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Impact of Vegetation on Microclimate in Different Layouts of Built-Up Areas in Urbanised Environment of Nitra Municipality in Spring Period

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Abstract

Vegetation has an important role in urbanised environment, as its functions enhance the quality of life in towns. Its structure shades anthropogenic surfaces, limiting the accumulation of direct solar radiation and subsequent emission of converted thermal radiation. This represents its potential in reducing the urban heat-island effect. It increases relative air humidity and reduces air temperature. Besides microclimatic function, vegetation also has health, aesthetic, recreational and other functions. Research is focused on comparing microclimatic factors (air temperature, relative air humidity, surface temperatures, airflow) between two monitored areas with different vegetation structures. Areas represent an area with vegetation cover (particularly tree plants) and an area without vegetation, respectively with minor representation of vegetation. Microclimatic conditions are also compared for four different types of built-up areas in the town of Nitra, which are represented by a characteristic street.

Key words: surface temperature, vegetation growth, urban texture, street canyon

Introduction

Replacement of natural surfaces like soil and vegetation cover by various urban surfaces – bricks, paving, asphalt, concrete surfaces, glass and iron started modifying urban atmospheric environment at different levels above ground in local geographic scale (Brian - Berry, 2008; Bonan, 2002). Urban climate was created as a result of replacing natural soil by vast areas of impermeable roads, pavements, parking places, roofs of walls with dense and artificial surface of solid and dense structure; reduction of surfaces covered by vegetation; reduction of longwave emissions of surfaces by street canyons and releasing gas, solid and liquid atmospheric polluting substances and waste heat (Kuttler, 2008; Bonan, 2002).

The factor of densely built-up area is considered to be one of the key reasons of UHI effect. Buildings, roads and hard surfaces accumulate heat during the day which is slowly released in the evening, while it maintains the air temperature of town warmer than in surrounding areas (Kantzioura - Kosmopoulos - Zoras, 2012). Changes to urban conditions often cause environment quality deterioration and can result in damage to health of the citizens of towns (Kuttler, 2008). Differences in temperature are also attributed to urban geometry – the size, shape and orientation of buildings and streets as well as the nature of urban areas – their albedo, thermal capacity of materials, thermal conductivity and humidity (Landsberg, 1981). Urban climate is directly connected to street axes configuration, height of buildings and their attributes. Relationship of urban morphology and microclimate change and air quality within a town centre also affects thermal comfort of pedestrians (Krüger - Minella - Rasia, 2011). Orientation and geometry of a street as well as its certain morphological characteristics have a fundamental role regarding surface temperatures. Even temperatures of horizontal earth surfaces are more significant than surface temperatures. Wind direction and speed combined with street orientation, as well as the effect of trees, increase of the height/width ratio, increase of the albedo of earth surface and walls, have the greatest impact on street canyon microclimate in relation to temperatures of air and surfaces (Andreou - Axarli, 2012). Vegetation has a significant impact on energy balance, as even though green areas have low albedo, thus absorbing a great part of emanating radiation, they maintain a lower temperature than usual regarding hard surfaces, as they are cooled by evapotranspiration (Pearlmutter et al. 2014). Vegetation improves environmental variables like solar radiation, temperatures of surrounding surfaces, temperature and humidity of air and wind speed, which are also important for thermal comfort of people due to their qualities – limited emission of direct solar radiation on surrounding buildings and surfaces, air cooling by evapotranspiration and wind speed reduction (Akbari - Pomerantz - Taha, 2001).

The paper aims at comparing microclimatic factors in different vegetation structures as well as within four street corridors representing different types of built-up areas of the town of Nitra. Partial evaluation of the ongoing research has been recorded for the period from April to June.

Materials and Methods

Four localities in the town of Nitra were selected. Each locality within a whole street block represents a different urban structure. Particular monitored locality with two monitored areas with different plant structure represents a relatively homogenous character of built-up area. They are particular streets predominantly oriented in north-south direction with different vegetation representations. Individual localities representing certain types of urban built-up areas were selected as follows:

1. Compact layout in the town historical centre, representing typical street canyon (Farská street, Fig. 1). It is a street with 10 to 15 m high historical terraced buildings (Locality 1).
2. Detached layout – family houses with gardens (Moyzesova street, Fig. 2). Detached single-storey family houses with front yards are most frequently represented in this layout. (Locality 2).
3. Industrial layout, industrial part of town (Bratislavská street, Fig.3). It is a broad and open street with a four-lane road, up to 8 m high buildings and spacious parking places with grassy islands (Locality 3).
4. Mixed layout adjacent to the town park (Jesenského street, Fig.4). It is a relatively narrow street (10 – 20 m) and its corridor on the southern part is created by buildings up to the height of 10 m with a gradual continuing to the park on the northern part (Locality 4).

