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Urban climate monitoring system suitability for intra-urban thermal comfort observations in Novi Sad (Serbia) – with 2014 examples

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dated: 12 June 2015

Abstract

In 2014, urban climate monitoring systems were established in two neighboring European cities (Novi Sad, Serbia; Szeged, Hungary) based on Local Climate Zones (LCZ) classification system, GIS model calculations and fieldwork. Seven built LCZ types in the built-up area of Novi Sad (112 km^2) and two LCZ land cover types in nonurban environment in the vicinity of the city were delineated.
Urban climate monitoring system in Novi Sad consists of 27 stations equipped with air temperature and relative humidity sensors distributed across all LCZs. This system provided 10-minute measured air temperature and relative humidity data since June 2014.
Human comfort observations in different LCZs of the city and its surroundings were investigated for warmest (tropical) and coldest (icy) day in 2014 in Novi Sad. Thermal comfort was assessed with the application of the Physiologically Equivalent Temperature (PET) thermal index. Differences in PET index amongst LCZs can be as high as 10-12 ºC during nocturnal hours when comparing built-up areas of the city (e. g. compact midrise - LCZ 2) and nonurban areas (low plants - LCZ D and dense trees - LCZ A). In general, smaller differences occurred between subsequent LCZ classes. These results suggest that urban climate monitoring system based on LCZ scheme can be used for the thermal comfort research during extreme temperature days.

Keywords: urban climate monitoring system, local climate zones, thermal comfort, tropical day, icy day, Novi Sad

1. Introduction

People living in urban areas experience various kinds of thermal stress during the year. Especially stressful are extreme weather events, e.g. heat waves and cold spells. With the usage of field measurements and models it is possible to quantify the human thermal conditions in urban areas. These are important data for urban planners and decision-makers if they want to create lively urban areas for its residents.

Urban climate monitoring system in Novi Sad was developed in 2014 under IPA HUSRB Project (URBAN-PATH, http://en.urban-path.hu). The system is based on LCZ concept (Stewart & Oke 2012) and consists of temperature and relative humidity sensors deployed on 27 locations in seven built and two land cover LCZ types (Unger et al. 2014) (Figure 1). Local climate zones are defined as "regions of uniform surface cover, structure, material, and human activity that span hundreds of meters to several kilometers in horizontal scale" (Stewart & Oke 2012). The usage of the LCZ scheme for urban heat island (UHI) and human thermal comfort assessment was performed in a number of studies (Puliafito et al. 2013, Alexander & Mills 2014, Fenner et al. 2014, Lehnert et al. 2014, Middel et al. 2014, Stewart et al. 2014, Leconte et al. 2015).

The aim of this study is to investigate intra-urban thermal comfort during extreme air temperature days. This study provides data in the form of the calculated human thermal comfort index (PET) (Höppe 1999) from selected eight LCZs delineated in a Central European city. Results and conclusions can provide the insight into human comfort conditions in different LCZs of the city and showcase the suitability of the LCZ concept for intra-urban thermal comfort research.

2. Materials and methods

Novi Sad is a mid-sized city in the northern part of the Republic of Serbia, located on a plain from 80 to 86 m above sea level. The river Danube flows along the southern and the south-eastern edge of the city, and its width varies from 260 to 680 m (Savić et al. 2013). The relatively narrow Danube-Tisza-Danube Canal passes through the northern part of the city (Fig. 1). To the south of the Novi Sad urban area, the northern slopes of Fruška Gora Mountain are located (the highest peak is 538 m a.s.l.) which descend steeply towards the Danube (Unger at al.

2011). Novi Sad is the second largest city in the Republic of Serbia with a population of 320 thousands (data from 2014) and built-up area of 112 km^2.

