109 EVALUATION OF SPATIAL AND TEMPORAL DISTRIBUTION OF AIR TEMPERATURE IN LOCAL CLIMATE ZONES BASED ON LONG-TERM DATABASE IN SZEGED, HUNGARY

Nóra Skarbit *, Tamás Gál, János Unger
University of Szeged, Hungary

1. INTRODUCTION

It is well-known that the number of urban inhabitants is continuously growing and the dwellers are exposed to the altered urban environment. The occurring heat load in cities of mid-latitudes has considerable impacts on human health. Therefore it is important to examine the temperature modifying effects of different built-up neighbourhoods. Even within urban areas the local effects create changes in the near-surface air temperature. To satisfy the need of a classification of urban area Stewart and Oke (2012) developed the local climate zone (LCZ) system. LCZs allow the objective comparison of the thermal characteristics in the different parts in and around the cities.

An urban climate measurement network has operated in Szeged since 2014, its deployment is based on the LCZ concept. The evaluation of the first-year air temperature data was carried out (Gál et al., 2016; Skarbit et al., 2017) and in addition the human comfort was also examined for a longer period (Unger et al., 2018). In these previous studies partly we have focused on ideal weather conditions for UHI developing, which was quantified by the so-called weather factor (Φ_w) (Oke, 1988).

The aims of the current study are

- to analyse the connection between
  (i) urban heat island (UHI) intensity by LCZs,
  (ii) spatial pattern of UHI
  and different weather situations using Φ_w, as well as
- to define a range of Φ_w as ideal weather condition

based on a long-term, 4-year database.

2. STUDY AREA AND MEASUREMENT NETWORK

Szeged is located in the Central European region, as a part of the Great Hungarian Plain in the south-eastern part of Hungary (46°25'N, 20°15'E) (Figure 1). Its terrain is almost completely flat with an average height of 79 m above sea level. The urbanized area is ~40 km^2 with approximately 161,000 inhabitants (in 2017). Szeged has a Cfb climate (temperate and warm with a uniform annual distribution of precipitation) according to Köppen's climate classification (Kottek et al., 2006). The average annual mean temperature is 10.9°C, while the amount of precipitation is 514 mm (1981–2010).

An automated GIS method was used to map the LCZ system to the study area (Lelovics et al., 2014). Comparison to the method of Bechtel et al. (2015) was carried out in order to determine the accuracy of the final LCZ map and only minor differences were found (Gál et al., 2015). The compact midrise and low-rise zones (LCZs 2 and 3) are located in the downtown, while the open and large low-rise (LCZs 6 and 8) as well as the sparsely built (LCZ 9) zones are mainly at the outlying area. The open midrise zone (LCZ 5) exists in both inner and the north-eastern outskirt. On the periphery the landscape changes from urban to rural, namely low plants (LCZ D). As far as water surfaces (LCZ G) are concerned, the River Tisza divides Szeged into two parts and west from the city some smaller lakes can be found (Figure 1).

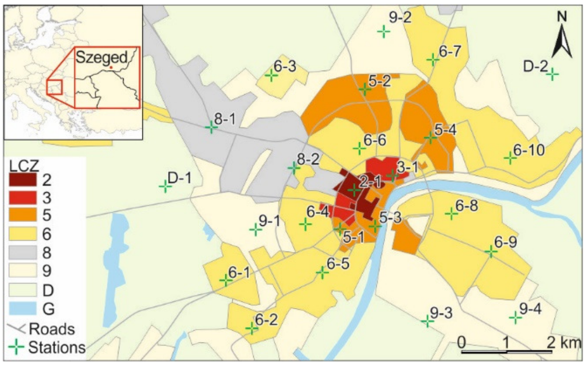

Figure 1. Location and LCZ map of Szeged as well as station locations of the measurement network

Within the framework of a European Union project a 24-element measurement network was established in Szeged in 2014 (Figure 1). The location of the stations accomplishes two criteria: the stations are representative for their LCZs and the spatial pattern of network is capable to reproduce the spatial distribution of UHI (Unger et al., 2015). In each station the measurement is provided by a Sensirion SHT25 sensor in a radiation protection screen at the end of a 60 cm console (Figure 2). The consoles are mounted on lamp posts at a height of 4 m above the ground for security reasons. Based on Nakamura and Oke (1988) we assume that air temperature at 2 and 4 m are nearly equal. For further technical details about the sensors, transmission and online displaying of the data see Unger et al (2015).


Figure 2. Typical setup of monitoring stations

* *Corresponding author address*: Nóra Skarbit, University of Szeged, Department of Climatology and Landscape Ecology, Egyetem utca 2, 6722 Szeged, Hungary, e-mail: skarbitn@geo.u-szeged.hu

3. DATA AND METHODS

4-year air temperature data from June 2014 to May 2018 in 10-min averages were used based on 1-min measurements. To compare temperature modifying effects of different LCZs in Szeged LCZ averages were used. Consequently, in case of LCZ 2 and 3 it means only one station, however in LCZ 6 the average of ten stations was used according to the size of this LCZ class.