All monitored surfaces in monitored areas are asphalt as the most frequently represented type of surface in urban environment in general. Each locality comprises two monitored areas – an area without vegetation cover, respectively with minimum cover, and an area with vegetation cover. Vegetation cover is represented by plants, particularly trees, representing public greens.

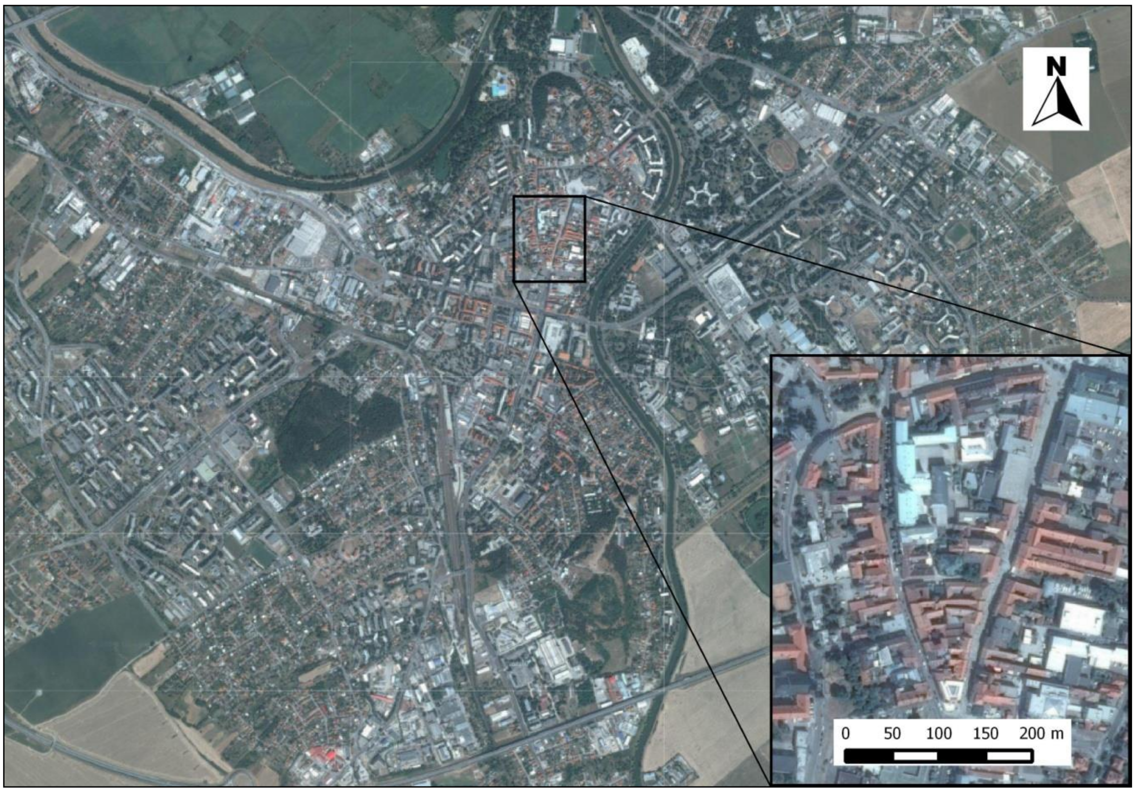

Fig. 1 Compact layout (historical), Farská street – Locality 1

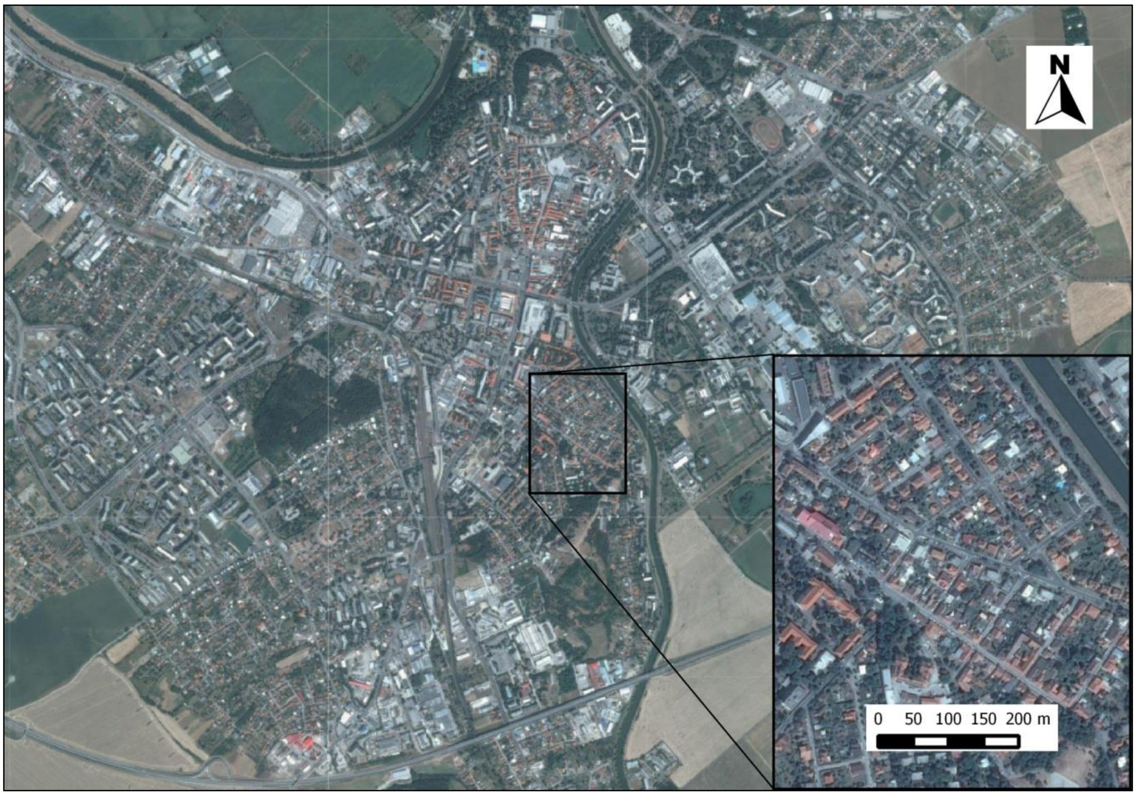

Fig. 2 Detached layout- family houses with gardens, Moyzesova street – Locality 2

Fig. 3 Industrial layout in industrial part of town, Bratislavská street – Locality 3

Fig. 4 Mixed layout adjacent the town park, Jesenského street – Locality 4

Measurements were carried out by anemometer TSI Veloci Cale 9565 – P (air temperature, relative air humidity, airflow, temperature of horizontal surfaces) once a week, three times a day. Monitored day is characterised by anticyclone weather, respectively by a prevalence of direct solar radiation, as the surface and adjacent air layers are intensely heated by solar radiation during the day. Morning and evening measurements were adapted to day-time during the monitored period with morning measurement an hour after sunrise and evening measurement an hour after sunset. We compared differences in measured values in the monitored areas with vegetation cover and without the cover within a single street corridor as well as differences between localities, respectively in different layouts of built-up areas. Data used for this research were recorded in the period from April to June. Data for March were not used as a result of incomparable days (starting vegetation period) because of statistical evaluation. Measurements were statistically evaluated by the one-way ANOVA test and confirmed by the Tukey HSD test. They were compared within monitored areas as well as localities in Statistica 7.

