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URBAN CLIMATE ISSUES IN COMPLEX URBANIZED ENVIRONMENTS: A REVIEW OF THE LITERATURE FOR NOVI SAD (SERBIA)

S SAVIĆ[1], D MILOŠEVIĆ[1], D ARSENOVIĆ[2], V MARKOVIĆ[2], I BAJŠANSKI[3] and I ŠEĆEROV[2]

[1]Climatology and Hydrology Research Centre, Faculty of Sciences, University of Novi Sad, Trg Dositeja Obradovića 3, 21000 Novi Sad, Serbia
[2]Departman of Geography, Tourism and Hotel Management, Faculty of Sciences, University of Novi Sad, Trg Dositeja Obradovića 3, 21000 Novi Sad, Serbia
[3]Department of Architecture and Urban Planning, Faculty of Technical Sciences, University of Novi Sad, Trg Dositeja Obradovića 6, 21000 Novi Sad
E-mail: stevan.savic@dgt.uns.ac.rs

Summary: In the last five years more than 30 articles have been published in scientific journals and conferences focused on urban climate research in Novi Sad. These researches were led by members from the Climatology and Hydrology Research Centre at the Faculty of Sciences, University of Novi Sad (Republic of Serbia), together with demographers, architects, environmental researchers and experts from medicine and biostatistics. Novi Sad is a mid-sized city in the northern part of the Republic of Serbia with a built-up area of 112 km^2 and a population of 340,000 (data from 2015). All results were published in 7 scientific journals, one PhD dissertation, a few books and presented in 12 conferences. Furthermore, all research activities in the last few years were covered by one international project (EU-funded IPA project) and one national project (funded by the Autonomous Province of Vojvodina). This paper presents all research and results of urban climate in the Novi Sad built-up area. Up to now, the results have been mostly focused on urban surface issues, definition of Local Climate Zones (LCZ) and adequate station cites, the analysis of urban heat island (UHI), outdoor human thermal comfort and the interaction of urban climate and urbanization and mortality.

Key words: urban climate, Local Climate Zones, urban heat island, outdoor thermal comfort, urbanization, mortality, Novi Sad, Serbia

1. INTRODUCTION

Urban environments are becoming increasingly important and relevant to study since most of the world's population now inhabits towns and cities (UN 2009, Grimmond et al. 2010), and as such, the proportion of the world's land and water surface covered by built-up environment is constantly expanding. Therefore it is essential to better understand atmospheric processes and impacts in urban areas and how they will be affected by climate change (Muller et al. 2013).

In Central Europe (where Novi Sad is situated), climate change is expected to increase the frequency, duration and intensity of heat waves (IPCC 2012, Pongrácz et al. 2013), along with the thermal stress experienced by people (Tomlinson et al. 2011). With reduced nocturnal cooling, the climate of cities is expected to make these already adverse projections worse, as elevated heat loads are linked to higher morbidity and mortality rates (Petralli et al.

2012). Thus, monitoring the spatial and temporal patterns of the elevated urban temperature is an important task that can help both in the mitigation of and in the adaptation to the altered circumstances of the future (Lelovics et al. 2016).

Therefore, in the last five years urban climate research was expanded, mostly led by the members from the Climatology and Hydrology Research Centre at the Faculty of Sciences, University of Novi Sad (Republic of Serbia). Up to now 38 references have been published in scientific journals and conferences, focused on urban climate issues in Novi Sad. 11 papers have been published in 7 journals (such as Building and Environment, Advances in Meteorology, International Journal of Biometeorology, Időjárás) and 22 abstracts and extended abstracts have been presented on 12 different conferences (such as ICUC9 – 9th International Conference on Urban Climate, Fifth EUGEO Congress on the Geography of Europe, European Population Conference 2014, IGU regional conference – Changes, Challenges, Responsibility). Within the urban climate research group in Novi Sad, one PhD dissertation has been defended related with the impact of air temperature on the seasonal variation of human mortality in Novi Sad (Arsenović 2014) and one PhD dissertation is in preparation related with the temporal and spatial analysis of outdoor human thermal comfort in different LCZs of Novi Sad. From 2012 to 2014, two projects related with urban climate issues were conducted. The first one was an EU-funded project in the frames of the IPA Hungary-Serbia programme (project title: Evaluation and public display of URBAN PATterns of Human thermal conditions) and the second one was a regional project funded by the Autonomous Province of Vojvodina (project title: Analysis of urban climate in Novi Sad and its impact on the thermal comfort of urban population). The published papers have been focused on urban surface characteristics, delineations of LCZs and definition of representative station sites (Popov 1994, 1995, Popov and Savić 2010, Unger et al. 2011a, 2011b, Savić et al. 2012b, Savić et al. 2013a, Savić et al. 2013b, Savić, et al. 2013c, Savić et al. 2014a, Savić et al. 2014b, Unger et al. 2014, Jovanović et al. 2015, Unger et al. 2015a, Savić 2015, Šećerov et al. 2015a, Šećerov et al. 2015b), analysis of UHI and outdoor human thermal comfort (Lazić et al. 2006, Savić et al. 2012a, Marković et al. 2013, Marković et al. 2014a, Marković et al. 2014b, Milošević et al. 2015a, Skarbit et al. 2015, Savić et al. 2015; Marković 2015, Milošević et al. 2015b, Milošević et al. 2015c, Bajšanski et al. 2015, Basarin et al. 2016, Lelovics et al. 2016) and interaction of urban climate and urbanization, human mortality, tourism attractiveness (Stankov et al. 2013, Stankov et al. 2014, Arsenović 2014, Arsenović et al. 2014a, Arsenović et al. 2014b, Arsenović and Đurđev 2015, Savić et al. 2015, Bajšanski et al. 2015).

The main goal of this study is to present the results of all published journal papers, conference presentations and other publications related with the urban climate research of Novi Sad city and represent and propose some activities and investigations in the future according to the urban climate issues.

2. INVESTIGATED AREA

Novi Sad is a mid-sized city in the northern part of the Republic of Serbia (Fig. 1), located on a plain between 80 and 86 m a.s.l. Hence, the climate is generally free of orographic effects. Based on a population of 340,000 (data from 2015), Novi Sad is the second largest metropolitan region in Serbia with a built-up area of 112 km^2. The Danube River passes through the southern and eastern edges of the urban area; its width varies from

260 to 680 meters. The relatively narrow Danube-Tisza-Danube Canal passes through the northern part of the city. The northern slopes of the Fruška Gora Mountains (which have a maximum peak of 538 m a.s.l.) are located south of the Novi Sad urban area (Unger at al. 2011).

