A vector-based GIS method for mapping of Local Climate Zones and its application in a Central-European city

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Introduction

Among the parameters of the urban atmosphere the near-surface (screen-height) air temperature shows the most obvious modification compared to the rural area. This urban warming is commonly referred to as the urban heat island (UHI) and its magnitude is the "urban–rural" difference. For landscape description of the site surroundings the simple "urban" versus "rural" is not appropriate because of the abundant variety of the landscapes according to their surface properties relevant to development of near-surface micro and local climates (Stewart 2007, 2011).

To diminish this deficiency, Stewart and Oke (2012) developed a climate-based classification system the so called "local climate zones" (LCZ) system for describing the local physical conditions around the temperature measuring field sites universally and relative easily based on the earlier studies from the last decades (e.g. Ellefsen 1991, Oke 2004), as well as a thorough review on the empirical heat island literature and world-wide surveys of the measurement sites with their surroundings.

Two situations arise related to the relationship between the intra-urban built and land cover LCZ types and the locations of the urban climate network sites:

(1) In the case of an already existing network (e.g. Schroeder et al. 2010) it may be required to characterize the relatively wider environment around the measuring sites, namely what type of urban area (LCZ) surrounds a given station. In other words, how representative is the location of a station regarding a specific, clearly defined LCZ type in an urban environment?

(2) In the case of a planned network (e.g. Unger et al. 2011) the most important questions are what built and land cover LCZ types can be distinguished in a given urban area, how precisely they can be delimited, and whether their extension is large enough to install a station somewhere in the middle of the area representing the thermal conditions of this LCZ.

The aims of this study are: (i) to determine the LCZ types in Szeged which are representative for the urbanized area of the city using seven geometric, surface cover and radiative properties from the ten ones listed by Stewart and Oke (2012), (ii) to develop GIS methods in order to calculate these values for any part of the study area and (iii) to compare the thermal reactions of the selected LCZ areas based on the earlier temperature measurement campaigns carried out in this city.