Results and Discussion

Statistical evaluation was processed complexly for morning, noon as well as evening measurements. Methodically proposed measurements and subsequent processing represent an average range of input data. The most characteristic conditions are presented by noon measurements due to the highest temperatures at which the impact of vegetation in respective area is best shown by shading, airflow reduction or transpiration in a certain extent while pores are open. Leaves prevent excessive vapour by closing their pores, which can cause their significantly greater overheating (Čaboun, 2008). Similarly at evening, respectively morning measurements, vegetation acts as a thermal stabilizer. The vegetation cover has a cooling effect during evening thermal radiation from asphalt surfaces. On the contrary, vegetation maintains a higher temperature than the temperature of its surroundings in the morning. Airflow is affected by the cover structure as well as street configuration. Well placed green lines in urban cities can significantly reduce unwanted airflow in form of gusty winds and thereby prevent soil erosion and influence variable changes of thermal conditions (Kavka - Šindelářová, 1978). Statistically significant difference in airflow in terms of locality was demonstrated in Locality 3 (Fig. 5), using the one-way ANOVA test $p<0.05$ (Tab. 1), and the Tukey HSD test (Tab. 2) to confirm. The locality represents an industrial layout in which such results were anticipated. Other localities representing a more distinctive street canyon with a similar orientation are not affected by the overall airflow. By their layout and geometry, they limit airflow to the corridor direction. Vegetation cover affects airflow (Akbari - Pomerantz - Taha, 2001). Fluctuating values were predominantly recorded in monitored areas without the cover.