The Novi Sad region has a Cfb climate (temperate climate, fully humid, and warm summers, with at least four $T_{mon} \geq +10$ °C) according to the Köppen-Geiger climate classification (Kottek et al. 2006). The mean monthly air temperature ranges from -0.4 ºC in January to 21.7 ºC in July. The mean annual precipitation is 598 mm (based on data registered from 1949 to 2013).

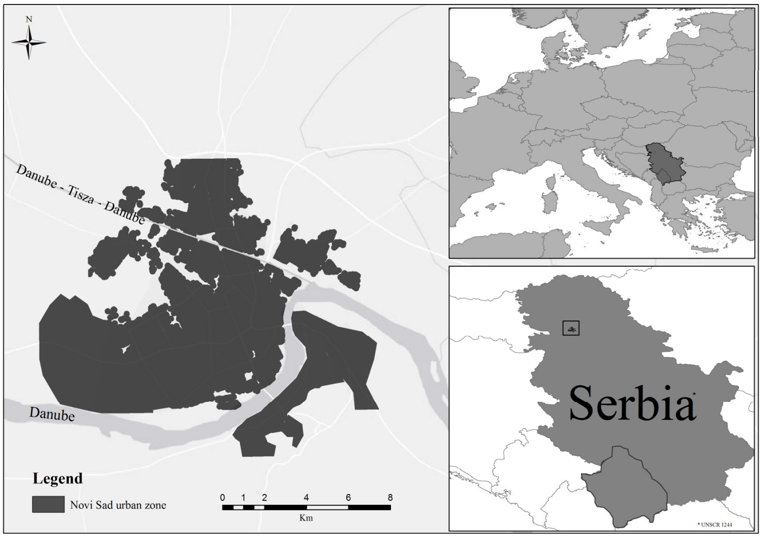


Fig. 1 Investigated built-up area of Novi Sad; its location in the Republic of Serbia and Europe

3. URBAN SURFACE ANALYSIS AND CLIMATE MONITORING NETWORK DEVELOPMENT

3.1. Local Climate Zones definitions

LCZ presents a comprehensive climate-based classification of urban and rural areas for temperature studies. This kind of analysis can contribute to the standardization of surface descriptions, the intercity comparison of UHI magnitude, the clear communication of station site metadata and the interdisciplinary transfer of urban climate knowledge (Stewart and Oke 2012). Therefore, the first papers of urban climate research in Novi Sad were focused on instead LCZ: urban built type definitions. The first definition and delineation of urban built types were made by Popov (1995) and Popov and Savić (2010). The eight urban built types (Fig. 2a) are defined based on various urban surface elements i.e. surface roughness, street width, sky view factor (SVF) and built-up ratio. The results showed that the coefficient of roughness of the terrain varies from about 0.4 m on the outskirts of the city, where about 20–30% of the surface is under family houses, to about 2.5 m in the center of the city, where 60–70% of the surface is under the high buildings. SVF decreases from about 0.9 at the suburban settlement to about 0.35 in some narrow streets in the downtown. Further steps in LCZ definition were made in 2011 based on Stewart and Oke's (2010) classification system. Novi Sad was one of the first cities where this new LCZ classification method was applied. The urban area of Novi Sad (60 km^2) was established as a grid network of 240 cells (0.5 km × 0.5 km). A Landsat satellite image (from June 26, 2006) was used in order to evaluate Normalized Difference Vegetation Index (NDVI) and built-up ratio by cells. The built-up ratio ranged from near 0% (the River Danube) to over 90% (densely built-up centre). Large density was found in the central part and in eastern areas, near the Danube. Furthermore, built-up maxima were located in the western, northern, northeastern and eastern urban areas (Figure 7). Further analysis based on guidance given by Stewart and Oke (2010), information extracted from Google Maps and the authors' local knowledge of the study area have been used to define 7 LCZ classes (Fig. 2b) (Unger et al. 2011a, 2011b).

Table 1 Names and designation of the LCZ types (after Stewart and Oke 2012)

Built types	Land cover types	Variable land cover properties
LCZ 1 – compact high-rise	LCZ A – dense trees	b – bare trees
LCZ 2 – compact midrise	LCZ B – scattered trees	s – snow cover
LCZ 3 – compact low-rise	LCZ C – bush, scrub	d – dry ground
LCZ 4 – open high-rise	LCZ D – low plants	w – wet ground
LCZ 5 – open midrise	LCZ E – bare rock / paved	
LCZ 6 – open low-rise	LCZ F – bare soil / sand	
LCZ 7 – lightweight low-rise	LCZ G – water	
LCZ 8 – large low-rise		
LCZ 9 – sparsely built		
LCZ 10 – heavy industry		

Table 2 Spatial characteristics of LCZ built types and distribution of stations in each LCZs (Šećerov et al. 2015b)

LCZ types	Number of patches	LCZ proportion in %	Number of stations
2	6	9.6	3
3	5	5.2	2
5	8	15.1	6
6	19	42.3	9
8	6	10.1	1
9	5	13.0	3
10	4	4.7	1
A			1
D			1

According to the spatial distribution, the most dominant classes are open low-rise, open midrise and large low-rise. Within the framework of the URBAN-PATH project, during 2013 and 2014 a new spatial distribution of LCZs in urban area of Novi Sad based on Stewart and Oke's (2012) classification (Table 1) was created. In this research a new method based on the automated Geographic Information System (GIS) method developed by Lelovics et al. (2014) (Fig. 3) was used. The study area was divided into 47,000 lot area polygons (Gál and Unger 2009) consisting of a building and the area of influence around it as basic areas in the calculation of surface parameters necessary to characterize the LCZ types. The first step in the analysis was the LCZ classification in each lot area polygon. In order to obtain LCZ areas with appropriate size, they were aggregated and merged according to their LCZ category and their location relative to each other. The aggregation procedure was carried out according to the recommendations of Stewart and Oke (2012) and Lelovics et al. (2014). Final results indicated the existence of 7 LCZ built classes within the city, named as: LCZ 2 – compact midrise, LCZ 3 – compact low-rise, LCZ 5 – open midrise, LCZ 6 – open low-rise, LCZ 8 – large low-rise, LCZ 9 – sparsely built and LCZ 10 – heavy industry. The types and areal distribution of these zones within the urban area of Novi Sad is supplemented by 2 land cover types (A – dense trees, D – low plants) (Fig. 4, Table 2) (Savić et al. 2013a, Savić et al. 2013b, Savić et al. 2014a, Savić et al. 2014b, Unger et al. 2014, Milošević et al. 2015a, Šećerov et al. 2015b).

