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TITLE OF PAPER:

A VECTOR-BASED GIS METHOD FOR MAPPING OF LOCAL CLIMATE ZONES AND ITS APPLICATION IN A CENTRAL-EUROPEAN CITY

The Paper can be sent by e-mail as attachment as Word document and in PDF format to the Secretariat.

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PAPER TEMPLATE

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

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Summary

In this study we determined the Local Climate Zones (LCZ) types which are representative for the urbanized area in a South-Hungarian city (Szeged) using seven geometric, surface cover and radiative properties from the originally proposed ten ones and compared their thermal reactions based on the earlier temperature measurement campaigns carried out in this city.

In Szeged urban climate investigations have already a long history. These studies have provided a thorough knowledge about the thermal peculiarities of the city, namely about the intra-urban temperature distribution on average and in different synoptic situations. These earlier obtained temperature patterns provide an opportunity for us to verify whether the identified zones with different physical properties have indeed different thermal reactions.

The values of the seven properties were calculated by GIS methods developed for this purpose and for the appropriate classification of the selected areas we used also our local knowledge about the districts of Szeged. The database for these methods contains topographic map, 3D building and 2D road databases, as well as remotely sensed information from RapidEye satellite image. The obtained parameters are the sky view factor, mean building height, terrain roughness class, building surface fraction, impervious/pervious surface fractions and albedo. 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 usefulness of these type of classification: the thermal influence of any change or difference in landscapes 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.

Keywords: Local Climate Zones, GIS methods, temperature patterns, Szeged, Hungary

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1. Introduction

Nowadays about half of the human population is affected by the burdens of urban environments: pollution, noise and the modified characteristics of the urban atmosphere compared to the natural environment. This makes studies dealing with the urban impact on climate particularly important. Owing to the anthropogenic activity, a local climate develops in the built-up areas. This urban climate is different from the pre-urban (natural) one and is a result of the construction of buildings, roads, etc., as well as of the emission of heat, moisture and pollution related to human activities.

Among the parameters of the urban atmosphere the near-surface (1.5-2 metres above ground level or screen-height) air temperature shows the most obvious modification compared to the rural area (Oke, 1987). This urban warming is commonly referred to as the urban heat island (UHI) and its magnitude is the UHI intensity (ΔT_{u-r}). Nevertheless, in the heat island literature the term “urban” has no single, objective meaning as the areas around the measuring sites could be very different depending on the investigated cities (e.g. park, college ground, street canyon, housing estate, etc.). In addition, for landscape classification or 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 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. Auer, 1978; Ellefsen, 1991; Oke, 2004; Stewart and Oke, 2009), as well as a thorough review on the empirical heat island literature and world-wide surveys of the measurement sites with their surroundings. The elements of this system are the “local climate zones” (LCZ) and they are presented shortly in Section 2.2.

Because of the complexity of the urban terrain the monitoring of the representative intra-urban thermal features is a difficult task (Oke, 2004). The locations of the sites of an urban station network within the city and thus the question about its appropriate configuration raises an essential problem. This problem is related to the relationship between the intra-urban built and land cover LCZ types and the locations of the network sites. Two situations arise:

(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 and whether it can be clearly determined. 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 station 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, how many they are, 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) while of course taking care to minimize the microclimatic effects of the immediate environment.

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 seven property 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.