Tab. 1 One-way ANOVA, p<0,05, variable air flow, Locality 3

Effect	SS	Degr. Of Freedom	MS	F	p
Intercept	0.12669	1	0.12669	45.4753	0.000000
Locality	0.01709	1	0.01709	6.13513	0.02008
Error	0.07244	26	0.00279		

Tab. 2 Tukey HSD test, variable air flow, Locality 3

Locality	{1} ,09197	{2},04256
BR_NV		0.02021
BR_V	0.020214	

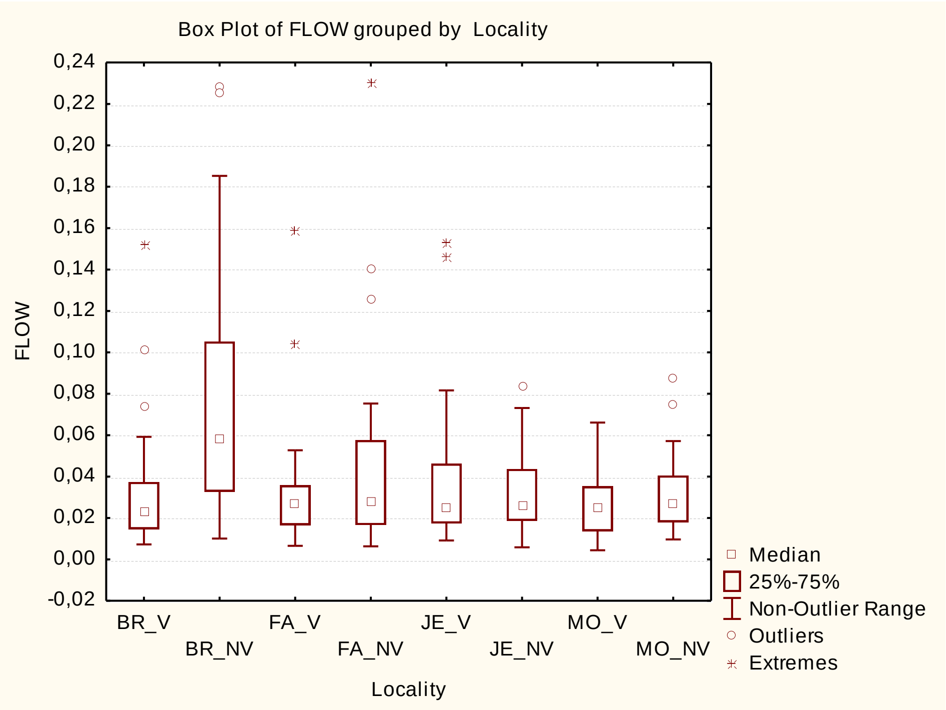

Fig. 5 Comparison of airflow in localities and monitored areas, airflow (m3/s); BR (Locality 3), FA (Locality 1), JE (Locality 4), MO (Locality 2); V (vegetation), NV (non-vegetation)