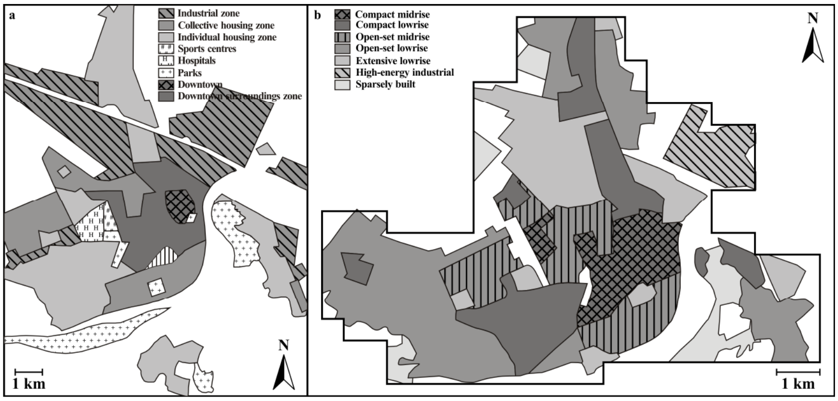


Fig. 2 Spatial distribution of urban built types a) Popov and Savić 2010 and LCZs b) Unger et al. 2011a in Novi Sad urban area

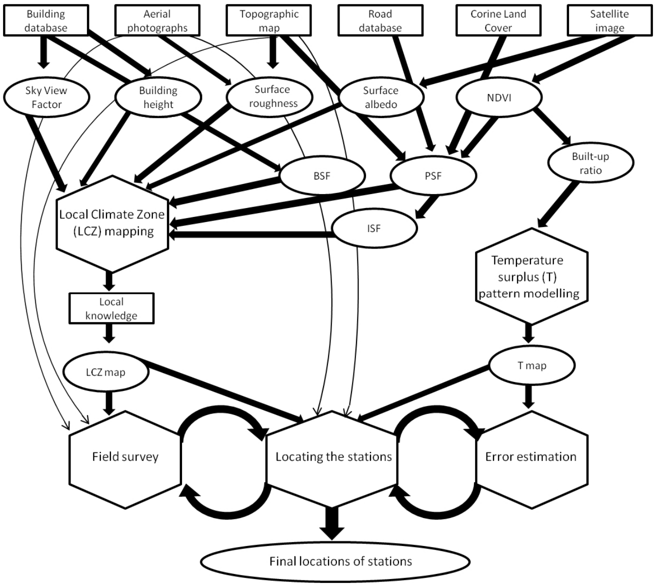


Fig. 3 Process of identifying and delineating LCZs and selecting the representative station sites for urban monitoring network in Novi Sad, Serbia (based on Lelovics et al. 2014). Note: NDVI – Normalized Difference Vegetation Index, BSF – Building Surface Fraction, PSF – Pervious Surface Fraction, ISF – Impervious Surface Fraction

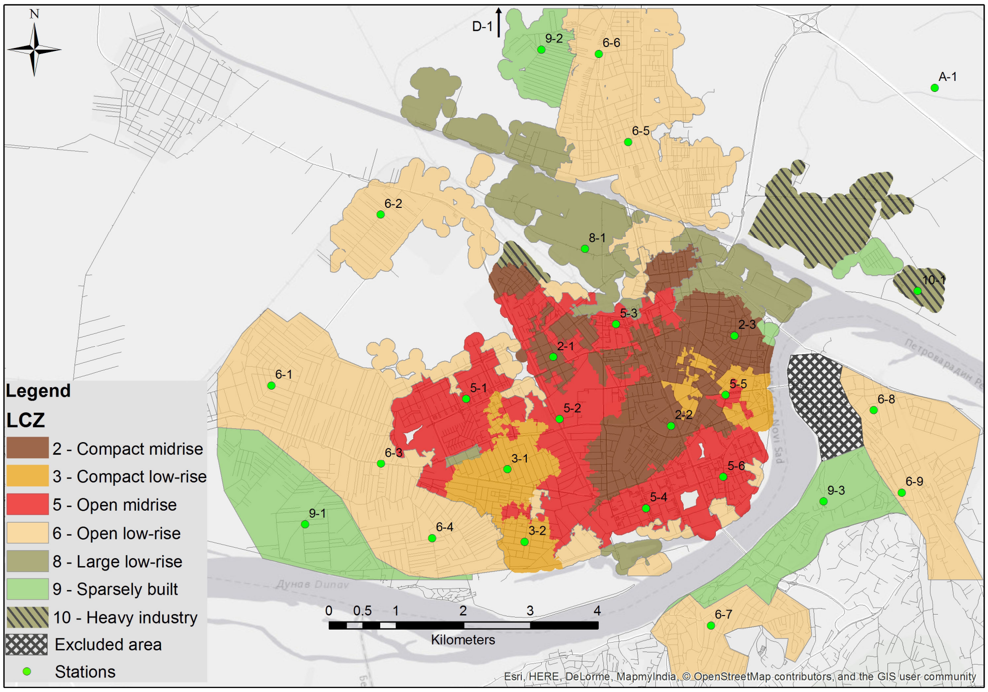


Fig. 4 The obtained LCZ classes and station locations of the urban monitoring network in Novi Sad (Serbia). Note (Station labels): first character – LCZ type; second character – station number in the given LCZ type (Unger et al. 2014, Šećerov et al. 2015b)

3.2. Urban station network development

The spatial and temporal variability of climate across whole cities or regions cannot be represented by individual monitoring stations while the precise allocation of any equipment is difficult (WMO 2006). Thus, the only appropriate way to monitor urban environments, such as the Novi Sad urban area, is with a dense sensor network. This kind of network maximizes the understanding of the urban environment, as well as any changes that are occurring and the likely impacts (Muller et al. 2013).

During 2010 and 2011 proposals have been published for an urban monitoring network containing 9–10 stations across the urban area (Popov 1995, Popov and Savić 2010, Unger et al. 2011a, 2011b) based on urban surface analysis and LCZs delineation. According to further publications (Savić et al. 2013a, 2013b, Unger et al. 2014, Lelovics et al. 2014) an urban monitoring network was developed in Novi Sad, financed by the EU-funded URBAN-PATH project. In order to have a representative urban monitoring network the locations of all stations were based on few criteria (Oke 2004, Lelovics et al. 2014): a) the sites had to be surrounded by at least 250 m wide homogeneous LCZ areas, and the number of stations per each LCZ had to be approximately proportional to the areas of different LCZs; b) the site's representativeness in terms of its microenvironment, i.e. the selected site had to be typical to the LCZ where the station was located; c) the sites had to be located near the areas where high and low temperature surpluses occurred, as well as near local maxima and around spatial temperature stretches, as indicated by the modelled temperature pattern; d) the site's suitability for instrument mounting (for instance: safety, constant electricity supply, stability of lamppost); according to Stewart and Oke's (2012) classification (Table 2 in Lelovics et al. 2016).