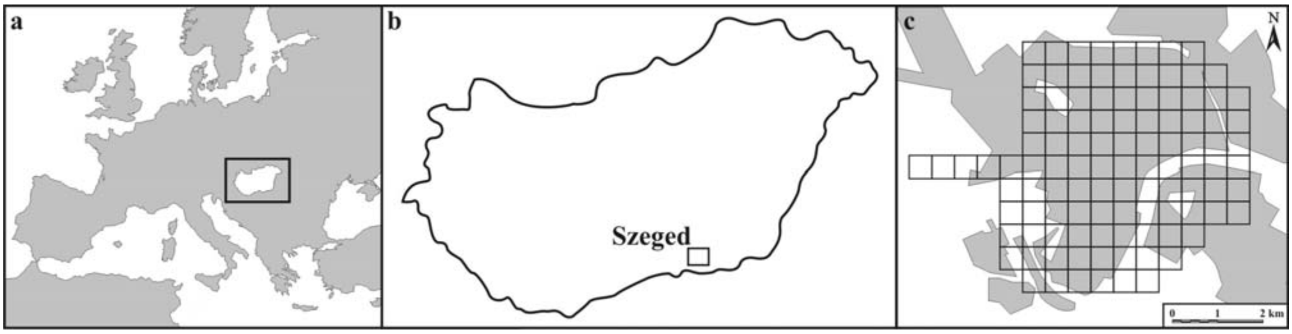
2. STUDY AREA AND METHODS

2.1. Temperature measurements in Szeged

Szeged is located in the south-eastern part of Hungary (46°N, 20°E) at 79 m above sea level on a flat terrain (Figures 1a and 1b) with a population of 160,000 within an administration district of 281 km^2. The area is in Köppen's climatic region Cf (temperate warm climate with a rather uniform annual distribution of precipitation). The annual mean temperature is 10.4ºC and the amount of precipitation is 497 mm (Unger et al., 2001).

The study area consists of 103 cells (500 × 500 m) covering the urban and suburban parts of Szeged (25.75 km^2). Additionally, in order to represent non built-up areas four cells (1 km^2) were added to the network at the western side of the area (Figure 1c).

Figure 1: (a) Location of the Szeged in Europe, (b) in Hungary and (c) the grid network of the study area (gray – urbanized area).



Mobile measurements were taken by cars at the same time on fixed return routes during a one-year period (April 2002 – March 2003) by several times. Return routes were taken to make time-based corrections to a reference time (4 hours after sunset). Readings were obtained using radiation-shielded resistance sensors mounted at 1.45 m above ground and connected to data loggers. Data were collected every 10 s, so at a car speed of 20-30 kmh^{-1} the distance between measuring points was 55-83 m. The logged values at forced stops were omitted. After averaging the usually 15-20 measurement values by cells in every measurement nights, the obtained values referred to the cell centres (for more details see 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 (WMO, 1996), 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.

2.2. Key features of the LCZ classification system

The necessity and ideas of the development of "local climate zone" classification system and its structure are presented and discussed in details by Stewart and Oke (2012). Therefore here we highlight only the key features of the system. LCZs are defined as "regions of uniform surface cover, structure, material, and human activity that span hundreds of meters to several kilometres in horizontal scale. Each LCZ has a characteristic screen-height temperature regime that is most apparent over dry surfaces, on calm, clear nights, and in areas of simple relief." (Stewart and Oke, 2012). Among them there are ten built types (from LCZ 1 to LCZ 10) and seven land cover types (from LCZ A to LCZ G), and additionally, the types can have variable seasonal or shorter period land cover properties. The main characters of the types are reflected in their names (Table 1).

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		

The LCZ types can be distinguished by the measurable physical properties (parameters) (Table 2). These parameters are partly dimensionless (e.g. sky view factor), partly given in %, m, etc. (e.g. building surface fraction) and their values have different ranges according to the different types. Stewart and Oke (2012) give the typical values of them (see Table 3 too).

Table 2. Zone properties of LCZ system (after Stewart and Oke, 2012)

	Type of properties	
	Geometric, surface cover	Thermal, radiative, metabolic
Properties	sky view factor aspect ratio building surface fraction (%) impervious surface fraction (%) pervious surface fraction (%) height of roughness elements (m) terrain roughness class	surface admittance ($Jm^{-2}s^{-1/2}K^{-1}$) surface albedo anthropogenic heat output (Wm^{-2})

In the frame of this new classification system the intra-urban UHI intensity is an LCZ temperature difference ($\Delta T_{LCZ:X-Y}$), not an "urban-rural" difference (ΔT_{u-r}) (Stewart and Oke, 2012).

2.3. *Vector based GIS method*

From the ten geometric, surface cover and radiative properties listed by Stewart and Oke (2012) we can determine seven of them with our methods for any given area inside the study area. These are the sky view factor (SVF), building surface fraction (BSF), impervious surface fraction (ISF), pervious surface fraction (PSF), height of roughness elements (HRE), terrain roughness class (TRC) and albedo (A). Our 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 (Stewart and Oke, 2012).

The applied methods by parameters:

- SVF: The input was a SVF database with 5 m horizontal resolution originated from our earlier studies. It was calculated using the 3D building database of Szeged with a vector based method. The building database contains building footprint areas as polygons, and the height value for each building measured with photogrammetric methods. During the SVF calculation all of the buildings were regarded with flat roof and the effect of the vegetation was neglected (Gál et al., 2009; Unger, 2006). Now the SVF values of grid points inside the examined circle area were averaged.