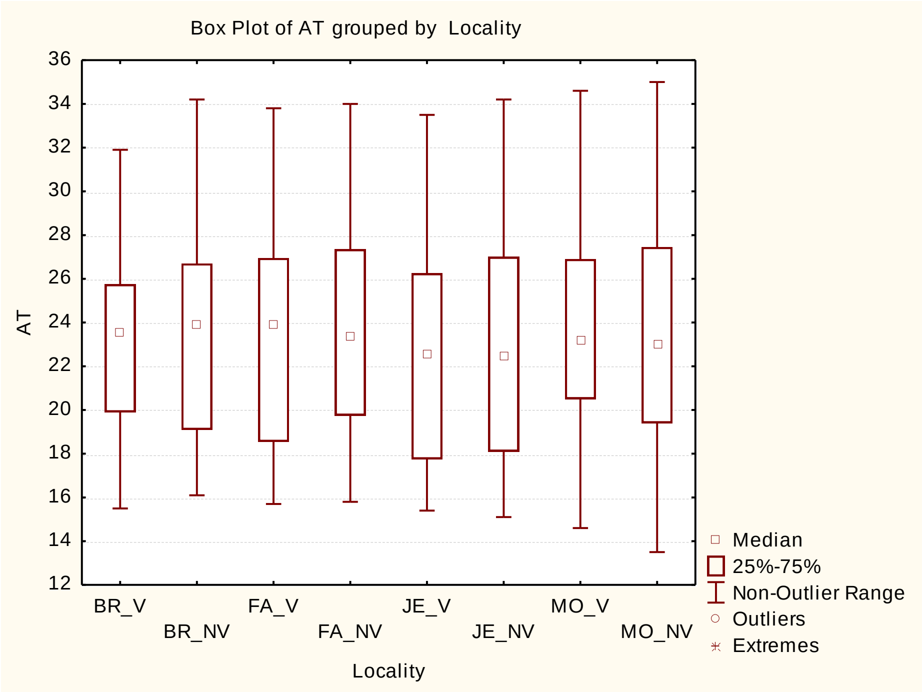

Fig. 6 Comparison of air temperatures in localities and monitored areas, AT – air temperature (°C); BR (Locality 3), FA (Locality 1), JE (Locality 4), MO (Locality 2); V (vegetation), NV (non-vegetation)

Within the factor of air temperature, we did not find a statistically significant difference in terms of neither locality nor monitored areas. The greatest differences were recorded in Locality 1 (Fig. 6). Average difference in air temperature between vegetation cover and outside of it at noon in Locality 1 is 0.68 °C. Lower air temperature in the cover was reflected not sooner than in May and June, when the examined covers were fully capable of physiological processes. Average difference in air temperatures in the evening in Locality 1 was 0.59 °C with lower temperatures recorded in the cover. Difference in air temperature in Locality 1 with median higher for vegetation cover is interesting. It can be caused by morning values or e.g. at the surrounding air temperature over 30 °C, higher temperature was recorded in the cover than on a non-covered area. Locality 1 – Farská street represents a typical street canyon and a precondition of higher temperature values due to the layout and configuration of street objects and their materials. Locality 4 – Jesenského street represents the locality with the lowest temperature values, as we had assumed. The street gradually continues as the town park.

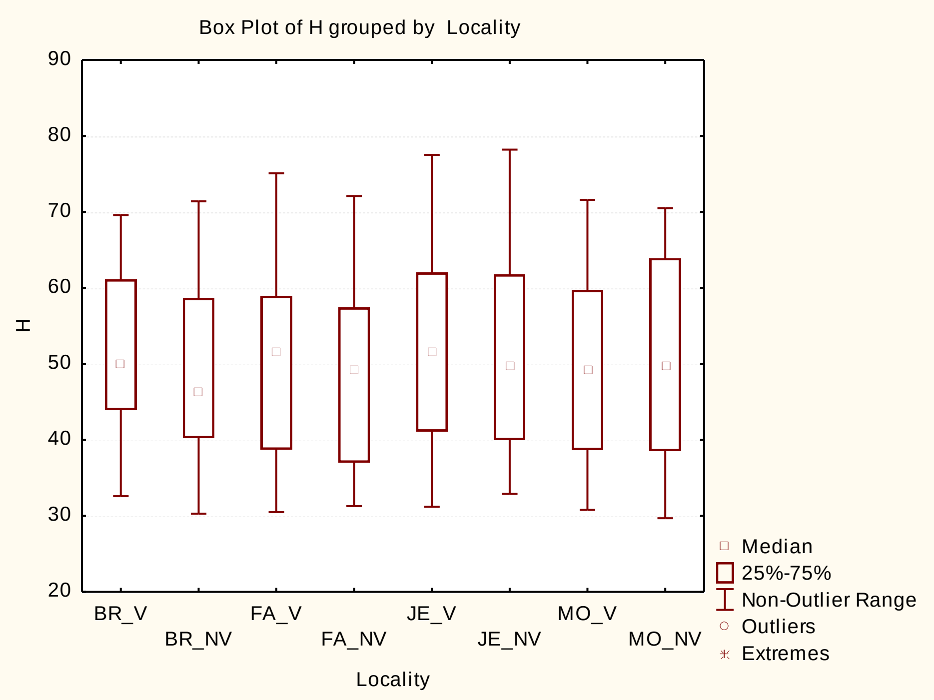

Fig. 7 Comparison of relative air humidity in localities and monitored areas, H – relative humidity (%); BR (Locality 3), FA (Locality 1), JE (Locality 4), MO (Locality 2); V (vegetation), NV (non-vegetation)