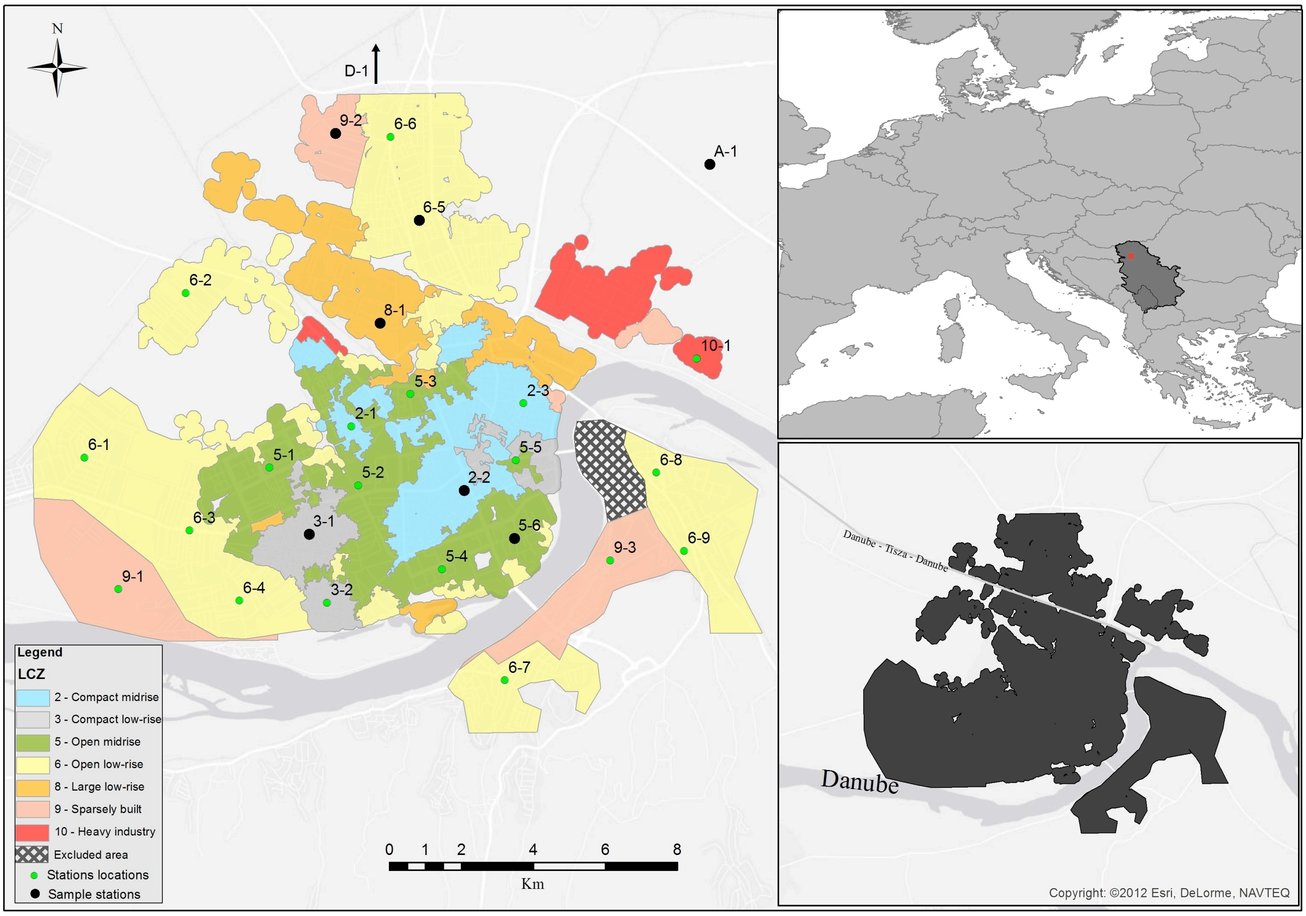

Fig. 1 Location of Novi Sad in Europe and Serbia (upper right - red square), its built-up area (down right) and the LCZ and urban climate monitoring system map of Novi Sad (left). In the sites' identification number the first digit refers to the LCZ class (Stewart & Oke 2012) and the second one is an assigned number. Black dots are the selected stations for the analysis presented in this paper.