The urban monitoring network in Novi Sad consists of 27 stations. 25 stations are located in the urban area and 2 stations are located in the land cover D and A classes and they represent general climate conditions in the non-urbanised areas (Fig. 4). The distribution of stations per LCZs is shown in Table 2.

Stations are installed at least 4 m above the ground (with exceptions ±0.2 m) on arms fixed to selected lampposts (Fig. 5) and equipped with air temperature (±0.3 °C accuracy) and humidity (RH accuracy: ±2% at 20–80%) sensors covered with radiation protection screens with dimensions of 200 × 240 mm. All stations have power supply through the city lights system. The stations measure the parameters every minute and send the readings related to air temperature, relative humidity, battery voltage, status values and other technical information to the main server (installed at University of Novi Sad, Faculty of Science) at 10-minute intervals. The system time of the stations is in UTC (Unger et al. 2014, Šećerov et al. 2015b).

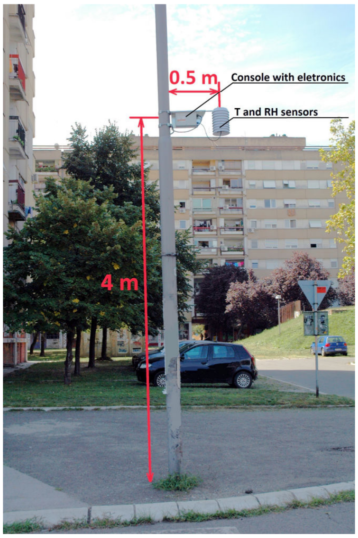


Fig. 5 Example of monitoring network station in Novi Sad (Serbia) mounted on a lamppost (Šećerov et al. 2015b)

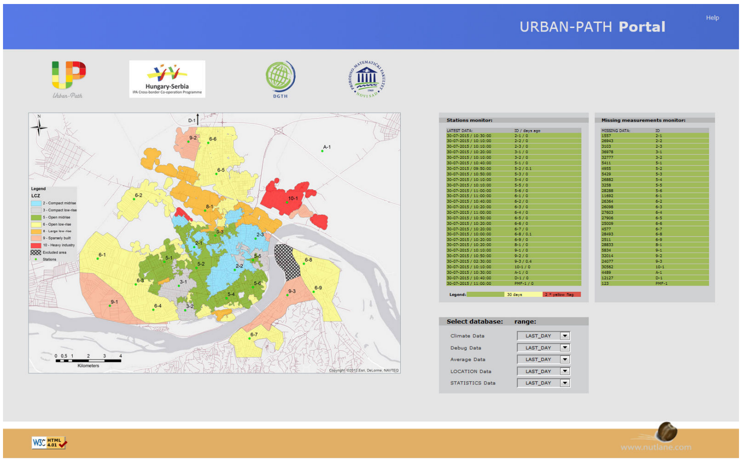
3.3. Monitoring and public display system

It is very important to implement the method of data representation and communication between stations and servers, working with data stored in database and the real-time public availability of the data (Šećerov et al. 2015b) in order to adequately use the temperature and relative humidity values from stations.

In order to receive and store data into the database server and monitor system behaviour, the Urban Path System tool (UP-SYS_tool) was built. Further climate studies, and work with gathered data can be done using URBAN-PATH Portal. Data uploaded to the primary server are being processed by the UP-SYS_tool. All data are processed whether they contain climatological *measurement* or *debug* data with statistics about station work. Error detection and notification is performed through the entire UP-SYS_tool work. As a final result of the UP-SYS_tool work, data are stored into the database server. Using defined periods, UP-SYS_tool starts the archiving process to relocate and compress processed files to archive location. After that they can be used, if needed, for recovery. URBAN-PATH Portal is an application built to support all demands related with urban climate studies and for analyzing the entire systems' work. It can be used for two purposes: a) to get data from the database in the desired format and b) to monitor current system status.

The latest inserted data for each station *(stations monitor)* are shown together with their 'age'. If the last inserted data are older than the defined thresholds, the line containing it is coloured with a different warning colour. Next to the *stations monitor* is the *missing measurements monitor*, used to provide adequate information about the number of missing data per station (Fig. 6). Although the system is built to handle different levels of problems whether they are hardware or software or related to connection problems, the final result is the data not being stored into the database server. The UP-SYS_tool periodically checks the database for missing data and stores results into a separate database, which is used for *missing measurements monitor* (Šećerov et al. 2015b).

The visualization of the measured values from the urban climate monitoring network in Novi Sad is provided by an automatic data procession system. This system was developed and installed at the Department of Climatology and Landscape Ecology of the University of Szeged. Every 10 minutes, the data from the monitoring network, stored into the main server at the Faculty of Science, University of Novi Sad, is transmitted to the main server at the University of Szeged and the automatic data procession system creates two final (site and spatial) databases in order to present these data as charts and maps on the public homepage of the URBAN-PATH project (http://en.urban-path.hu/monitoring-system.html). All of the measured and calculated values can be accessed in a way that the time of the maps and charts can be defined by the visitors. Additionally, public display is installed at a frequently visited place, i.e. in the main building of the University of Novi Sad (Savić and Unger 2014, Unger et al. 2015b).



Stations monitor:

LATEST DATA:	ID / days ago
30-07-2015 / 10:30:00	2-1 / 0
30-07-2015 / 10:10:00	2-2 / 0
30-07-2015 / 10:10:00	2-3 / 0
30-07-2015 / 10:20:00	3-1 / 0
30-07-2015 / 10:10:00	3-2 / 0
30-07-2015 / 10:40:00	5-1 / 0
30-07-2015 / 09:50:00	5-2 / 0.1
30-07-2015 / 10:50:00	5-3 / 0
30-07-2015 / 10:10:00	5-4 / 0
30-07-2015 / 10:10:00	5-5 / 0
30-07-2015 / 11:00:00	5-6 / 0
30-07-2015 / 11:00:00	6-1 / 0
30-07-2015 / 10:40:00	6-2 / 0
30-07-2015 / 10:20:00	6-3 / 0
30-07-2015 / 11:00:00	6-4 / 0
30-07-2015 / 10:50:00	6-5 / 0
30-07-2015 / 10:20:00	6-6 / 0
30-07-2015 / 10:20:00	6-7 / 0
30-07-2015 / 10:00:00	6-8 / 0.1
30-07-2015 / 10:20:00	6-9 / 0
30-07-2015 / 10:20:00	8-1 / 0
30-07-2015 / 10:10:00	9-1 / 0
30-07-2015 / 10:50:00	9-2 / 0
30-07-2015 / 02:30:00	9-3 / 0.4
30-07-2015 / 10:10:00	10-1 / 0
30-07-2015 / 10:30:00	A-1 / 0
30-07-2015 / 10:40:00	D-1 / 0
30-07-2015 / 11:00:00	PMF-1 / 0