Within the factor of relative air humidity, we did not find a statistically significant difference neither in terms of locality nor monitored areas. The greatest differences in relative air humidity between vegetation and non-vegetation were recorded in Locality 3 (Fig. 7). Average difference represents 3.78 %. Relative air humidity is most frequently dependent on air temperature, transpiration and airflow. Relative air humidity under vegetation cover is increased due to decreased temperature, transpiration of plants and airflow prevention, thus maintaining such humidity in the air. A greater difference can be seen under broadleaf species than under coniferous species (Čaboun, 2008). In Locality 2 – Moyzesova street coniferous create the monitored area with vegetation cover. Similarly to Čaboun (2008), the difference can be seen in graphic representation (Fig. 7). In Locality 3 a significant difference in airflow was recorded, which can affect relative air humidity. Lower marginal plants along the street are the monitored area with vegetation cover in Locality 3. Compared to Locality 1, difference can be in the transpiration of vegetation cover, whose canopy layer covers the street in the given area. The greatest difference in relative air humidity between localities is approximately 6 % between mixed layout adjacent to the town park and industrial layout of the commercial and industrial part of town. Air humidity, increasing in natural environment, reduces the effect of solar radiation. Vegetation increases relative air humidity compared to uncovered areas by 18 – 22 % (Čaboun, 2008).

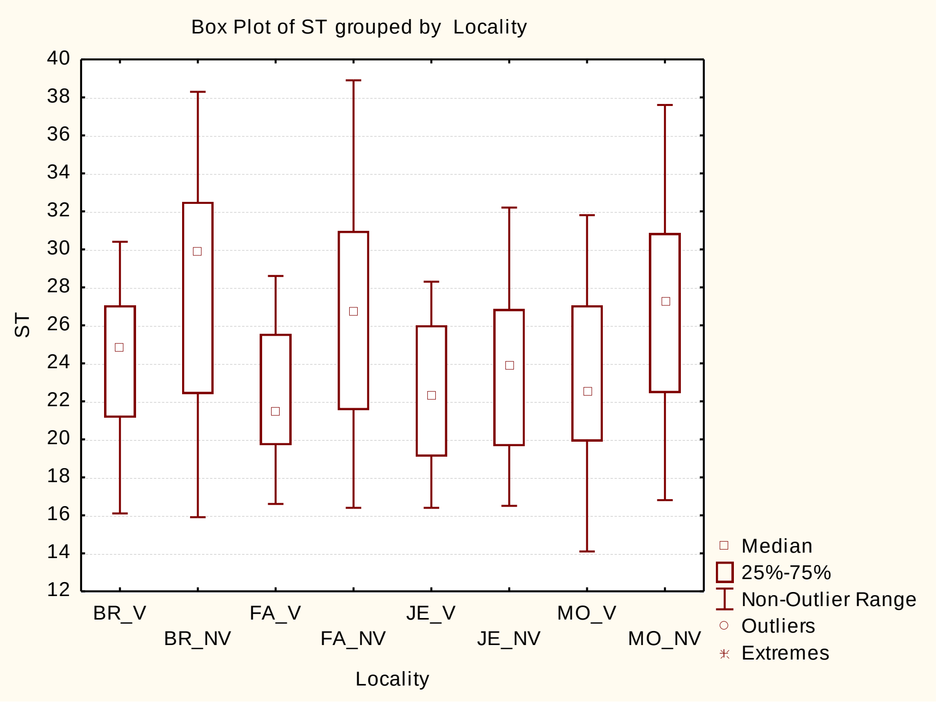

Fig. 8 Comparison of surface temperatures in localities and monitored areas, ST – surface temperature (°C); BR (Locality 3), FA (Locality 1), JE (Locality 4), MO (Locality 2); V (vegetation), NV (non-vegetation)