The calculation of urban heat island intensity was considered as the temperature difference between LCZ average and LCZ D (station D-1):

$$UHI_{LCZ\,X} = \Delta T_{LCZ\,X-(D-1)}\,, \qquad \mathrm{x} = 2, 3, 5, 6, 8, 9$$

Our data analyses concentrate on the night-time conditions, when the near-surface air temperature differences are the most relevant. Accordingly, the nocturnal UHI was analysed, which was calculated as the average UHI from sunset to sunrise.

The dynamics of nocturnal UHI was also evaluated in normalized time steps in order to avoid the disturbing effect of changing length of the nights. Therefore, the time period from sunset (0h) to sunrise (12h) was divided into 12 parts called them as ‘hours’. The nocturnal change of the spatial pattern of UHI was examined via four time steps: at sunset, four and eight hours after sunset as well as at sunrise. The patterns were based on all of the station data using Kriging interpolation method with 100 m resolution.

The weather factor (Oke, 1998) was applied in order to quantify the effect of cloud and wind speed on UHI:

$$\Phi_w = u^{-\frac{1}{2}} \cdot (1 - kn^2)$$

where u is wind speed in ms^{-1}, k is the Boltz correction factor for cloud height and n is cloud cover in tenths. Values range from 0 to 1, where 1 indicates the most appropriate conditions for enforcing local temperature modifying effects.

4. RESULTS

The average nocturnal UHI was analysed weather factor categories ranged by 0.1 in the different LCZs (Figure 3). In all of the Φ_w categories the highest UHI intensities appear in LCZs 2 and 3. In most cases (except 0.9–1) the value of LCZ 3 slightly exceeds the one of LCZ 2. The main reason of this deviation is that the possible station places in these zones were limited, thus the direct environments do not differ considerably. After the compact zones, LCZs 5 and 8 show the highest values, which are followed by LCZs 6 and 9. The outstanding values of LCZ 8 can be explained by the high ratio of impervious land cover and lack of vegetation in this area.

The thermal differences between the zones increase towards the higher Φ_w values (Figure 3). While in the lowest categories the deviation between LCZ 3 and 9 is only about 0.3°C, in case of the higher classes it exceeds 3.5°C. The temperature difference of compact zones depends mostly on the weather factor since the most spectacular difference between the lowest and highest Φ_w category appears in these zones. On the contrary the values of LCZ 9 only slightly modifies, moreover they are lower in the higher classes than in the medium ones. Therefore this built-up zone affects the least the air temperature.

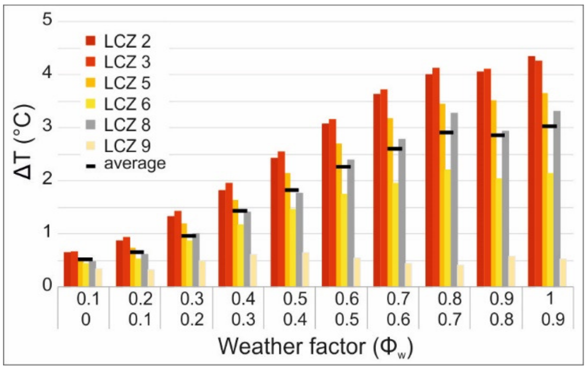

Figure 3. Average nocturnal UHI ranged by 0.1 weather factor categories via LCZs in Szeged (June 2014 – May 2018)

Based on the outcomes of Figure 3 three Φ_w groups can be separated considering the temperature difference values of LCZs. Comparable ΔT appears in Φ_w categories of 0–0.3, 0.3–0.7 and 0.7–1. In these categories the average ΔT is 0.7°C, 2.0°C and 2.7°C, respectively.

According to these three categories the spatial pattern of nocturnal UHI dynamics was examined at four normalized time steps (Figure 4). At the first case a slightly changing, featureless UHI can be detected with ΔT_{max}=1.1°C during the night. The contour of temperature difference 0.5°C appears approximately at the border, when values over 1°C occur only at the downtown as relatively small spots.

If Φ_w is in the category of 0.3–0.7 the highest UHI intensity reaches 2.9°C (Figure 4). In this case regular UHI form develops with a medium magnitude. The UHI stretches northwest direction due to the location of LCZ 8. At this case noticeable UHI appears already at sunset. The temperature difference is higher than 1°C in almost the whole city. In the centre the values exceed 2°C. Four hours after sunset the UHI reaches its maximum intensity. At this time the difference approaches 3°C and remain almost constant during the night. At sunrise the intensity decreases slightly however the UHI magnitude is still remarkable.