Legend: 🟩 30 days 2 * yellow flag

Missing measurements monitor:

MISSING DATA:	ID
1557	2-1
26943	2-2
3103	2-3
36978	3-1
32777	3-2
5411	5-1
4955	5-2
5429	5-3
26882	5-4
3258	5-5
28288	5-6
11692	6-1
26364	6-2
26098	6-3
27603	6-4
27906	6-5
25009	6-6
4577	6-7
28493	6-8
2511	6-9
28833	8-1
5834	9-1
32014	9-2
24077	9-3
30562	10-1
4489	A-1
12127	D-1
123	PMF-1

Select database:	range:
Climate Data	LAST_DAY
Debug Data	LAST_DAY
Average Data	LAST_DAY
LOCATION Data	LAST_DAY
STATISTICS Data	LAST_DAY

Fig. 6 URBAN-PATH Portal main page with data monitoring and database selection tool (Šećerov et al. 2015b)

4. URBAN HEAT ISLAND TEMPERATURE PATTERN AND OUTDOOR THERMAL COMFORT RESEARCH

4.1. Urban heat island analysis

Urban heat island occurs in almost all urban areas, large or small, in warm or cold climates. The traditionally described heat island is measured at standard screen height (1–2 m above ground), below the city's mean roof height in a thin section of the boundary layer atmosphere called the urban canopy layer. Air in this layer is typically warmer than that at screen height in the countryside. The main causes of the heat island are related to structural and land cover differences of urban and rural areas (Stewart and Oke 2012).

The results from the Novi Sad urban area show that the built-up ratio has a significant influence on the spatial pattern of the annual mean UHI intensity, i.e. the ΔT values follow the change in the built-up values (Fig. 7). The main feature of this pattern in the central study area is that the isotherms show concentric-like shapes with values increasing from the suburbs towards the inner urban areas with the highest ΔT (>4 °C) in the densely built-up centre. Deviations from this concentric-like shape occur in the western, northern and northeastern parts where the isotherm of 2 °C stretches towards the outskirts. Furthermore, three island-like local maxima appear in the northern, northeastern and eastern parts of the study area with values over 3 °C, 2.5 °C and 2 °C, respectively. The largest area with very low ΔT values, due to the influence of the River Danube, can be found in the southeastern part of the study area (Unger et al. 2011a, 2011b). The applied method for the determination of the suspected spatial structure of the mean annual UHI intensity in Novi Sad is based on the study of Balázs et al. (2009). The main advantage of this regression method was to predict the spatial distribution of the annual mean UHI using just a few input parameters which can be determined in a simple way (remote sensing) without having detailed local information about the city. For the evaluation of the model estimation a comparison has been made using the datasets of the Rimski Šančevi (rural) and Petrovaradin (urban) stations (1956–1992). Since there were no night-time measurements, the daily minimum temperature data was used for the comparison. The differences (ΔT_{min}) of the measured daily minimum temperature were calculated for each day and the average of these differences can be considered as an approximate value of the annual mean UHI intensity. Finally, the ΔT value of Petrovaradin calculated by the statistical model is 1.66 °C and the measured (ΔT_{min}) is 1.8 °C. This insignificant difference proves that the accuracy of the model estimation meets the requirements of the aim of the study (Unger et al. 2011a).

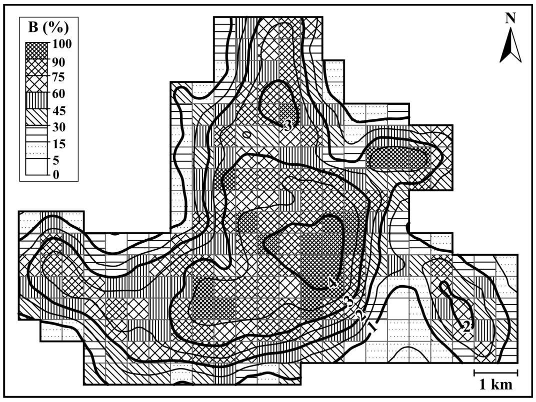


Fig. 7 Spatial distribution of the built-up ratio (B) and the modelled annual mean UHI intensity (°C) in the study area of Novi Sad (Unger et al. 2011a)

The first intra-urban and inter-urban comparisons from Novi Sad (Serbia) and Szeged (Hungary), based on daily minimum and maximum temperature values were made by Lelovics et al. (2016). The research period was three summer months (June, July and August) in 2014, i.e. during two time periods with prevailing anticyclonic conditions with 72 (July 3 to 5) and 48 (July 19 to 20) hours in length, respectively. In Novi Sad, the temperatures were slightly higher, but the classes differ less compared to Szeged. The greatest temperature surpluses occurred in LCZ 2 and LCZ 6 (between 5–7 °C), while LCZ 5, LCZ 3 and LCZ 8 remained somewhat cooler. The cycles of LCZ A and LCZ D were similar. The temperature difference between the two types remained within the ±3 °C interval, with the largest values occurring around 0 UTC (Fig. 8). According to Fig. 9 for the most time, the UHI intensity remained positive with highest values at night, while negative values occurred predominantly during the day (urban cool island). The dividing line between these two periods was around

6 UTC and 12 UTC in both cities. The range of UHI intensity was between -1.48 °C and 5.22 °C in Szeged, and between -3.70 °C and 6.85 °C in Novi Sad. Urban cool islands occurred in both cities during the day. It was typically around -1 °C in Szeged and -2 °C in Novi Sad (Lelovics et al. 2016).

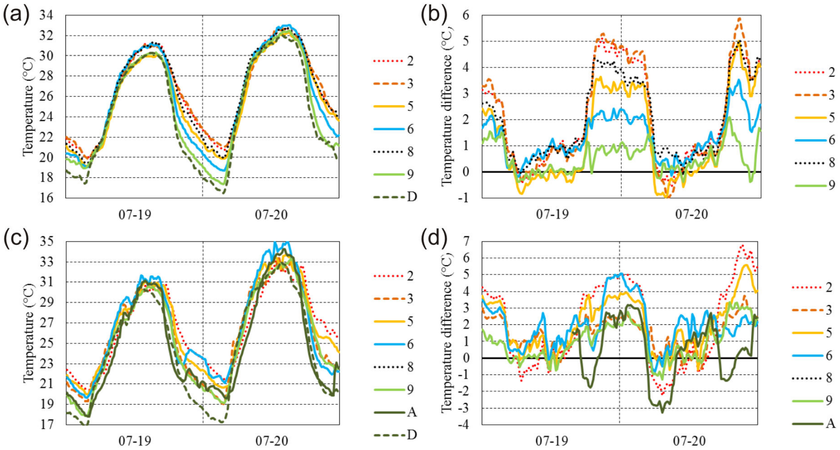


Fig. 8 Absolute and relative (difference from LCZ D) temperature variations at selected sites in Szeged (a, b) and Novi Sad (c, d) (3 to 5 July 2014) (Lelovics et al. 2016)