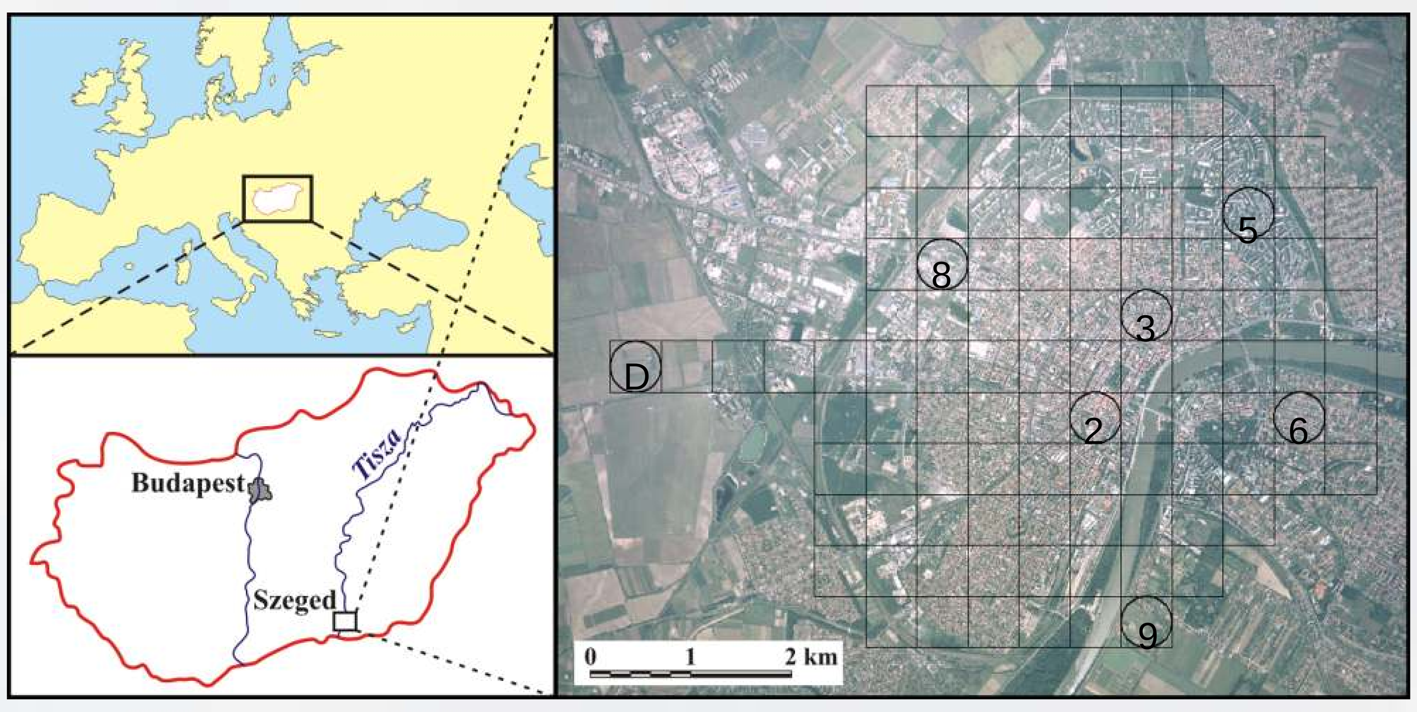
Study area, temperature measurements

Our study area is a medium-sized city in Central Europe (Szeged, Hungary) at 79 m a.s.l. on flat terrain (Fig. 1). Urban area and its near environment was divided into 107 cells (500 × 500 m).

Mobile measurements was taken in 2002/2003 by cars on fixed return routes by several times. Data was collected every 10 seconds, thus the distance between measuring points was 55-83 m. Time-based correction was made to a reference time (4 hours after sunset). After averaging all measurements by cells, they are regarded as representing the cell centers (Unger, 2004, 2006; Balázs et al., 2009).

That is, as a result of mobile measurements, our "measuring sites" are in the centres of the cells so the obtained average values by cells are regarded as "measured" temperature values in these "measuring sites" in a given night. As the most ideal conditions for UHI developments prevail in summer and early autumn in this region, two nights were selected in summer (15 July 2002, 21 August 2002), one in autumn (18 September 2002), and additionally one in spring (25 March 2003). At these times the weather was clear and calm in the preceding days too, thus during these nights the weather conditions promoted the surface influence on the thermal conditions in the near-surface air layer. Additionally, the ground was relatively dry and the trees had foliage.

Fig. 1: Szeged in Hungary and in Europe, selected circle areas on the grid map of the city



Local Climate Zones

LCZs are areas extend to several hundred meters to few kilometers, where surface cover, human activity, geometry and materials of buildings are uniform. When the weather conditions let local radiative and conductive processes to prevail, these areas have characteristic screen-height temperature (Stewart and Oke, 2012).

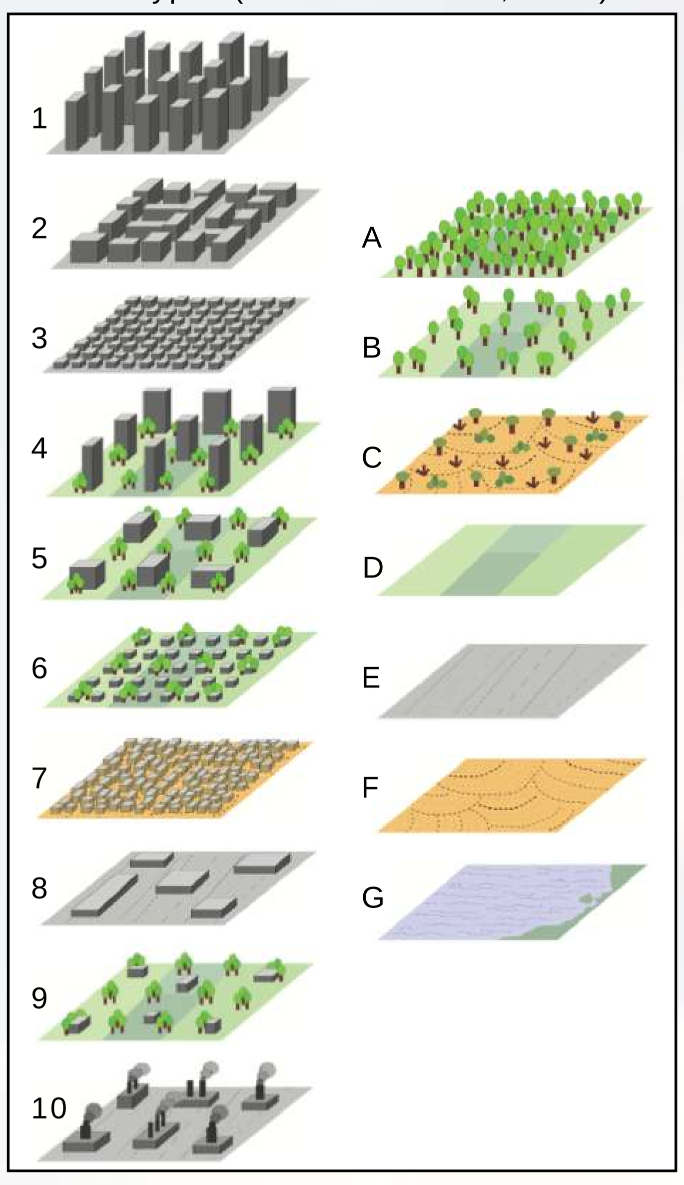
LCZ classes can be represented with the typical geometric, radiative and thermal properties. Among their description the following physical properties are given: sky view factor, aspect ratio, building surface fraction, impervious surface fraction, pervious surface fraction, height of roughness elements, terrain roughness class according to classification of Davenport et al. (2000), surface admittance, albedo, anthropogenic heat output.

