Bryanet al.2008; Supuka, Feriancová et al., 2008). New trends are also being associated with the urban spaces' density increasing (Vitková, 2008; Supuka and Halajová, 2015). The density of built-up areas, growth of the cities, anthropogenic heat and prevalence of abiotic surfaces over the biologically active ones caused creation of the Urban Heat Islands (UHI). The measured results are known in Thessaloniki city, where the air temperature is by 2 – 2.5 °C higher, compared to the surroundings (Katsioura, Kosmopoulos and Zoras, 2012). Similar data were measured in the Chinese city of Bozhou with the average air temperature differences of 2.5–3.0 °C (Yang et al., 2016). As an example, we will present some results from the measurements in the Slovakian cities and their comparison with the adjacent open country. The city of Bratislava has an elevated average annual temperature of 1.1 °C., approximately the same difference values were also measured in the city of Košice (Lapin, 2007). In Brno city, The Czech Republic, the average differences between the urban spaces and the adjacent country were +4 °C in winter, from +3.6 to +3.8 °C in the other year seasons. An absolute maximum difference in summertime reached from +8 to +15 °C (Dobrovolný et al., 2012). The warming of the urban spaces is directly linked to the increase in the concentration of greenhouse gases in atmosphere. Ecosystem components have shown they are capable of removing the airborne pollutants and greenhouse gases, converting them, utilising and incorporating into the metabolic process. Measurement results in 55 US cities have show the ability of the urban assimilation organs to absorb NO_2, O_3, SO_2, PM_{10} in 2.7–14.5 $g^{-1}.m^{-2}$ leaf area (Nowak and Grane, 2006). It is one of the possible ways to reduce the potential of UHI in the urban spaces. Similar results were published through the research outputs in five Polish cities (Popek, Łukowski and Oleksyn, 2017). A direct mitigation of UHI through the

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shade and cooling effect of vegetation surfaces and the entire city green infrastructure system are the parts of the second form. Green spaces as a part of a green infrastructure complex fulfil multiple ecosystem services and improve the urban environmental and residential quality. The values of the positive effects of green spaces depend on their area, distribution within the urban structure and a share of tree elements. The degree of an effective influence of green spaces on the city environment quality is often expressed using the Green Indices, which express the ratio of the green areas to the built-up area of the city (Zhu et al., 2019). On the other hand, urban green areas are under high pressure from stressors, which inhibit their growth and health (Fornal-Pieniak, Ollik and Schwerk, 2019). Quality maintenance and a management of green spaces are a partial elimination of this factor. The urban vegetation overshadows the solar active surfaces, cools the air by evapotranspiration and reduces air pollutants and wind flow by its structure, which improves the urban environmental quality (Reháčková and Pauditsová, 2006; Keresztesová and Rózová, 2013; Tóth, Halajová and Halaj, 2015). The mitigation and equalization of the urban extreme climate values, due to the vegetation formations, was measured in different cities and reached by 1.5–2.5 °C (Norton et al., 2015), while the higher cooling effect was measured in summertime (leafy trees) and at higher air temperatures. The climate fugal effect of the large urban parks is also proven, up to an adjacent distance by 100–150 m of the built-up area (Supuka, 2002; Bowler et al., 2010). The cooling effect of the urban park vegetation was 2 °C higher on average compared to the open square and 2.5 °C in the street corridor at noon, with a maximum difference of up to 6 °C. Similarly, the relative humidity was by 10% higher in the park in comparison to the other sites (Spangenberg et al., 2008). Different tree species have different effects on the microclimate mitigation; therefore, their properties can be effectively used to improve the thermal comfort of indoor and outdoor urban areas (Tsutsumi, Ishii and Katayama, 2003). Reduction of solar radiation and mean radiation temperature depend on the tree species characteristics such as crown density, size and structure. The best shading effect was shown by massive solitary trees and dense canopy stands (Harbich et al., 2012). The surface temperatures in Fuzhou parks were measured by 4–8 °C lower than the non-green areas. Concerning the green areas greater than 10 hectares, the positive correlation and a good cooling effect was shown (Yu et al., 2018). When evaluating the microclimate factors of the urban vegetation (surface temperature and air humidity) in Nitra town, it was found that the cooling effect is dependent on the canopy shape and a tree crown cover and reaches a differential value of 0.55 °C to 1.83 °C, compared to the streets without any green areas (Klein and Rózová, 2017). The aim of the contribution is to present the microclimatic measurements in Nitra town territory with an emphasis on the differences in the compared areas of the urban green spaces and the open areas without greenery. The accent is put on an assessment of the importance of the green infrastructure elements in the mitigation of the urban thermal island characteristics and improving the urban dwelling environment.