- BSF: The input was the 3D building database of Szeged where all of the footprints of the buildings are available from the study area. BSF is the fraction of summarized area of buildings inside the circle. The buildings on the border of the circle were divided into two parts, and the area of intersecting part had been taken into account for the summarized building area.

- PSF: The input for the PSF was a built-up dataset calculated from RapidEye satellite image using NDVI index, a 1:25000 topographic map, a road database and the Corine Land Cover (CLC) (Bossard et al., 2000) database. The RapidEye image is atmospherically corrected (resolution of 5.16 m) and the NDVI was calculated using bands 3 and 5. Basically the point where the NDVI is above 0.3 was regarded as built-up area. The CLC dataset was used to locate the agricultural areas as these areas have small NDVI because after harvest the amount of plants on them is almost zero. As a second correction the shape of water bodies were digitized in the topographic map because water has NDVI values very similar to the values of some building materials. As a last correction the road database was used to locate the asphalt roads in the area because in the urban canyons these roads are usually under tree cover and roads (ISF) which slice agricultural areas do not appear in CLC dataset.

- ISF: The value of the ISF were calculated using this formula: ISF = 1 – (BSF + PSF).

- HRE: The input for the HRE was also the 3D building database of Szeged. For each examined circle area height of the buildings (and building parts) weighting with their footprint areas were averaged.

- TRC: For describing the roughness the Davenport roughness classification method was used (Davenport et al., 2000). All of the circle areas were classified into roughness classes with visual interpretation of aerial photographs, the topographical map and the building database.

- A: As an input we used the atmospherically corrected reflectance values of the 5 band RapidEye satellite image. Broadband albedo was calculated as an average of reflectance values weighted with the integral of the radiation within the spectral range of a given band (Starks et al. 1991).

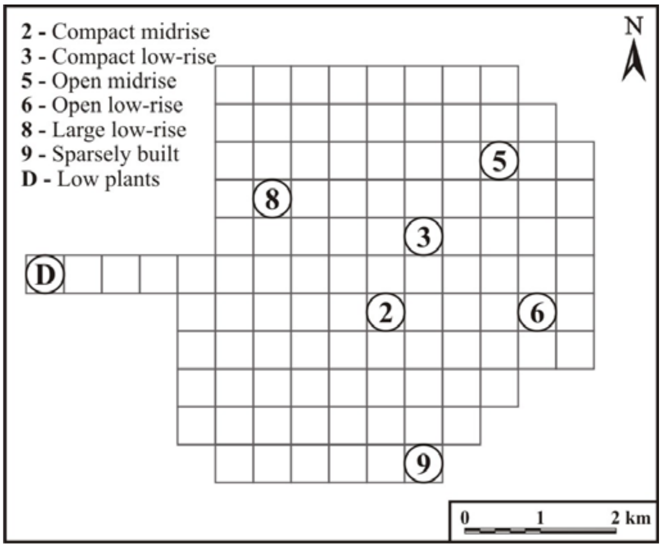
3. RESULTS

As a first step we determined the possible LCZ types occurring in the study area of Szeged and we selected areas with 250 m radius for each type which represent them. Secondly, the temperature differences between these areas were compared on the above mentioned measurements nights separately and on average, too.

3.1. LCZ types in Szeged and their representative areas

With the help of the obtained parameter values supplemented by viewing aerial photographs and authors' local knowledge of the study area, theoretically every areas in the 103 cells can be classified. 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 a non built-up cell, because it consists of agricultural fields with low plants without trees and a few small houses. So, according to the land cover type classification, the circle area in this cell can be regarded as a representative area of LCZ D type (low plants). As a result, Figures 2 and 3 show the locations and aerial photographs of the selected circle areas.

Figure 2: Locations of the selected circle areas representing the LCZ types occurring in Szeged with their names and designations.



The values of the areas characterized as LCZs 2 and 6 fit into the formally defined parameter ranges given in Table 3. Nevertheless, in some cases there are smaller deviations in the obtained parameter values from the defined ranges (these values are marked with underlines). The aerial pictures in Figure 3 give us much help in the final decision regarded the classification. Although we are convinced that the selected areas represent the LCZ types as we specified, these deviations require some explanation:

- LCZ 3 "Compact low-rise" – It has extended covered areas, the ISF barely exceeds the upper limit (50.4%), thus it has a slightly higher SVF (0.68). The BSF is a bit under the lower limit of this parameter (31.4%) so it could be even LCZ 6 (open low-rise), but the PSF is under 20% which is typical of LCZ 3.