There are 10 built LCZ categories (according to the heightness and compactness of the buildings) and 7 land cover categories (Table 1 and Fig. 2). Additionally, they can have temporary properties which depend on season and preceding weather.

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 2 – Compact midrise LCZ 3 – Compact low-rise LCZ 4 – Open high-rise LCZ 5 – Open midrise LCZ 6 – Open low-rise LCZ 7 – Lightweight low-rise LCZ 8 – Large low-rise LCZ 9 – Sparsely built LCZ 10 – Heavy industry	LCZ A – Dense trees LCZ B – Scattered trees LCZ C – Bush, scrub LCZ D – Low plants LCZ E – Bare rock / paved LCZ F – Bare soil / sand LCZ G – Water	b – bare trees s – snow cover d – dry ground w – wet ground

Fig. 2: View of built and land cover LCZ types (Stewart and Oke, 2012)



Determining Local Climate Zones in our examined area

From the ten geometric, surface cover and radiative properties listed by Stewart and Oke (2012) seven of them were determined with our methods for any given area inside the study area. These are the sky view factor, building surface fraction, impervious surface fraction, pervious surface fraction, height of roughness elements, terrain roughness class and albedo. For the calculations we used vector-based methods developed for this purpose (Fig. 3).

The calculations were carried out in circle areas with 250 m radius centered in the middle of the grid network cells. This size is necessary as the upwind fetch of typically 200-500 m is required for air at screen-height to become fully adjusted to the underlying, relatively homogeneous surface (Oke, 2004).

In Szeged the high-rise type areas (LCZs 1 and 4), the lightweight low-rise shanty districts (LCZ 7) and the heavy type industry (LCZ 10) are not present among the built type LCZs, thus we searched for representative areas of the remaining six types (LCZs 2, 3, 5, 6, 8 and 9). As the study area of temperature measurements concentrated on the urbanized parts of the city (Fig. 1c), only the westernmost cell can be regarded as LCZ D (low plants) area, because it consists of agricultural fields with low plants without trees and a few small houses (Figs. 1, 2 and 4).