Material and method

For the measurement of the climate characteristics, localities in a different urban structure and with a different share of the green areas in Nitra territory were chosen. We assumed that the different urban-spatial structure of the individual town segments will also be reflected in the different values of the measured climatic traits. The basic climatic elements, namely the air temperature and relative humidity, were measured. The chosen localities for the climate measurements consisted of the street, residential and park spaces. The assessed streets are oriented mostly in the north-south direction:

A/ **Locality A** – housing estate Chrenová with a low share of the built-up land and with 10 m height of the estate in average (4 residential floors). Among the blocks of flats, there are compact green spaces, while almost a size of 35 m^2 of the reserved greenery is available per inhabitant. The settlement is one of the first in the city with a progressive approach to the construction and planting large areas of the green spaces, which thus creates residential and recreational environment in a high quality.

B/ **Locality B** – Jesenského street, a mixed built-up area, a 10 m height of buildings in average, a street with only a two-sided tree alley that leads to the city park.

C/ **Locality C** – Moyzesova street, in the centre of the street, there has been a 8 m wide belt of the green area designed and surrounded by a tree alley. On both sides of the street, there are family houses of one floor height with gardens of a recreational and production character placed.

D/ **Locality D** – Bratislavská street, this street includes a commercial and an industrial part of the city with an average height of the buildings being 8 m. A four lane road runs through the street and leads to the highway. The vegetation elements consist of small grassy strips, which pass into the poplar tree line in the next section.

E/ **Locality E** – Farská street, this forms a part of the historical core of the monument zone of the city, the average height of the built-up area is almost 12 m, the street is only 8 m wide.

F/ **Locality F** – Štúrova street, this forms a relatively long transport corridor with a four lane road with high frequency of transport vehicles. The street width is approximately 30 m. The traffic route is on both sides separated from the pedestrian paths by a 6–8 m wide green belt with a mixed composition of trees, shrubs and grass areas.

G/ **Locality G** – Sihoť City Park, it was founded in the middle of the 19^{th} century and currently its area reaches 20 hectares. Dendrologically, it is very rich. In 2001, a total of 1516 trees were surveyed, resulting in 84 woody species. The proportions of shrubs and flower beds are also quite rich. After the reconstruction in 2000, when playgrounds, ZOO corners, objects of social entertainment and culture were set in the park, it has got a high degree of use by the city inhabitants.

We have used the automatic measurement stations for the climate characteristics, namely TSI Veloci Cale 9565-P type. The measurements were made in 2014 at A–E sites during the summer months in a high pressure anticyclone type of weather at noon and repeated 5 times a month. At each locality, values were measured on two types of plots spaced approx. 50 m apart – both in the vegetation area and a non-vegetation area (Klein, 2017). Other station type AMS-2 was used at F and G sites and measurements were carried out in 2010, also in summertime, in sunny anticyclone weather. The measurement was performed once, but continually for 24 hours in August 20–21st, 2010. This method of measurement was also used on two types of plots, but with different types of surfaces – on the stand under a tree in a shade and on the open grassland, similarly spaced approx. 50 m apart (Jasenka, 2011).

The measured results are presented graphically with a mutual comparison of differences among the localities and areas. The statistical processing was done in STATISTICA 7 environment. One – Way ANOVA, (p <0.05), and the verification test by Tukey Honest Significant Difference (HSD) was used. The data between the monitored localities and the area plots were compared.