The area is in Köppen-Geiger climate region Cfb (temperature warm climate with a rather uniform annual distribution of precipitation) (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 amount of precipitation is 615 mm (based on the data from 1949 to 2013).

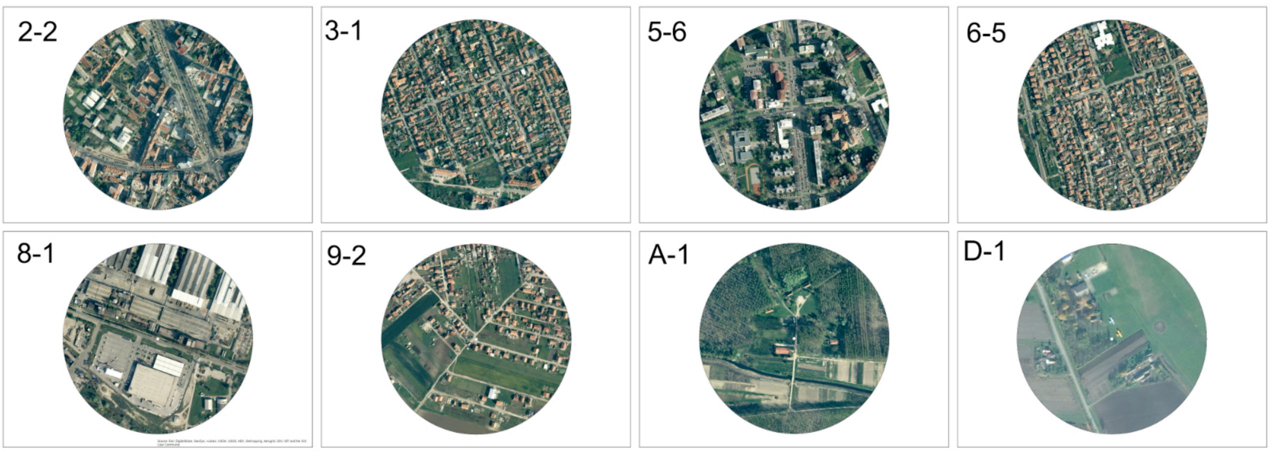

Fig. 2 Aerial photographs illustrating selected measurement sites (white dot in the middle of the photo) with a 500 m environment diameter in Novi Sad. First number – LCZ class number, second number – station's identity number in the given LCZ class: 2-2 (compact midrise), 3-1 (compact low-rise), 5-6 (open midrise), 6-5 (open low-rise), 8-1 (large low-rise), 9-2 (sparsely built), A-1 (dense trees), D-1 (low plants).

In this study we use PET to evaluate the human bioclimatological comfort sensations in different LCZs during the warmest and coldest day in Novi Sad in 2014. Representative station for each LCZ was selected (Fig. 2) and their urban environment was modeled in RayMan model (Matzarakis et al. 2007). The exception was LCZ 10 (heavy industry) because station 10-1 did not work during the analyzed days. Selected days were August 13th and December 31st with prevailing anticyclonic conditions. August 13th was the warmest day in Novi Sad in 2014 with T_{max} higher than 30 °C (tropical day) on all stations. December 31st was the coldest day in Novi Sad in 2014 with T_{max} lower than 0 °C (icy day) on all stations. The input data for the calculation of PET are hourly air temperature, relative humidity and wind speed for selected days. The temperature and relative humidity are measured by the station network, while the wind speed for Novi Sad are from daily WRF model (Michalakes et al. 2004) predictions initiated at 0 UTC for the Pannonian Basin using and NOAA/NCEP global forecast (GFS) (EMC 2003). The wind speed was corrected using the roughness length calculated by the Roughness Mapping Tool (Gál & Unger 2009). Radiation fluxes were calculated in the RayMan model. Time is given in Universal Time Coordinated (UTC) in the analyses.