Fig. 3: Flow chart of data processing

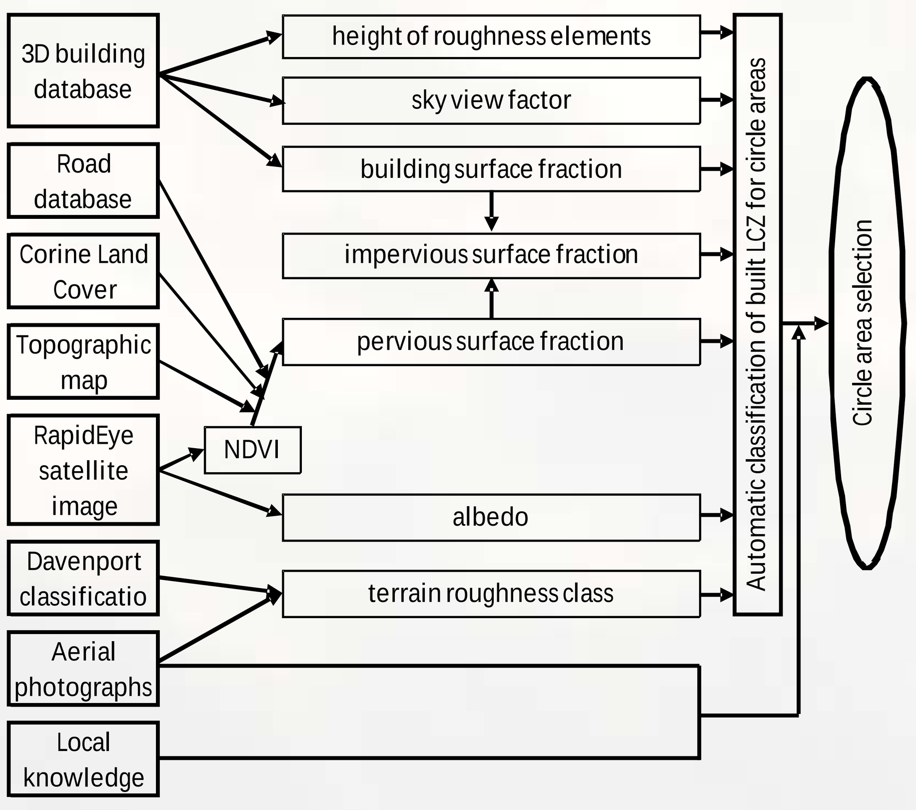
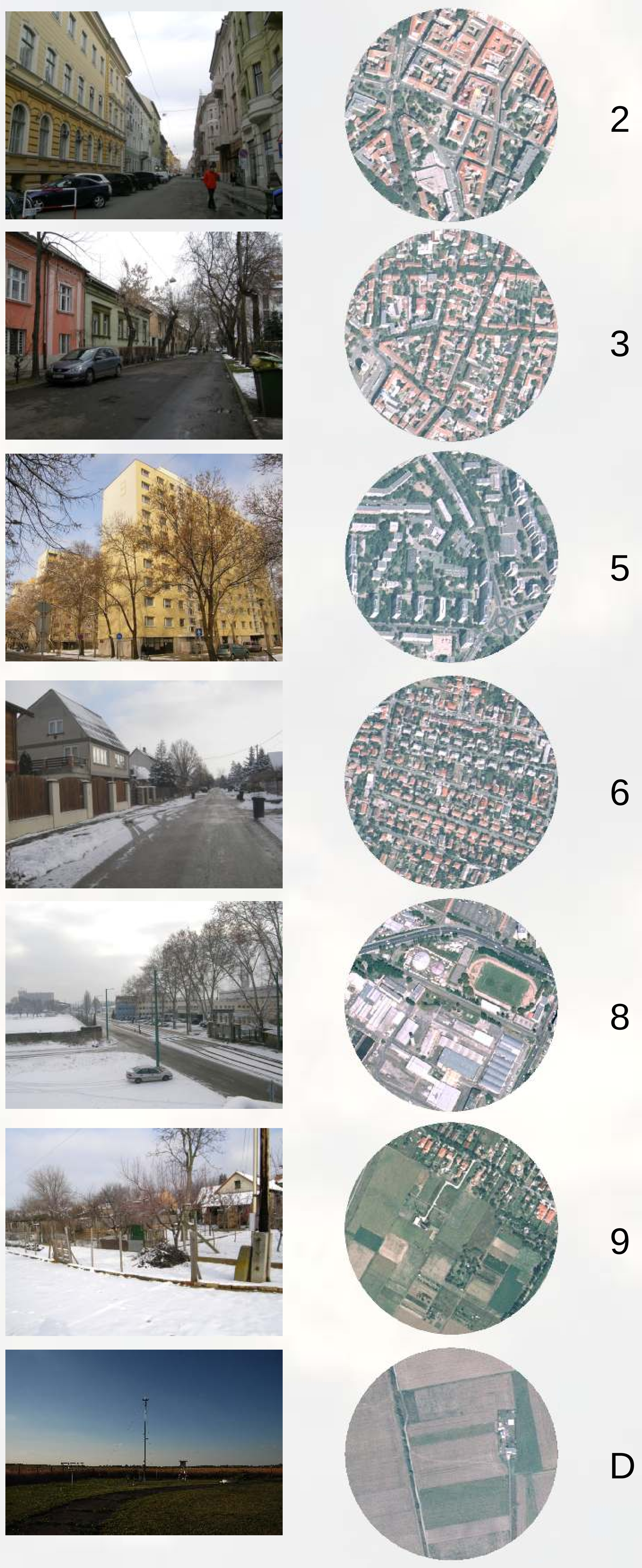