Results and discussion

Acquired results of the air temperature and relative humidity measurements at the localities A – E showed differences between the localities and the area sites. These reflect the urban structure of the built-up area as well as the size and the natural level of the vegetation formation, in which the measurement was performed. There was no statistically significant difference concerning the air temperature factor depending on the locality (Fig. 1). The largest average difference in the air temperature between the vegetation stand and the area without vegetation was measured at the locality D (1.2 °C). The median values were close. The lowest average difference in the air temperature was at the locality B (0.6 °C). The average air temperature difference between the vegetation and non-vegetation area at the measured localities was 0.84 °C. Higher air temperature differences (above 2 °C) were almost all recorded in the locality D, which consisted of the dispersed buildings and the industrial part on Bratislavská street. The maximum air temperature difference between the vegetation stand and the stand without any vegetation achieved 4.1 °C and was measured at the locality D. There was no statistically significant difference in the air temperature factor between the monitored area plots at the individual localities (Fig. 1). However, on two plots of D and E locality, the difference between the area with and without vegetation was m_d = 1.6 °C.

There was no statistically significant difference in the relative air humidity factor depending on the location (Fig. 2). The medians between the sites showed minimal differences. The highest average difference in the air humidity between the vegetation and without the vegetation was at the locality D (5.1% only). However, the maximum values are more interesting. The greatest maximum value difference in the air humidity was 15.1%, with the differences above 10% achieved five times – all at the locality D, consisting of the scattered buildings and the industrial part of the city. This may be caused because of the highest airflow values at this locality. In the monitored area, the vegetation was dense, high and shrubby and thus, it eliminates the air flow and keeps the air humidity on the higher level. Concerning the relative air humidity factor, there was a statistically significant difference, which depended on the area at the localities (Fig. 2) p = 0.000297, one-way ANOVA, (p <0.05), (post hocs, p <0.05). The largest difference (d) between the medians (m) of the relative air humidity on the plots was at the locality D – Scattered buildings and the industrial part (m_d = 8.3%), followed by E – Historical compact development (m_d = 6.2%), the third is the locality B – Mixed development (m_d = 4,5%), the fourth is the locality C – Street free development (m_d = 1.1%) and the fifth is the locality A – Settlement area (m_d = 0.6%) (Fig. 2).

In the summary assessment, we compared all the localities, but also the area plots with each other. A statistically significant difference, depending on the localities, was recorded in the surface temperature climate factor, p = 0.000004, one-way ANOVA (p <0.05), (post hocs,

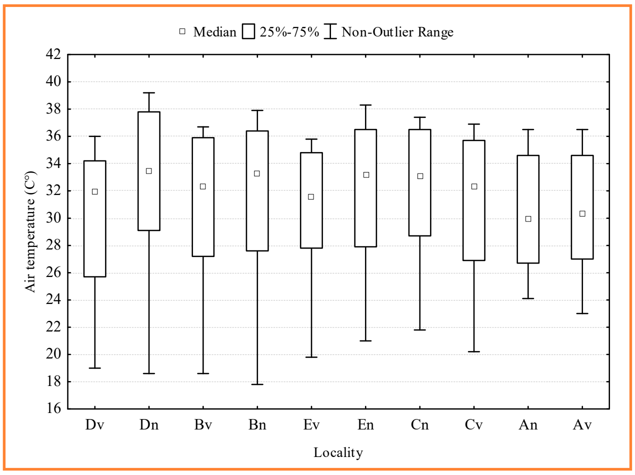

Figure 1 Air temperature at localities
A – E – locality; v – vegetation area, n – non-vegetation area
Source: Klein, 2017