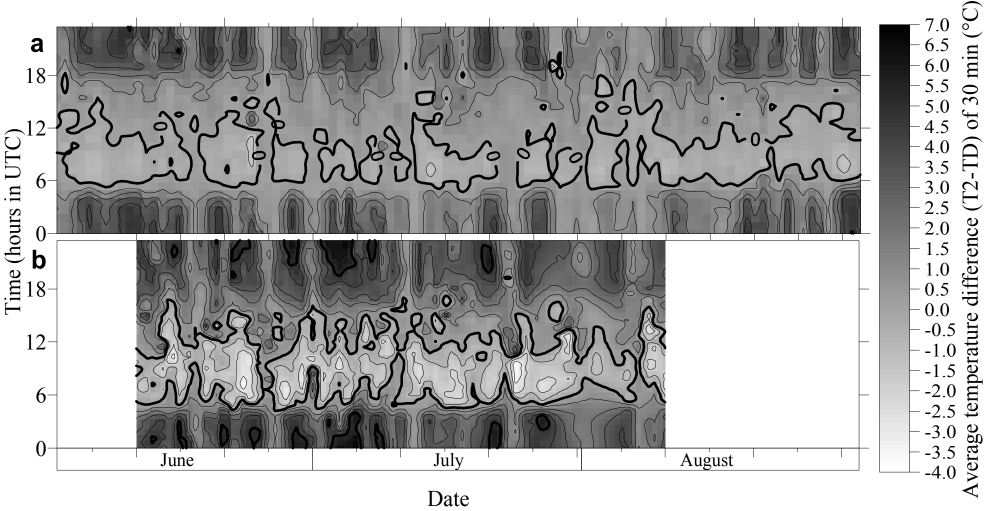


Fig. 9 Average temperature differences (°C) between LCZ 2 and LCZ D (a) in Szeged and (b) Novi Sad in summer 2014 (thin isotherms – integer °C, thick isotherms – 0 and 5 °C) (Lelovics et al. 2016)

4.2. Outdoor thermal comfort outcomes

People living in urban areas experience various kinds of thermal stress during the year. Extreme weather events, e.g. heat waves and cold spells, are especially stressful. With the usage of field measurements and models it is possible to quantify the outdoor thermal conditions in urban areas. These are important input data for architects and urban planners in order to create comfortable urban areas for their residents (Milošević et al. 2015a).

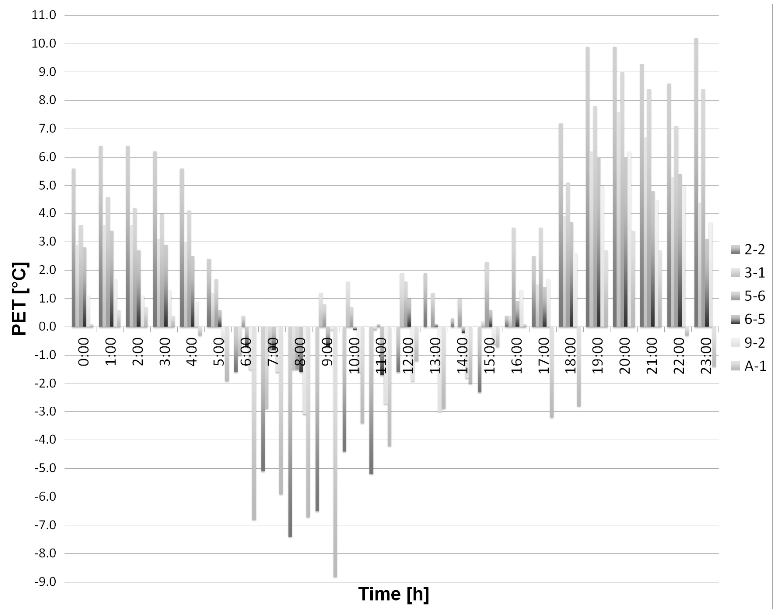


Fig. 10 Mean hourly PET differences between selected LCZs and LCZ D (ΔPET_{LCZx-D}) in Novi Sad during the tropical day (13th August 2014) (Milošević et al. 2015b)

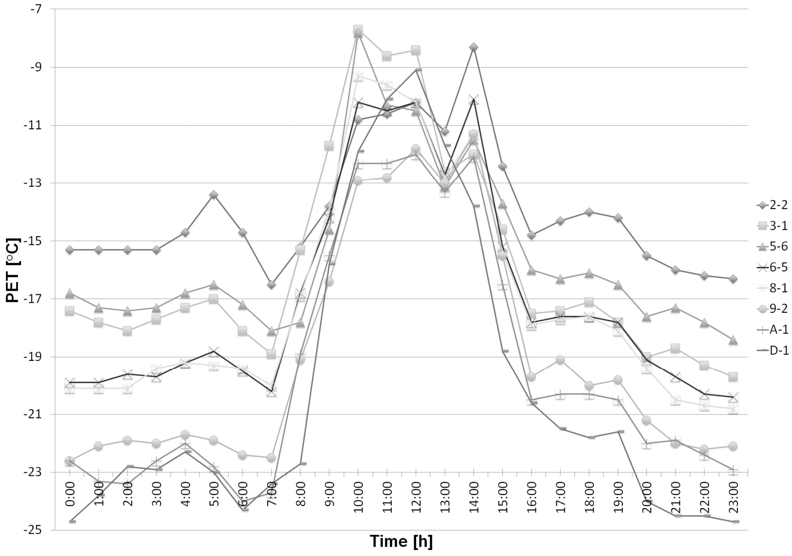


Fig. 11 Diurnal variation of human bioclimatic characteristics expressed via PET index in selected LCZs in Novi Sad on icy day (31st December 2014) (Milošević et al. 2015b)

The first analysis related with outdoor thermal comfort conditions in different LCZs of the Novi Sad and its surroundings was based on the calculated Physiologically Equivalent Temperature (PET) values for 13th August (the hottest day in 2014) and 31st December (the coldest day in 2014). Comparing hourly PET values in each selected LCZ with hourly PET values in LCZ D (low plants), all LCZs, in general, had higher PET values compared to LCZ D during late afternoon and nocturnal hours. Maximum PET difference was 10.2 °C between LCZ 2 and LCZ D at 23 UTC. This suggests that urban areas are substantially more uncomfortable during the night compared to the low plant (rural) areas in the vicinity of the city. In the early morning hours (7–8 UTC) all LCZs had smaller heat loads compared to LCZ D and this continued until the midday hours for all LCZs except LCZ 3 and LCZ 5. LCZ D had higher heat loads (up to 8.8 °C) during the majority of the day when compared with LCZ A (dense trees) (Fig. 10). On the coldest day, urban LCZs were warmer compared to the LCZ D during most of the day with smaller diurnal temperature ranges. Maximum PET difference (9.6 °C) occurred between LCZ 2 and LCZ D in the period 5–6 UTC. Only in the period 11–13 UTC did the majority of the urban LCZs have lower PET compared to the LCZ D (Fig. 11). Intra-urban analysis for an icy day showed that the smallest difference in average daily PET occurred between similar LCZs and the largest difference between urban and non-urban LCZs (Milošević et al. 2015a).