Characteristic UHI appears in the third case (Φ_w > 0.7) with maximum intensity of 4.5°C (Figure 4). At sunset the difference from the previous case is not as remarkable as at the later time steps. At this time higher temperature difference with larger spatial distribution appears only the inner part of the city. Four hours after sunset a strong UHI develops, the intensity is more than 2°C in the most part of the city. In the downtown the temperature difference already exceeds 4°C. Accordingly, in case of these Φ_w values the effects of local features become remarkable. This influence does not only occur in the higher temperature differences, but it is represented as the effect of lakes as well. The form and intensity of UHI remain strong at the whole night. Negligible alteration from previous time step occurs at eight hours after sunset. At sunrise the UHI is still remarkable with values more than 3.5°C in the downtown and 1°C in the other part of the city.

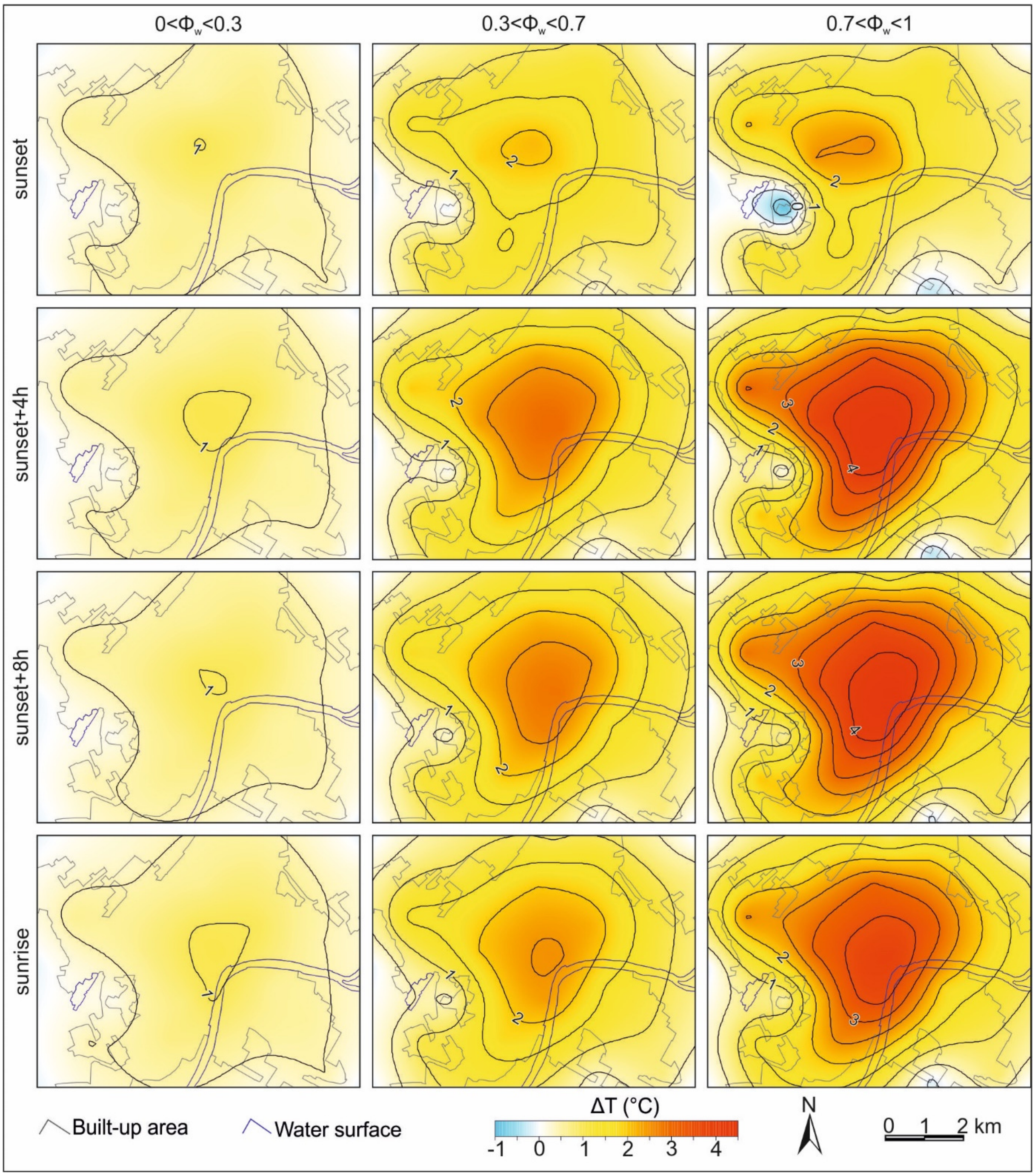

Figure 4. Night-time change of spatial pattern of urban heat island at four time steps by weather factor categories (Φ_w) in Szeged (June 2014 – May 2018)

5. CONCLUSION

In this study the nocturnal UHI intensity was evaluated in different weather situations applying the so-called weather factor in a 4-year period (June 2014 – May 2018) in Szeged. The temperature data was derived from a 24-element urban measurement network.