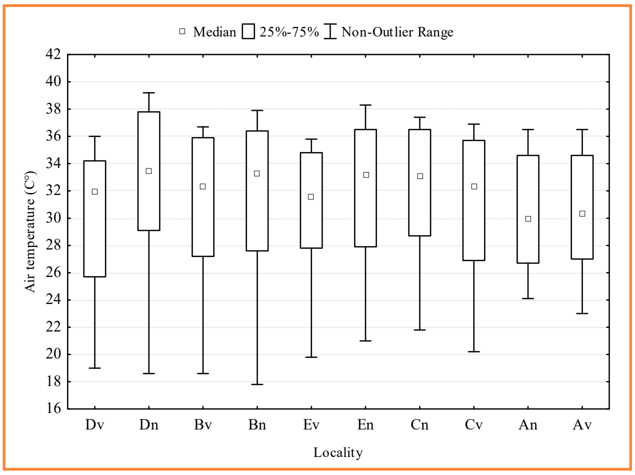

Figure 2 Relative air humidity at localities
A – E – locality; v – vegetation area, n – non-vegetation area
Source: Klein, 2017

Table 1 Median difference comparison of the measured climate characteristics among the studied localities A – E

LOCALITY	$_{d}F$ ($m^3.s^{-1}$)	$_{d}AT$ (°C)	$_{d}H$ (%)	$_{d}ST$ (°C)
A	–	3.80	8.90	4.90
B	0.02	0.60	1.80	1.50
C	0.01	0.75	1.75	4.15
D	0.03	0.90	3.45	6.00
E	0.02	0.50	1.31	6.30

$_{d}F$ – airflow, $_{d}AT$ – air temperature, $_{d}H$ – relative air humidity, $_{d}ST$ – air temperature
Source: Klein, 2017

p <0.05). The largest difference was between the localities A, B and D (Fig. 3). However, the air temperature and the relative humidity did not show a statistically significant difference between the localities. An overview of the median differences (*d*) of all the microclimate factors is given in the Table 1.

The second part of the paper is focused on the evaluation of temperature and the relative air humidity at two localities F and G, where the measurements were performed in a continuous 24-hour regime. At each locality, the climate characteristics were measured at two different habitats, under a tree canopy shade and on the open grassland plot. The presented values are processed from the automatic measuring station AMS, where the readings module was set in 5 minute intervals with a high degree of interpretation accuracy. The aim of the measurements was to obtain information on how the measured characteristics change during the day and night and what are the differences among the localities and also between two different area plots in the studied sites. This methodological approach and the achieved results have a great deal of information value and at the same time they complement and refine the outputs from the daily measurements at the A–E localities. Two distinctly different localities were deliberately chosen in terms of the proportion of the vegetation elements. In addition, the city park is the dominant recreational and cultural space of Nitra town with a high level of attendance by its inhabitants. When evaluating the total sum of the air temperatures, we identified lower values in the park area (the locality G), which in the open area represent a difference of 417.8 °C and under the tree crown shades 413.4 °C, compared to the street space (the locality F), which is significantly warmer. The highest differences in the open grass land were measured between 11:00 and 14:00, when the differences between the street space and the city park reached 2–2.3 °C. An increased value in the air temperature difference was also identified in the time period 18:00–19:00, when it reached more than 2.3 °C. The temperature differences in the tree stands under a tree crown shade are similar to those in the open grass spaces. In the time period from 11:00–14:00, the differences reached 2.2 °C, in the period from 18:00–19:00, up to 2.5 °C. The city park locality G is logically and demonstrably cooler. The temperature differences between the tree stand and the open grassland are also interesting, as in the city park, they reach up to 0.8 °C during the day (the open area is warmer) and 0.6 °C at night (the area under the trees is warmer). The differences in the street space between the tree stand and the open grass area are almost similar (Figs. 4 and 5).