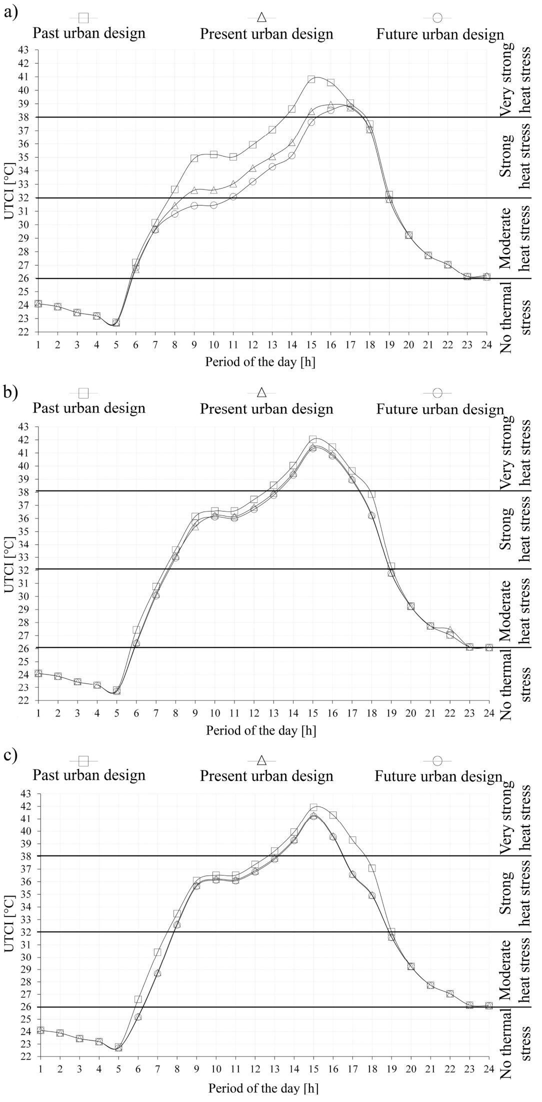


Fig. 12 The average UTCI values for 7th July 2014 at all predetermined body locations at: a) the northern footway, b) the middle of the street, and c) the southern footway (Bajšanski et al. 2015)

In order to quantify relative differences in diurnal thermal comfort conditions during heat wave period (from 5th to 8th July 2014), the average hourly PET in each selected LCZ was compared with average hourly PET values in LCZ D. Fig. 10 shows that all LCZs (except

LCZ A – dense trees) had higher PET values compared to LCZ D (low plants) from 17 UTC to 5 UTC. Maximum PET difference of 7.1 °C is noticed between LCZ 2 (compact midrise) and LCZ D (low plants) at 0 UTC. Contrary to this, LCZ D (low plants) had higher PET values compared to the majority of LCZs in the period 7–16 UTC with maximum difference of 8.5 °C compared to LCZ A (dense trees) at 9 UTC (Milošević et al. 2015b).

Built urban environment creates a climate that influences outdoor thermal comfort conditions and this is a well-established fact (Bajšanski et al. 2015). Therefore, during 2015 the first common research of urban climatologists and architects was carried out in order to create new possibilities for the evaluation and improvement of outdoor human thermal comfort in built urban environments using different software packages and parametric approach. Algorithms were developed and applied for the evaluation and improvement of non-stationary outdoor thermal comfort conditions and one street and one station from a compact midrise built-up area (LCZ 2) was used as database. The evaluation of thermal comfort in urban designs of linear street showed that periods with very strong heat stress have decreased on s hot summer day by up to 9.8% (Fig. 12). In contrast, the greatest thermal stress in winter (strong cold stress) increased by up to 3.5%. Universal Thermal Climate Index (UTCI) values decreased by up to 6.1 °C at 10 UTC when comparing past and future urban designs on hot summer day. On a cold winter day, the greatest UTCI decrease of 3.2 °C was observed at 11 UTC. Maximum UTCI changes were detected in shadowed body locations. The improvement of outdoor thermal comfort between future planned and proposed urban design of linear street is a consequence of up to 2.9 °C UTCI decrease on summer day and up to 1.7 °C UTCI increase on winter day. The UTCI decrease in non-linear streets between future planned and proposed urban designs was up to 3.9 °C on summer day and increase was up to 1.1 °C on winter day (Fig. 13). The developed automatic algorithms showed to be suitable for evaluating and improving the outdoor thermal comfort sensation in any built urban environment with appropriate weather data (Bajšanski et al. 2015, Savić et al. 2015).

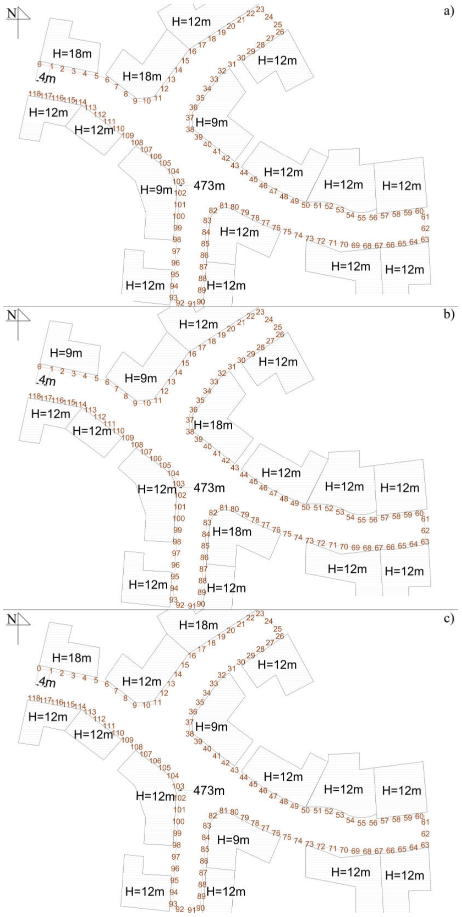


Fig. 13 The buildings heights arrangement of the non-linear streets: a) future planned urban design, b) proposed urban design in summer and c) proposed urban design in winter (Bajšanski et al. 2015)

5. AIR TEMPERATURE AND MORTALITY IN URBAN AREA

Strong evidence exists that seasonal variations of mortality are caused by different physiological parameters, e.g. haemostatic factors, blood pressure, as well as malnutrition (Stout and Craword 1991, Woodhouse et al. 1993). Several research articles suggested that these changes are consequences of the seasonal variation of temperature (Rose 1966, Kalkstein and Greene 1997). Strong relation between mortality and temperature was found during heat wave occurrences (Arsenović et al. 2014a). Therefore, in 2011 the urban climate research group from Novi Sad started with first analysis related with the seasonal variation of mortality caused by air temperature pattern in urban area. The first published papers (Đurđev et al. 2012, Arsenović et al. 2012) focused on air temperature and crude death rate (CDR) in the Belgrade urban area for the period 1988–2008.