- LCZ 5 "Open midrise" – As this area is well vegetated the PSF is slightly higher (41.5%) than the upper limit with the result of a bit lower BSF value (16.2%). This could us lead to classify this area even as LCZ 6 (open low-rise), but the HRE value (15.4 m) justifies the selection of LCZ 5.

- LCZ 8 “Large low-rise” – The PSF is larger (24.9%) as this area has a sport field, as well as the ISF is also higher (59.6%) thus the BSF is a bit smaller (15.5%). However, as the picture in Figure 3 shows, it is a typical warehouse area with factory buildings, so it is classified as LCZ 8.

- LCZ 9 “Sparsely built” – This area is characterized with low BSF (2.5%) and TRC (4) so it could be even LCZ D (low plants), but because of its high ISF (22.5%) it is better classified as LCZ 9.

Figure 3: Aerial photographs of the circle areas with their designations representing the LCZ types occurring in Szeged.

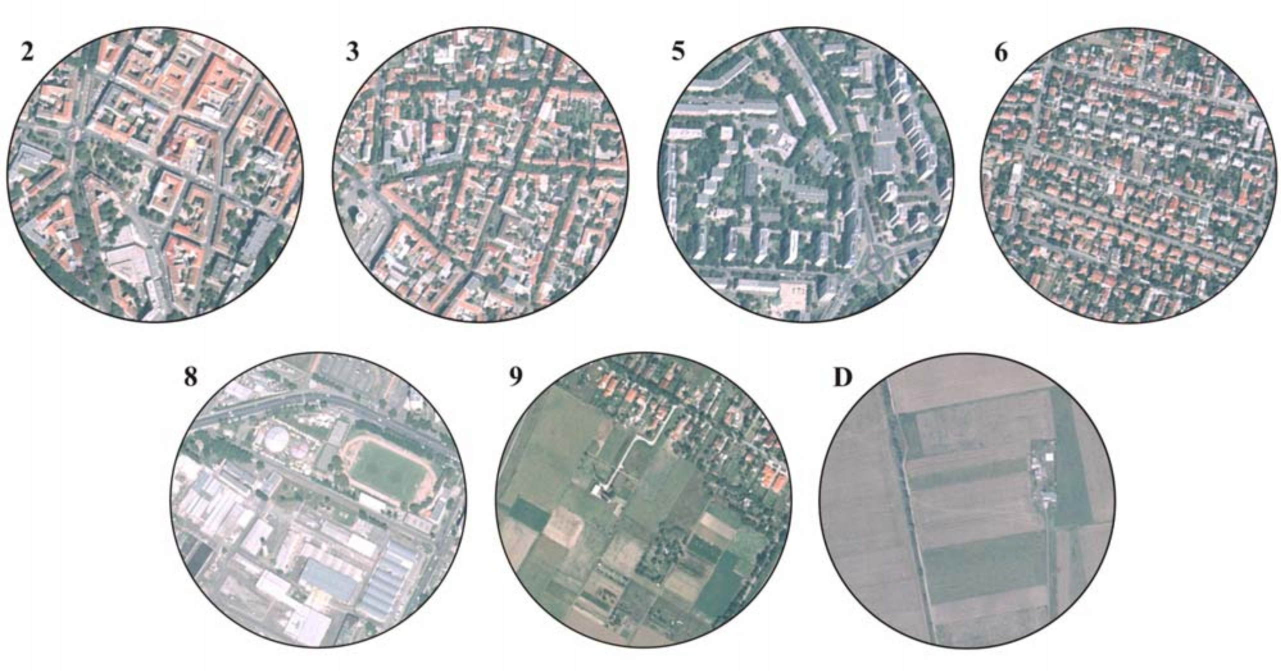


Table 3. Formally defined ranges of the properties for LCZ types (Stewart and Oke, 2012) compared to the values (*italics*) of the representative areas in Szeged (underlined values deviate from the defined ranges).