Firstly, the night-time temperature difference from LCZ D was examined via LCZs based on Φ_w categories ranged by 0.1. The UHI intensity decreased from the densely built-up to the more vegetated zones. Therefore the sequence in thermal reactions of LCZs was the following:

2/3 > 5 > 8 > 6 > 9

In compact and open midrise zones the ΔT increases with Φ_w. However the values of LCZ 9 are slightly modified since the cooling effect of vegetation becomes more characteristic in case of higher Φ_w. Consequently, the temperature values of LCZs 2, 3 and 5 depend the most on the weather situation, while the ones of LCZ 9 the least. Three categories of Φ_w could be separated based on the temperature values of LCZs: $0 < \Phi_w < 0.3$, $0.3 < \Phi_w < 0.7$ and $0.7 < \Phi_w < 1$.

Secondly, the spatial and temporal distribution of nocturnal UHI was evaluated at four normalized time steps and distinguished by the above mentioned categories. If Φ_w doesn't reach 0.3 there is no characteristic UHI form and the intensity is weak, approximately 0.5-1°C. The typical spatial distribution of UHI appears if Φ_w exceeds 0.3. In this case the local features already appear, but with less intensity (ΔT_{max}=2.9°C). The remarkable UHI intensity (ΔT_{max}=4.5°C) occurs if Φ_w more than 0.7, when the effect of local features become strong. Accordingly, in order to analyse the temperature modifying properties of built-up types and vegetation days with $\Phi_w > 0.7$ should be considered. Thus this minimum limit is recommended as a definition of ideal weather conditions for UHI evaluating analyses.

Using high temporal and spatial resolution measurement data in cities contributes to understand the modifying effects of different built-up types and local features. The long-term database helps to reveal the impacts of different weather situations. These kinds of studies can support the urban planning strategies, which can moderate and mitigate the effects of climate change in our cities.

ACKNOWLEDGMENT

The study was supported by the Hungarian Scientific Research Fund (OTKA K-111768) and by the National Research, Development and Innovation Office (NKFI 120346).

REFERENCES

Bechtel, B., Alexander, P. J., Böhner, J., Ching, J., Conrad, O., Feddema, J., Mills, G., See, L., Stewart, I. D., 2015: Mapping local climate zones for a worldwide database of the form and function of cities. *ISPRS Int. J. Geo-Inf*., 4, 199–219.

Gál, T., Bechtel, B., Lelovics, E., Unger, J., 2015: Comparison and integration of LCZ classification methods based remote sensing and GIS. *9th Int. Conf. on Urban Climatology*, ICUC-9, Toulouse, France.

Gál, T., Skarbit, N., Unger, J., 2016: Urban heat island patterns and their dynamics based on an urban climate measurement network. *Hung. Geogr. Bull*., 65, 105–116.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F., 2006: World Map of the Köppen-Geiger climate classification updated. *Meteorol. Z.,* 15, 259–263.

Lelovics, E., Unger, J., Gál, T., Gál, C.V., 2014: Design of an urban monitoring network based on Local Climate Zone mapping and temperature pattern modelling. *Climate Research*, 60, 51–62.

Nakamura, Y., Oke, T. R., 1988: Wind, temperature and stability conditions in an east-west oriented urban canyon. *Atmos. Environ*., 22, 2691–2700.

Oke, T. R., 1998: An algorithmic scheme to estimate hourly heat island magnitude. In *Preprints, 2nd Urban Environment Symposium*, Albuquerque, NM.

Skarbit, N., Stewart, I. D., Unger, J., Gál, T., 2017: Employing an urban meteorological network to monitor air temperature conditions in the 'local climate zones' of Szeged (Hungary). *Int. J. Climatol.,* 37(S1), 582–596.

Stewart, I. D., Oke, T. R., 2012: Local climate zones for urban temperature studies. *Bull. Am. Meteorol. Soc*., 93(12), 1879–1900.

Unger, J., Gál, T., Csépe, Z., Lelovics, E., Gulyás, Á., 2015: Development, data processing and preliminary results of an urban human comfort monitoring and information system. *Időjárás*, 119, 337–354.

Unger, J., Skarbit, N., Gál, T., 2018: Evaluation of outdoor human thermal sensation of local climate zones based on long-term database. *Int. J. Biometeorol*., 62(2), 183–193.