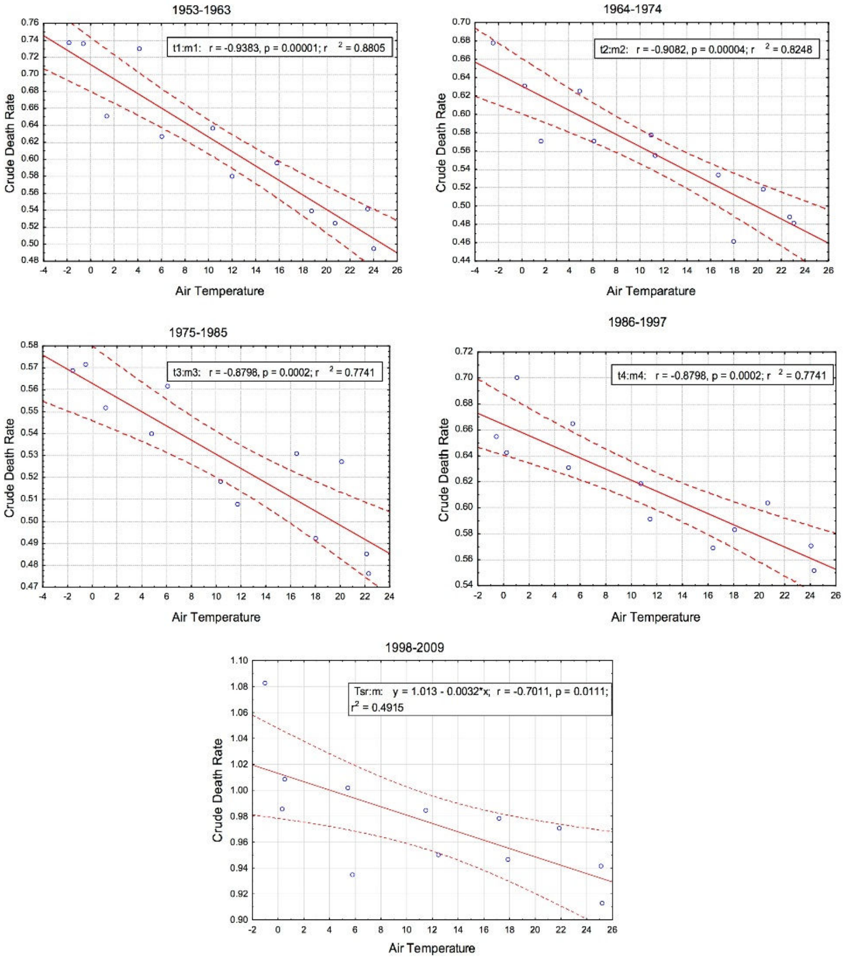


Fig. 14 Trends of crude death rate (CDR) in winter and non-winter periods (preceding and following period) (Arsenović et al. 2014a, Arsenović and Đurđev 2015)

The first results for Novi Sad are presented in the papers of Arsenović (2014) and Arsenović et al. (2014a, 2014b) and Arsenović and Đurđev (2015). Winter mortality in Novi Sad in the period from 1953/54 until 2008/09 was about 15% higher than in the preceding and following period and the results of regression analysis indicated that crude death rate and temperature are negatively associated; the decrease of average temperature is followed with an increase of crude death rate. During the last observed period, results show lower statistical significance in regression (Fig. 14). The results of Healy for the period 1988–1997 show that winter mortality in region EU 14 is about 16% higher than in non-winter period. The population in Novi Sad is more sensitive during the colder period of the year and the seasonal pattern of mortality has changed during the observed period. During the analysis it was noticed that in January, May, June, July and August, the average temperature has been increasing. Such trend of average temperature may alter balance between mortality in the winter and non-winter period. In regions with temperate climate, such as Novi Sad, even small changes of temperature could influence the seasonal fluctuations of mortality during year. Similar results for Belgrade also show that during the second half of the 20th century and the first decade of the 21st century, the population is less sensitive to cold periods (Đurđev et al. 2012).

6. CONCLUSIONS

According to the analysis of the reviewed papers in the last five years a substantial contribution has been made to urban climate research in Serbia, i.e. in the Novi Sad urban area, which is the second largest city in the country. In order to provide detailed research of morphologically heterogeneous urban environments it is necessary to implement multidisciplinary and interdisciplinary approaches.

Up to now the urban climate research group from Novi Sad was focused on LCZ classifications and development of urban climate network in order to analyze in fine detail UHI and outdoor human thermal comfort patterns in Novi Sad. Outcomes from these urban climate researches should play an important role in urbanization, demography and health issues. Therefore, this kind of common research can contribute to the understanding of weather and climate interactions and impacts in urban areas.

Further research will be focused on the improvements of the urban surface classifications. The members of the Novi Sad research group are a part of the WUDAPT (World Urban Database and Access Portal Tools) group (http://www.wudapt.org). The main activities through the WUDAPT group are to create LCZ maps of important cities in South-East Europe using a new approach of LCZ mapping. Outdoor human thermal comfort is connected with the quality of life in urban areas, urbanization and mortality of the population. Therefore, spreading activities related with these issues is an important task. Our urban climate research group joined the Working Group on Protocols for the Assessment and Reporting of Outdoor Thermal Comfort that is initiated by Professor Rohinton Emmanuel.

Today, increased energy consumption is a huge problem in urban areas, mostly during the extreme temperature events (heat and cold waves). Research from Savić et al. (2014c) showed that extreme air temperature spells impact electrical energy consumption, not only in large-sized cities, but also in small-sized too. Therefore, correlation of air temperature and energy consumption in the Novi Sad urban area will be one of the research goals in further years.

Urban climate survey can provide detailed spatial and temporal data and outcomes of temperature and thermal comfort patterns in order to help local authorities in urban planning strategies and to counterattack the adverse effect of urban climate and climate change.

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