The values of the relative air humidity (RH) were higher in the city park under a tree stand, in which the average 24-hour value reached 72.27%, compared to the street space, where it averaged 64.02%. The highest differences between the city park (the locality G) and the street space (F) were measured from 03:00–08:00 and reached from 19.6% to 24.4% value with a higher RH in the favourable city park. The highest differences between the compared habitats were measured at the locality F and averaged 9.6% in the period from 04: 00–07: 00 in favour of the tree stand. At the locality G, the city park, RH values were previously balanced

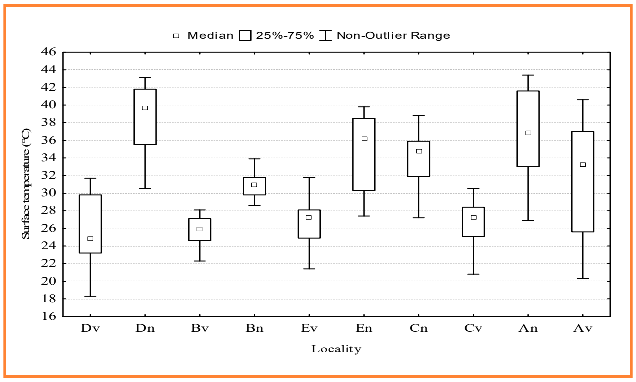

Figure 3 Surface temperature climate factor
A – E – locality; v – vegetation area, n – non-vegetation area
Source: Klein, 2017

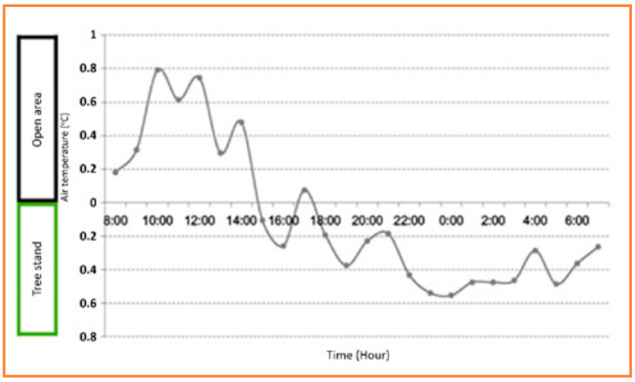

Figure 4 Course of the air temperature differences during 24-hour measurement in Štúrova street (the locality F) according to the area characteristics
Source: Jasenka, 2011

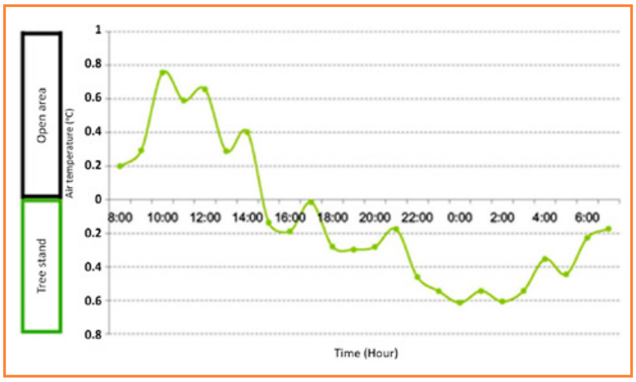

Figure 5 Course of the air temperature differences during 24-hour measurement in the City park (the locality G) according to the area characteristics
Source: Jasenka, 2011

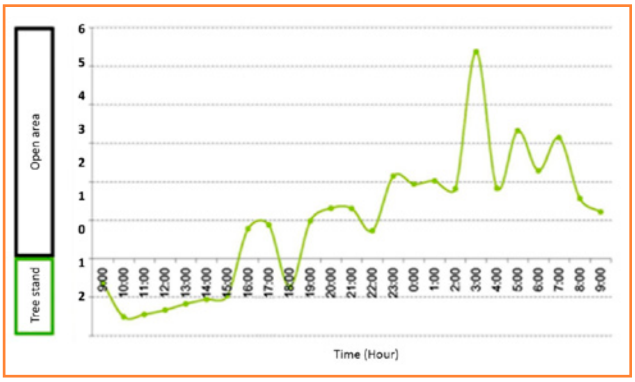

Figure 7 Course of the relative air humidity differences during 24-hour measurement in the City park (the locality G) according to the area characteristics
Source: Jasenka, 2011