LCZ name and designation	Properties						
	SVF sky view factor	BSF building surface fraction (%)	ISF impervious surface fraction (%)	PSF pervious surface fraction (%)	HRE height of roughness elements (m)	TRC terrain roughness class	A albedo
LCZ 2	0.3–0.6	40–70	30–50	< 20	10–25	6–7	0.10–0.20
Compact midrise	*0.59*	*45.4*	*44.0*	*10.5*	*13.6*	*7*	*0.15*
LCZ 3	0.2–0.6	40–70	20–50	< 30	3–10	6	0.10–0.20
Compact low-rise	*0.68*	*31.4*	*50.4*	*18.2*	*7.9*	*6*	*0.14*
LCZ 5	0.5–0.8	20–40	30–50	20–40	10–25	5–6	0.12–0.25
Open midrise	*0.74*	*16.2*	*42.3*	*41.5*	*15.4*	*6*	*0.12*
LCZ 6	0.6–0.9	20–40	20–50	30–60	3–10	5–6	0.12–0.25
Open low-rise	*0.83*	*20.3*	*45.3*	*34.4*	*5.4*	*6*	*0.16*
LCZ 8	> 0.7	30–50	40–50	< 20	3–10	5	0.15–0.25
Large low-rise	*0.92*	*15.5*	*59.6*	*24.9*	*6.6*	*5*	*0.16*
LCZ 9	> 0.8	10–20	< 20	60–80	3–10	5–6	0.12–0.20
Sparsely built	*0.99*	*2.5*	*22.5*	*75.0*	*5.0*	*4*	*0.17*
LCZ D	> 0.9	< 10	< 10	> 90	< 1	3–4	0.15–0.25
Low plants	*0.999*	*0.2*	0.0	99.8	*0.0*	*3*	*0.15*

3.2. Thermal differentiation: comparison of LCZ temperatures

Figure 4 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. 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 deviation 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 4). These findings are similar to those obtained by Stewart and Oke (2010) in Uppsala (compact midrise and low plants difference can exceed 5ºC).

Figure 4: Temperature differentiation of built LCZ types from the LCZ D type at the selected nights and on average in Szeged.

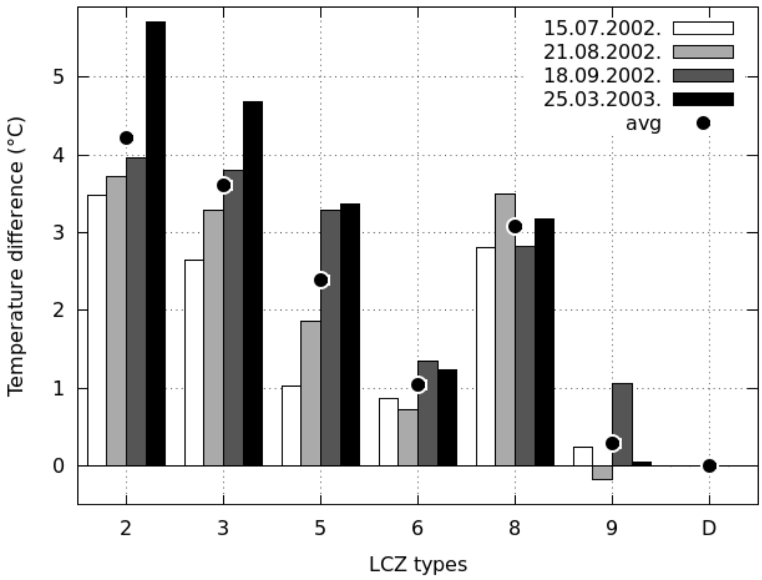


Table 4. Pairwise average temperature differences (ºC) of LCZ types in Szeged (line 1 minus column 1)

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

As already mentioned above, in this new system the UHI intensity not an "urban-rural" difference but a temperature difference between the LCZ areas. This is reflected in the values of Table 4 which contains the pairwise average temperature differences (ºC) of LCZs representative for Szeged. The largest average difference is 4.22ºC ($\Delta T_{LCZ:2–D}$), but $\Delta T_{LCZ:2–9}$, $\Delta T_{LCZ:2–6}$, $\Delta T_{LCZ:3–D}$, $\Delta T_{LCZ:3–9}$, $\Delta T_{LCZ:8–D}$ mean also significant differences, as they all are above 3ºC.

4. CONCLUSIONS

In this study we determined 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) and compared their thermal reactions based on the earlier temperature measurement campaigns carried out in this city.

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