3. Results and discussion

3.1. Thermal comfort during tropical day

Human thermal comfort conditions in different LCZs of the city and its surroundings were analyzed based on the calculated PET values on August 13th, 2014.

From Fig. 3 the number of hours (h) with different thermal stress classes can be examined. It can be noticed that heat stress classes (PET > 23 °C) are most frequent in built LCZs ranging from 15 h in low-rise LCZs (3 and 6) to 17 h in midrise LCZs (2 and 5). The heat stress classes are less frequent in sparsely built areas (LCZ 9) followed by non-urban areas (LCZ D and LCZ A). Contrary to this, cold stress classes (PET < 18 °C) are most frequent in non-urban (from 8 h in LCZ D to 9 h in LCZ A) and sparsely built LCZs (6 h). Built LCZs had fewer occurrences of cold stress (e.g. 1 h in LCZ 2) compared to sparsely built and non-urban LCZs. The comfortable level of human comfort sensation was noticed during nocturnal hours and ranged from 3 h in LCZ 5 (open midrise) to 6 h in LCZ 2 (street canyon).

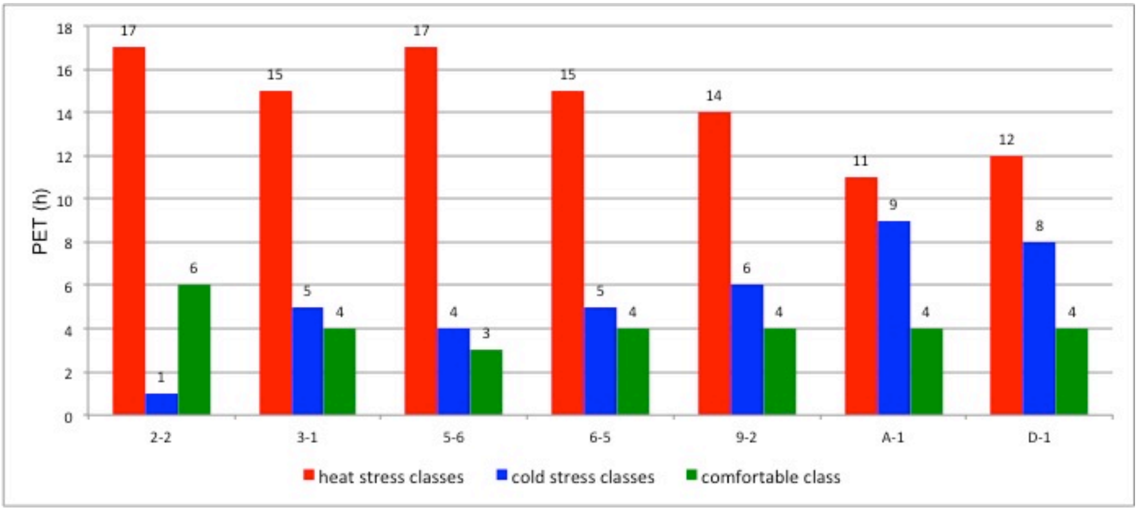

Fig. 3. Distribution of PET classes (in hours) for different grades of thermal perception by human beings (According to Matzarakis & Mayer 1996) in LCZs of Novi Sad on August 13th, 2014.

The highest heat load is calculated for LCZ 2 at 13 UTC (PET = 45 °C) and the lowest for LCZ A at 4 UTC (12.6 °C). When comparing average daily PET of every LCZ (ΔPET_{LCZx-y}) obtained differences can suggest similarity or contrasts of the thermal environment of LCZs. PET differences were smallest between LCZ 2 and 3 (0.2 °C), LCZ 6 and 3 (-0.4 °C), LCZ 9 and D (0.7 °C), LCZ 5 and 2 (0.9 °C) and LCZ A and D (-1.7 °C). It can be noticed that smallest differences occurred between subsequent LCZ classes (LCZ 2 and 3). In general, thermal differences increased for dissimilar LCZs types (e.g. LCZ 2 and LCZ A) (Tab. 1). The warmest LCZ was open midrise (LCZ 5) due to its micro-location on crossroads (Fig. 2) with high irradiation during the day.