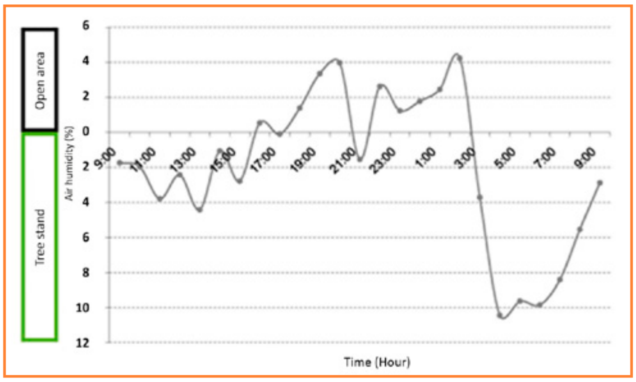

Figure 6 Course of the relative air humidity differences during 24-hour measurement in Štúrova street (the locality F) according to the area characteristics
Source: Jasenka, 2011

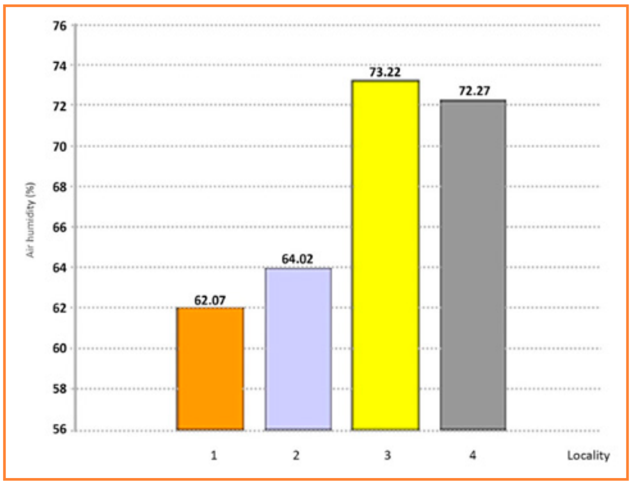

Figure 8 Average values of the relative air humidity during 24-hour measurement at different assessed city localities
Locality: 1 – Štúrova street, an open area, 2 – Štúrova street, a tree stand, 3 – City park, an open area, 4 – City park, a tree stand
Source: Jasenka, 2011

and the differences between the habitats reached 5.4% at 3:00 am, but on the contrary, in favour of the open space (Figs. 6 and 7). Based on the results of the air temperature and the relative humidity measurements among the compared localities, we identified higher climatic comfort in the city park (the locality G) compared to the street space (F). It confirms the achieved average air humidity value differences among the measured localities, too (Fig. 8).

Based on the results of our measurements in the chosen segments of Nitra town, we have found out that the differences in the air temperature and the relative humidity depend on the urban structure of the assessed localities and the proportion and composition of the vegetation areas. The largest average difference in the air temperature between the vegetation and the no-vegetation area was 1.2 °C at the locality D. On the other hand, the largest air temperature difference was measured between the street space (the locality E) and the city park (F), reaching 2.3–2.5 °C. Similarly, Tsutsumi, Ishii and Katayama (2003) show, that the maximum difference in the air temperature between the areas with vegetation and the areas without vegetation is 2 °C. Based on the urban climate investigation, it was discovered that a park, almost like vegetation with an area over 10 ha, is necessary to obtain the air temperature decreasing by 1 °C. On a larger scale, however, the differences are significant in microclimate of hard and soft surfaces, e.g. vegetation surfaces and hard paved surfaces (Gómez, Gil and Jabaloyes, 2004). Many measurements of the city microclimate confirmed that the cooling effect of larger green areas is reflected not only at the lower air temperatures in parks, but also in its adjacent areas (Dobrovolný et al., 2012; Yu et al., 2018). The air temperature is closely correlated with the relative humidity. The highest differences in the relative humidity were measured between F (the open street) and G (the city park), where they reached a difference of 19–24% RH, which represents a significant effect of the vegetation element on the quality of the city residential and recreational environment. In terms of the studied area character, a significant difference in the relative air humidity was also found in the locality D, which corresponds to the differences in the air temperature at the measured locality.