Within the factor of surface temperature, statistically significant difference was not recorded only in Locality 4 – Jesenského street. Differences in values of individual localities are shown in Fig. 8. All monitored surfaces are asphalt with law albedo. Asphalt is capable of long lasting radiation of accumulated converted heat. Temperature of active surface directly influences temperature conditions in ground and boundary atmospheric layer (Středa – Středová – Rožnovský, 2011). Vegetation acts as a stabilizer. Under certain conditions, it can overheat more than artificial surfaces – asphalt, paving and concrete (Čaboun, 2008). Even though vegetation has relatively low albedo, it does not accumulate heat. Its qualities have cooling effects. It absorbs a major part of direct solar radiation, which would otherwise be converted, accumulated and radiated back. Tree vegetation consumes approximately

2 % of solar energy for photosynthesis, 60 – 80 % is absorbed by leaves, 5 – 15 % is reflected back to space (glossy leaves reflect more sunshine than darker ones), the rest goes through leaves. Sparse treetops absorb 60 – 80 % of solar radiation, while only 2 – 3% of solar radiation penetrates through dense treetops (Pauditšová – Reháčková, 2006). Measurements on the monitored areas with vegetation covers were carried out in shades of the given covers. Monitored area without vegetation used shades of buildings of the given street canyon.

Tab. 3 One-way ANOVA, p<0,05, variable suface temperature, Locality 3

Effect	SS	Degr. Of Freedom	MS	F	p
Intercept	32617.2	1	32617.2	1106.4	0.000000
Locality	195.82	1	195.82	6.642	0.01323
Error	1356.1	46	29.48		

Tab. 4 Tukey HSD test, variable suface temperature, Locality 3

Locality	{1} 28,087	{2} 24,048
BR_NV		0.01335
BR_V	0.013347	

Tab. 5 One-way ANOVA, p<0,05, variable suface temperature, Locality 1

Effect	SS	Degr. Of Freedom	MS	F	p
Intercept	28975.4	1	28975.4	995.968	0.000000
Locality	235.54	1	235.54	8.0963	0.0066
Error	1338.26	46	29.09		

Tab. 6 Tukey HSD test, variable suface temperature, Locality 1

Locality	{1} 26,785	{2} 22,354
FA_NV		0.00673
FA_V	0.006732	

Tab. 7 One-way ANOVA, p<0,05, variable suface temperature, Locality 2

Effect	SS	Degr. Of Freedom	MS	F	p
Intercept	30235.5	1	30235.5	1037.32	0
Locality	180.58	1	180.58	6.195	0.01649
Error	1340.79	46	29.15		

Tab. 8 Tukey HSD test, variable suface temperature, Locality 2

Locality	{1} 27,038	{2} 23,158
MO_NV		0.0166
MO_V	0.016601	

Statistically significant difference in the microclimatic factor of surface temperature was recorded in localities 1, 2 and 3 depending on the presence of vegetation cover at the level of $p<0.05$ (Tab. 3, Tab. 5, Tab. 7) using the one-way ANOVA test, confirmed by the Tukey HSD test (Tab. 4, Tab. 6, Tab. 8). Monitored area with vegetation cover in Locality 3 is a lower scrubland and tree wall not absorbing solar radiation. Stronger airflow was recorded in this locality, however without affecting surface temperature. Effects of vegetation on surface temperature were also recorded in Locality 2 as well as in Locality 1. Monitored area with vegetation cover in Locality 1 recorded the lowest medians.

Conclusion

Four localities with different built-up area layouts and vegetation representations were selected in the town of Nitra. Each locality comprises a monitored area with vegetation cover and without vegetation cover. Surface thermal monitoring was carried out in the period from April to June. Microclimatic factors of surface temperature, air temperature, relative air humidity and airflow were recorded. Statistically significant differences depending on the presence of vegetation cover and locality were confirmed for the factors of airflow (one-way ANOVA, $p<0.05$) – industrial layout in the industrial part of town; surface temperature (one-way ANOVA, $p<0.05$) – compact layout in the historical centre of town, detached layout – family houses with gardens and industrial layout in the industrial part of town. Different airflow in industrial layout of the industrial part of town on the monitored area without vegetation is a result of open space of a broad street. Street canyon airflow is limited to its orientation, while it is affected by vegetation cover. Eccentric airflow values were predominantly recorded in monitored areas without vegetation. The surface temperature factor with the greatest values was also reflected in industrial layout of the industrial part of town. It means that airflow does not affect surface temperature; however, on the other hand, it affects air temperature. In compact layout of the historical centre of town, air temperature medians were higher in the monitored area with vegetation cover, while lower airflow medians were recorded there. During hot days, cover closes pores and does not increase air humidity by transpiration; respectively it does not lower air temperature. Area without vegetation recorded lower air temperature medians, which was affected by higher airflow. It did not affect surface temperature.