Tab 1. Average difference between pairs of LCZ types ΔPET_{LCZx-y} for August 13th, 2014 in Novi Sad. Differences are presented as the LCZ type in column minus the LCZ type in row.

Stations	**2-2**	**3-1**	**5-6**	**6-5**	**9-2**	**A-1**	**D-1**
2-2	-	-0.2	0.9	-0.7	-1.7	-4.2	-2.4
3-1	0.2	-	1.2	-0.4	-1.5	-3.9	-2.2
5-6	-0.9	-1.2	-	-1.6	-2.6	-5.1	-3.4
6-5	0.7	0.4	1.6	-	-1.0	-3.5	-1.8
9-2	1.7	1.5	2.6	1.0	-	-2.5	-0.7
A-1	4.2	3.9	5.1	3.5	2.5	-	1.7
D-1	2.4	2.2	3.4	1.8	0.7	-1.7	-

In order to quantify relative differences in diurnal thermal comfort between urban and non-urban areas, we have compared hourly PET values in each selected LCZ with hourly PET values in LCZ D (low plants) (ΔPET_{LCZx-D}). Fig. 4 shows that 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 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).

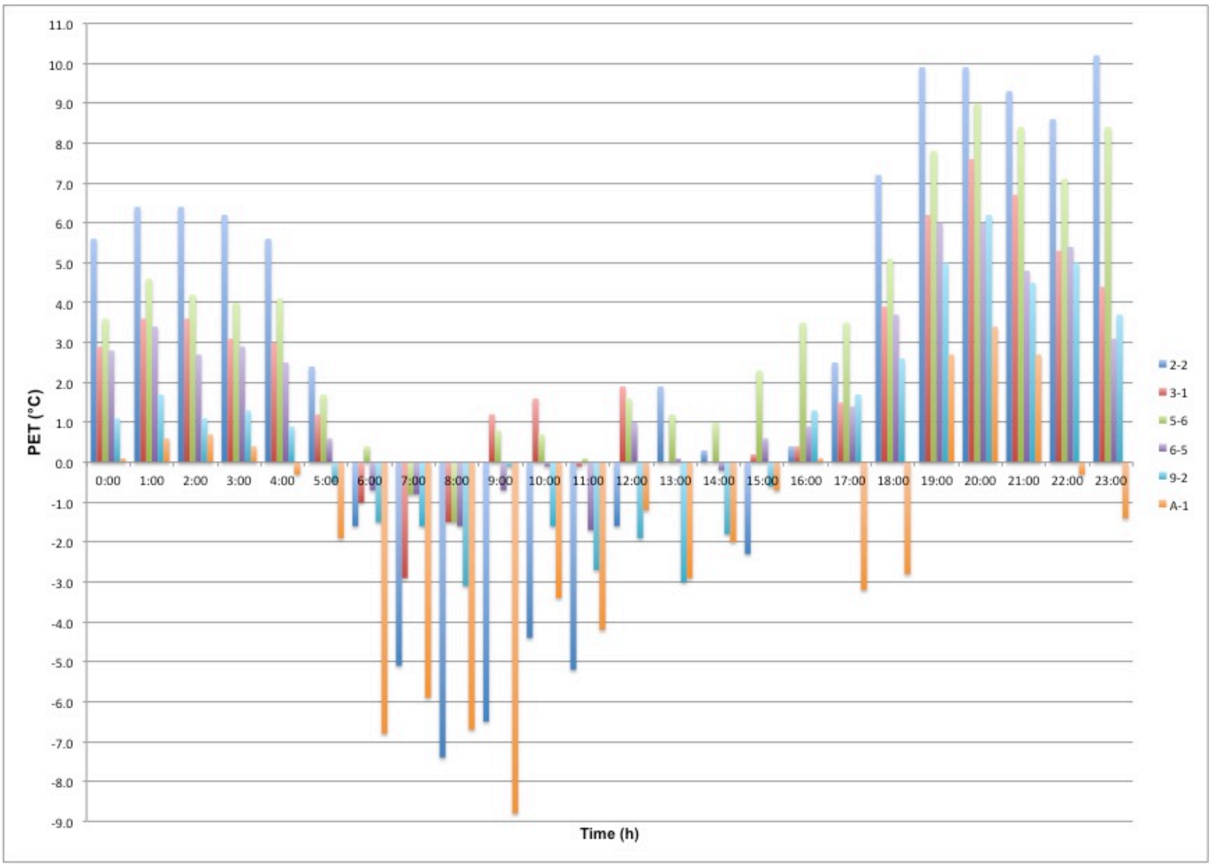

Fig. 4. Mean hourly PET differences between selected LCZs and LCZ D (ΔPET_{LCZx-D}) in Novi Sad during the tropical day (August 13th, 2014).

3.3. Thermal comfort during icy day