Conclusions

The results of the climatic measurements at the studied localities of Nitra town showed a significant difference in the air temperature and the relative humidity. Also differences between the vegetation areas and the areas without vegetation were found. The results reflect the urban spatial structure, distribution and frequency, as well as the area of the vegetation elements in the city territory. In addition, the results reflect the share of the composition elements and growth forms of woody species in the urban green areas, as well as the share of a tree layer, shrubby composition and grassland. These significantly contribute to the shade proportion and solar insulation and also to the amount of evapotranspiration by the vegetation elements. The above mentioned features contribute to the cooling of the open spaces in the urban structure differently. Among other things, the vegetation elements and their areas significantly contribute to the creation of an aesthetic cultural environment and strengthen the biodiversity of an entire city ecosystem.

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References

BOWLER, D. E. – BUYUNG-ALI, L. – KNIGHT, T. M. – PULLIN, A. S. 2010. Urban Greening to Cool Towns and Cities: A Systematic Review of the Empirical Evidence. In Landscape and Urban Planning, vol. 97, 2010, no. 3, pp. 147–155.

BRIAN, J. – BERRY, L. – MARZLUFF, J. M. – SCHULENBERGER, E. – ENDLICHER, W. – ALBERTI, M. – BRADLEY, G. – RYAN, C. – ZUM BRUNNEN, C. – SIMON, U. (Eds.). 2008. Urban ecology. New York : Springer, 2008, 807 p. ISBN 978-0-387-73411-8.

DOBROVOLNÝ, P. – ŘEZNÍČKOVÁ, L. – BRÁZDIL, R. – KRAHULA, L. – ZAHRADNÍČEK, P. – HRADIL, M. – DOLEŽELOVÁ, M. – ŠÁLEK, M. – ŠTEPÁNEK, P. – ROŽNOVSKÝ, J. – VALÁŠEK, H. – KIRCHNER, K. – KOLEJKA, J. 2012. Klima Brna. Víceúrovňová analýza městského klimatu. Brno : Masarykova univerzita, 2012, 200 p.

FORNAL-PIENIAK, B. – OLLIK, M. – SCHWERK, A. 2019. Impact of different levels of anthropogenic pressure on the plant species composition in woodland sites. In Urban Forestry & Urban Greening, 2019, 38, pp. 295–304.

GÓMEZ, F. – GIL, L. – JABALOYES, J. 2004. Experimental investigation on the thermal comfort in the city: Relationship with the green areas, interaction with the urban microclimate. In Building and Environment, vol. 39, 2004, no. 9, pp.1077–1086.

HARBICH, L. V. – DeABREU, L. – LABAKI, C. – MATZARAKIS, A. 2012. Different Trees and configuration as microclimate control strategy in Tropics. In ICUC8 – 8th International Conference on Urban Climates, Dublin: UCD, 2012.

JASENKA, M. 2011. Vplyv mestského prostredia na biologické procesy drevinovej vegetácie. Doktorandská dizertačná práca. Nitra : SPU, 2011, 137 p.

KATZIOURA, A. – KOSMOPOULOS, P. – ZORAS, S. 2012. Urban surface temperature and microclimate measurements in Thessaloniki. In Energy and Buildings, vol. 44, 2012, pp. 63–72.

KERESZTESOVÁ, S. – RÓZOVÁ, Z. 2013. Influence of vegetation on surface temperature in urban areas. In Folia oecologica, vol. 40, 2013, no. 1, pp. 55–64.

KLEIN, J. – RÓZOVÁ Z. 2017. Methods of trees evaluation with the site-specific for microclimate in urban environment: the case of study Nitra (Slovakia). In Ekológia, vol. 36, 2017, no. 1, pp. 40–51.

KLEIN, J. 2017. Vzťahy medzi vegetáciou a mikroklímou urbanizovaného prostredia mesta Nitra. Doktorandská dizertačná práca. Nitra : UKF, 2017, 91 p.