Vegetation favourably affects microclimatic factors which can affect perceived temperature. Vegetation is necessary in urbanized environment. It affects anthropogenic surfaces radiating accumulated heat by its structure and qualities, thus improving thermal comfort of people. Appropriate proposals of vegetation structures in urban planning as well as its shaping should result in improved urban climate and thus the quality of life of the inhabitants of towns.

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Summary

Cieľom tohto príspevku bolo porovnať mikroklimatické faktory v rôznych vegetačných štruktúrach, ako aj v rámci štyroch uličných koridorov reprezentujúcich rôzne typy zástavby mesta Nitra. Čiastkové vyhodnotenie prebiehajúceho výskumu zachytáva obdobie apríl - jún. Marcové dáta neboli použité v dôsledku začínajúceho vegetačného obdobia. V meste Nitra boli vybrané štyri lokality s rôznou štruktúrou zástavby a zastúpením vegetácie. Každá lokalita pozostáva z monitorovacej plochy s vegetačným porastom a bez vegetačného porastu. Lokality výskumu predstavujú uličnú kompaktnú zástavbu v historickom centre mesta; uličnú voľnú zástavbu - rodinné domy so záhradami; rozptýlenú zástavbu, priemyselnú časť mesta a zmiešaná zástavba priľahlá k mestskému parku. Výskum bol realizovaný metódou pozemného termálneho monitoringu záznamom mikroklimatických faktorov - teplota povrchu, teplota vzduchu, relatívna vlhkosť vzduchu a prúdenie vzduchu.

Monitorovacie dni sa vyznačovali prevahou priamej slnečnej radiácie. Vegetácia pôsobí ako tepelný stabilizátor. Večer má ochladzovací efekt, ráno naopak drží vyššiu teplotu ako okolie. Prúdenie vzduchu je ovplyvňované štruktúrou porastov aj konfiguráciu ulice. Štatisticky významný rozdiel v prúdení vzduchu v závislosti od lokality sa preukázal v rozptýlenej zástavbe, priemyselnej časti mesta na monitorovacej ploche bez vegetácie. Vo faktoroch teplota vzduchu a relatívna vlhkosť vzduchu nebol zistený štatisticky významný rozdiel v závislosti od lokality, ani od monitorovacích plôch. Vo faktoroch teplota povrchu vyšiel štatisticky významný rozdiel na troch lokalitách okrom lokality zmiešaná zástavba priľahlá k mestskému parku. Svojimi vlastnosťami má vegetácia ochladzovací efekt. Zachytáva väčšiu časť priameho slnečného žiarenia, ktoré by inak bolo premenené, akumulované a vyžarované späť. Rozdielne prúdenie vzduchu v rozptýlenej zástavbe, priemyselné časti mesta na monitorovacie ploche bez vegetácie je následkom otvoreného priestoru širokej ulice. V uličnom kaňone je prúdenie vzduchu obmedzené na jeho orientáciu, pričom vegetačný porast ho ovplyvňuje. Excentrické hodnoty v prúdení vzduchu sa vyskytli väčšinou na monitorovacích plochách bez vegetácie. Faktor teplota povrchu s najvyššími hodnotami sa prejavil tiež v rozptýlenej zástavbe, priemyselnej časti mesta. To znamená, že prúdenie vzduchu nemá vplyv na teplotu povrchu. Na druhej strane ovplyvňuje teplotu vzduchu. V uličnej kompaktnej zástavbe v historickom centre mesta boli stredné hodnoty teplôt vzduchu vyššie na monitorovacej ploche s vegetačným porastom, v ktorom boli zaznamenané nižšie stredné hodnoty prúdenia vzduchu. V horúcich dňoch porast uzatvára prieduchy a nezvyšuje vlhkosť vzduchu transpiráciou, resp. neznižuje teplotu vzduchu. Plocha bez vegetácie sa vyznačovala nižšími strednými hodnotami teplôt vzduchu, ktoré ovplyvňovalo vyššie prúdenie vzduchu. Na teplotu povrchu tiež nemalo vplyv.

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