December 31st was the coldest day in Novi Sad in 2014. Thermal comfort was characterized as "very cold" (PET < 4 °C) during the whole day in all LCZs. The highest cold load was calculated for LCZ D at 23 and 00 UTC (PET = -24.7 °C) and the lowest for LCZ 3 at 10 UTC (PET = -7.7 °C). Urban LCZs were warmer compared to the LCZ D during the major part 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, majority of the urban LCZs had lower PET compared to the LCZ D (Fig. 5).

Intra-urban analysis (ΔPET_{LCZx-y}) for icy day showed that smallest difference (0.1 °C) in average daily PET occurred between similar LCZs (e.g. LCZs 6 and 8). Largest difference of 6.3 °C occurred between urban and non-urban LCZs (LCZ 2 and D) (Tab. 2).

Tab 2. Average difference between pairs of LCZ types ΔPET_{LCZx-y} for December 31st, 2014 in Novi Sad. Differences are presented as the LCZ type in column minus the LCZ type in row.

Stations	**2-2**	**3-1**	**5-6**	**6-5**	**8-1**	**9-2**	**A-1**	**D-1**
2-2	-	-1.9	-1.6	-3.0	-3.1	-5.1	-5.6	-6.3
3-1	1.9	-	0.3	-1.1	-1.3	-3.2	-3.7	-4.4
5-6	1.6	-0.3	-	-1.4	-1.5	-3.5	-4.0	-4.7
6-5	3.0	1.1	1.4	-	-0.1	-2.0	-2.5	-3.2
8-1	3.1	1.3	1.5	0.1	-	-2.0	-2.4	-3.1
9-2	5.1	3.2	3.5	2.0	2.0	-	-0.5	-1.2
A-1	5.6	3.7	4.0	2.5	2.4	0.5	-	-0.7
D-1	6.3	4.4	4.7	3.2	3.1	1.2	0.7	-