Fig. 4: Aerial views and pictures of selected circle areas



Comparison of LCZ temperatures

Figure 5 shows the temperature differences of the built LCZ types from the land cover D type ($\Delta T_{LCZ:X-D}$) at the selected nights and on average, too. The average and individual values follow the expected sequence: compact built and midrise types have larger temperatures than open and low-rise ones, respectively. That is, the differences decrease from compact midrise (LCZ 2) to open low-rise (LCZ 6) areas, then there is an increment at the large low-rise (LCZ 8) area and finally, the difference is around 0ºC at the sparsely built (LCZ 9) area.

The largest average difference, $\Delta T_{LCZ:2-D}$ is more than 4oC which means a very significant temperature deviation between the two areas (Table 2). Even the smallest differences (at LCZs 6 and 8) are about 1ºC, only the LCZ 9 located at the city edge has similar value as the westernmost (agricultural) LCZ D.

At the individual nights deviations can be even larger: as an example, in March the $\Delta T_{LCZ:2-D}$ reaches almost 6oC, but the $\Delta T_{LCZ:3-D}$ were over 4.5oC, as well as even $\Delta T_{LCZ:5-D}$ and $\Delta T_{LCZ:8-D}$ exceeded 3oC (Figure 5).

Fig. 5: Temperature differences between selected circle areas with built LCZ type and circle area representing LCZ D at the selected nights and in average

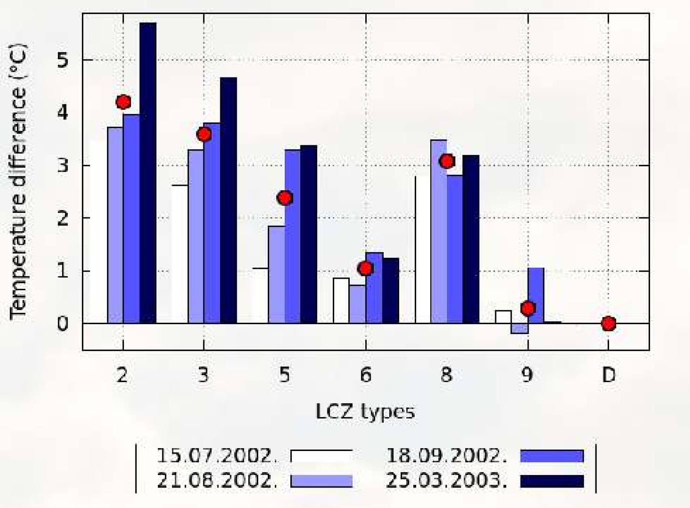


Table 2: Pairwise average temperature differences (ºC) of LCZ types in Szeged

LCZ code	2	3	5	6	8	9	D
2	0.00	-0.61	-1.83	-3.17	-1.14	-3.92	-4.22
3	0.61	0.00	-1.21	-2.56	-0.53	-3.31	-3.60
5	1.83	1.21	0.00	-1.35	0.69	-2.10	-2.39
6	3.17	2.56	1.35	0.00	2.04	-0.75	-1.04
8	1.14	0.53	-0.69	-2.04	0.00	-2.78	-3.08
9	3.92	3.31	2.10	0.75	2.78	0.00	-0.29
D	4.22	3.60	2.39	1.04	3.08	0.29	0.00

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Conclusions

In this study we determined the LCZ types in Szeged which are representative for the urbanized area of the city by GIS methods developed for this purpose. As a result, six built and one land cover LCZ types were distinguished in the studied urban area.

The temperature comparisons of LCZs at selected times which were characterized with calm and clear weather conditions, relatively dry ground surfaces and leafy trees confirmed the findings of Stewart and Oke (2012): the thermal influence of any change or difference in landscapes (thus the different levels of urbanization too) are better expressed using LCZ difference concept than a simple but generally not clear urban-rural approach, and additionally, it provides an opportunity for intra- and inter-urban comparisons.