KUTTLER, W. 2008. The urban climate – Basic and applied aspects, In MARZLUFF, J. M. – SCHULENBERGER, E. – ENDLICHER, W. – ALBERTI, M. – BRADLEY, G. – RYAN, C. – Zum BRUNNEN, C. – SIMON, U. (Eds.) 2008. Urban ecology. New York : Springer, 2008, 807 p. ISBN 978-0-387-73411-8.

LAPIN, M. 2007. Klimatické zmeny a ich možné dôsledky v mestách. In Životné prostredie, vol. 41, 2007, no. 5, pp. 240–244.

NORTON, B. A. – COUTTS, A. M. – LIVESLY, S. J. – HARRIS, R. J. – HUNTER, A. M. – WILLIAMS, N. S. G. 2015. Planning for Cooler Cities: A Framework to Prioritise Green Infrastructure to Mitigate High Temperatures in Urban Landscape. In Landscape and Urban Planning, vol. 134, 2015, pp. 127–138.

NOWAK, D. J. – GRANE, D. E. 2006. Air Pollution Removal by Urban Trees and Shrubs in the United States. In Urban Forestry and Urban Greening, vol. 4, 2006, no. 3–4, pp. 115–123.

POPEK R. – ŁUKOWSKI, A. – OLEKSYN, J. 2017. Accumulation of particulate matter, heavy metals, and polycyclic aromatic hydrocarbons on the leaves of *Tilia cordata* Mill. in five Polish cities with different levels of air pollution. In International Journal of Phytoremediation, 2017, 12, pp.1134–1141.

REHÁČKOVÁ, T. – PAUDITSOVÁ, E. 2006. Vegetácia v urbánnom prostredí. Bratislava : Cicero, 2006. ISBN 80-969614-1-1.

SPANGENBERG, J. – SHINZATO, P. – JOHANSSON, E. – DUARTE, D. 2008. Simulation of the influence of vegetation on microclimate and thermal comfort in the city of São Paulo. In Rev. SBAU, vol. 3, 2008, no. 2, pp. 1–19.

SUPUKA, J. 2002. Štruktúra zelene mesta vo vzťahu k jeho urbanistickej štruktúre. In SUPUKA, J. (ed.): Sídlo, park, krajina I. Nitra : OPTIMA, s. r. o., 2002, pp. 72–76.

SUPUKA, J. – FERIANCOVÁ, Ľ. a i. 2008. Vegetačné štruktúry v sídlach. Parky a záhrady. Nitra : SPU, 2008, 504 p.

SUPUKA, J. – HALAJOVÁ, D. 2015. Sídliská a priestory zelene. In Žívotné prostredie, vol. 42, 2015, no. 2, pp. 94–99.

TÓTH, A. – HALAJOVÁ, D. – HALAJ, P. 2015. Green Infrastructure: A Strategic Tool for Climate Change Mitigation in Urban Environments. In Ecology and Safety, vol. 9, 2015, pp. 132–138.

TSUTSUMI, J. G. – ISHII, A. – KATAYAMA, T. 2003. Quantity of plants and its effect on local air temperature in an urban area. In ICUC – 5th International Conference on Urban Climate, 1–5 September 2003, Lodz : ICUC, 2003.

VITKOVÁ, Ľ. 2008. Hustota urbánnych štruktúr. In Životné prostredie, vol. 42, 2008, no. 5, pp. 235–239.

ZHU, Z. – LANG, W. – TAO, X. – KAILIU, J. F. 2019. Exploring the Quality of Urban Green Spaces Based on Urban Neighborhood Green Index – A Case Study of Guangzhou City. In Sustainability, 11, 2019, 5507 p.

YANG, L. – QUIAN, F. – SONG, D. X. – ZHENG K. J. 2016. Research on urban heat island effect. In Science Direct, Procedia Engineering, vol. 16, 2016, no. 9, pp. 11–18.

YU, Z.L. – GUO, X. – ZENG, Y. – KOGA, M. – VEJRE H. 2018. Variations in land surface temperature and cooling efficiency of green space in rapid urbanization: The case of Fuzhon city, China. In Urban Forestry and Urban Greening, vol. 29, 2018, pp.113–121.