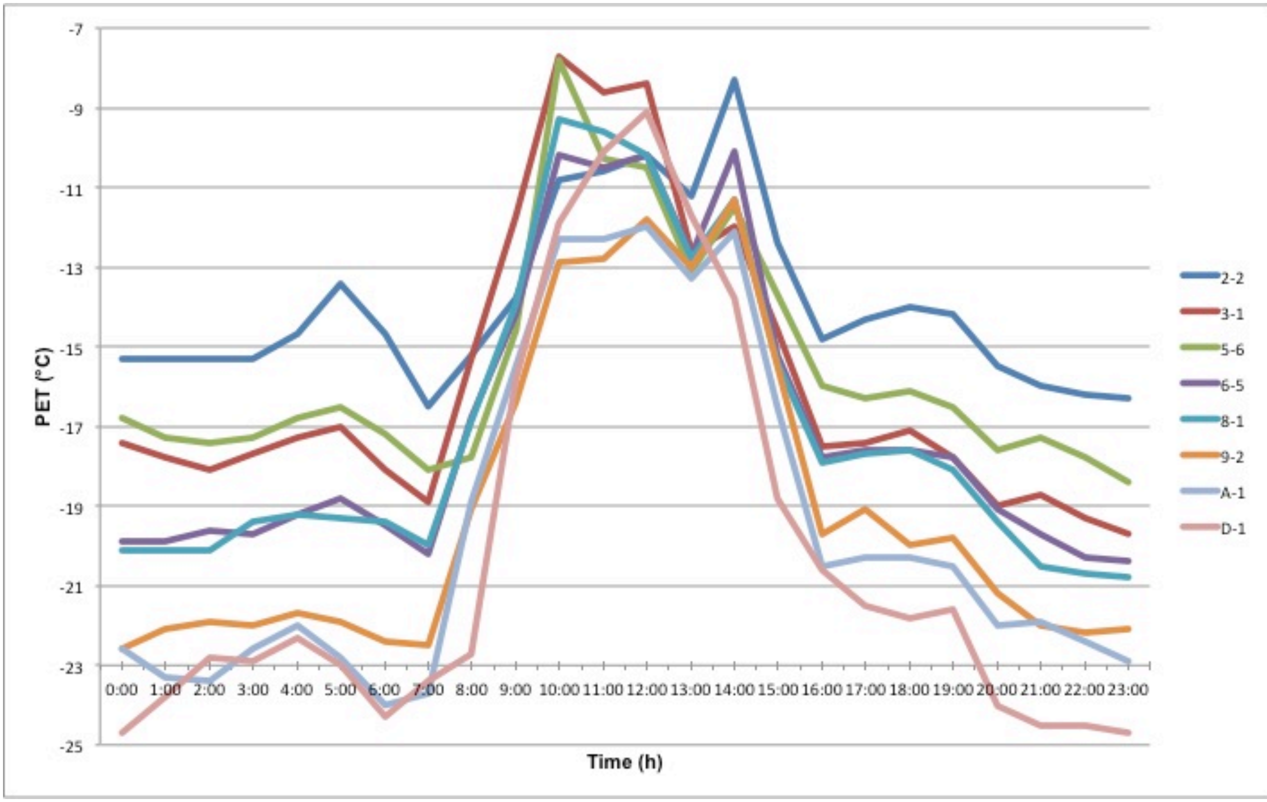

Fig. 5. Diurnal variation of human bioclimatic characteristics expressed via PET index in selected LCZs in Novi Sad on icy day (December 31st, 2014).

4. Conclusions

The results presented here are to assess the human thermal comfort conditions in different LCZs during extreme temperature days. The data originated from the urban climate monitoring system developed in Novi Sad (Serbia). PET differences between subsequent LCZs are less than 1.6 °C and up to 5.1 °C for dissimilar LCZs on tropical day. On icy day, PET differences are up to 2.0 °C between close LCZs and up to 6.3 °C between dissimilar LCZs. Noticed differences in human thermal comfort conditions revealed that LCZs have unique thermal conditions for humans that correspond to LCZs surface characteristics (e. g. building height and spacing, pervious surface fraction). Results from this short-term study justified the division of urban areas into LCZs. Nevertheless, further UHI and human thermal comfort investigations are needed in order to evaluate and improve the proposed LCZ scheme.

Long-term studies of human thermal comfort from urban climate networks based on LCZ division could locate heat stress, comfortable and cold stress areas in the cities. This would be a valuable contribution for urban planning strategies in order to counterattack the adverse effects of urban climate and climate change.

Acknowledgment

The study was supported by the Hungary-Serbia IPA Cross-border Co-operation EU Programme (HUSRB/1203/122/166 – URBAN-PATH) and the Serbian Ministry of Education, Science and Technological Development (project no. 43002). We want to thank Vladimir Marković for his contribution in making some of the Figures.

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