DETERMINATION OF AN URBAN TEMPERATURE MONITORING NETWORK USING GIS METHODS

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ABSTRACT. Determination of an urban temperature monitoring network using GIS methods. Local Climate Zones (LCZ) classification system describes the physical conditions of a local-scale environment of a measuring site from the viewpoint of the generated local thermal climate. It is based on quantitative geometric, radiative and thermal properties of the surface. Using GIS methods on the available vector-based and raster-based databases, six built LCZ types were distinguished and mapped in the studied urban area, in a South-Hungarian city. Spatial pattern of temperature surplus – defined as the temperature excess of the built-up areas compared to the temperature of non-built area – was estimated for the whole study area with the application of an empirical model.Appropriate locations of measurement sites were determined considering the two mentioned information sources. First, homogeneous LCZ areas with a radius of a few hundred meters should be around the sites, and the number of the sites should be roughly proportional to the areas of the corresponding LCZs. Second, sites should be located at around the high and low temperature surplus areas, as well as at around the areas of the local maxima and stretches assumed by the modelled pattern. After this designation the sites were adjusted regarding our local knowledge (e.g. representative micro-environment, appropriate circumstances to place the instruments). The representativeness of the network could be evaluated through the estimation of the expected geometric error.

Keywords: urban climate, Local Climate Zones, urban network, Szeged, Hungary.

1. INTRODUCTION

Nowadays about half of the human population is affected by the burdens of urban environments. This makes studies dealing with the urban impact on climate particularly important. By definition urban climate is a local climate that is generated by interactions between the surface of the built-up area and the regional climate. Among the parameters of the urban atmosphere the near-surface air temperature shows the most obvious difference compared to the rural area. This urban warming is commonly referred to as the urban heat island (Oke, 1987).

To help standardize the description of the environment around measurement sites according to their ability to influence the local thermal and dynamic conditions of the near-surface atmosphere, Stewart and Oke (2012) developed a classification system called Local Climate Zones (LCZ). It is based on

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the earlier works of Auer (1978), Ellefsen (1991) and Oke (2004) as well as a world-wide survey of heat island measurement sites and literature (Stewart, 2011). Categories of the used LCZ system are displayed in Table 1.

Table 1. Local Climate Zones categories (Stewart and Oke, 2012)

1. Compact highrise	2. Compact midrise	3. Compact lowrise	4. Open highrise
5. Open midrise	6. Open lowrise	7. Lightweight lowrise	8. Large lowrise
9. Sparsely built	10. Heavy industry	A. Dense trees	B. Scattered trees
C. Bush, scrub	D. Low plants	E. Bare rock or paved	F. Bare soil or sand
G. Water			

The objective of this paper is to find appropriate locations of temperature and relative humidity measurement sites to monitor human thermal comfort in the built-up region ofSzeged, regarding delineated Local Climate Zones and an empirical temperature surplus model based on our earlier research (Balázs et al., 2009).

2. SHORT DESCRIPTION OF THE STUDY AREA AND THE USED DATASETS

Szeged is located in the south-eastern part of Hungary, at 46°N, 20°E,79 m a.s.l. on flat terrain with a population of 160,000 within an urbanized area of about 40 km^2. It is located in Köppen's climatic region Cfb (temperate warm climate with a rather uniform annual distribution of precipitation) with an annual mean temperature of 10.4°C and an amount of precipitation of 497 mm(Unger et al., 2001). The study area covers a 10 km × 8 km rectangle (Fig. 1).

Fig. 1. Location and surrounding of the study area

For the classification the following properties were applied:

- *Sky view factor* (SFV) was originated from our earlier studies (Gál et al., 2009).
- *Building surface fraction* (BSF) was calculated using building footprints from the 3D building database of the city.
- *Pervious surface fraction* (PSF) was calculated based on a RapidEye (2012) satellite image using NDVI (Tucker, 1979). A road database, Corine Land Cover (Bossard et al.,2000) and a topographic map was used to make some necessary corrections.

- *Impervious surface fraction* (ISF) was derived using the following formula: ISF = 1 – (BSF + PSF).
- *Height of roughness elements* (HRE) was also obtained from the 3D building database of Szeged.
- *Terrain roughness class* (TRC) was determined using the Davenport roughness classification method (Davenport et al., 2000) using visual interpretation of aerial photographs, the topographical map and the building database.
- *Surface albedo* (SA)was calculated as a weighted average of reflectance values of the 5 band RapidEye satellite image (Starks et al., 1991; Tasumi et al., 2008).

3. DELINEATIONOF LOCAL CLIMATE ZONES

Primary point of view in the process of locating the siteswas that a few hundred metres wide homogeneous LCZ area should be around each site and the number of stations should be roughly proportional to the extension of the corresponding LCZs. Second, the sites should be located around the areas of the local temperature maxima and stretches. Third, the network have to be able to represent well the temperature field without large geometric errors.

The basic area of the calculation was the lot area polygon, which consists of a building and its area of influence. Their determination was made using the building database of Szeged. Firstly, buildings which are in physical contact with each other were contracted into blocks of buildings. Secondly, the Thiessen-polygons belonging to the blocks were calculated. In order to curtail the size of lot area polygons next to large open spaces (e.g. parks, fields, water), polygon areas that lay 100 m beyond the building encompassed by the polygon were cut off (examples of the defined lot area polygons are displayed on Fig. 2).

Fig. 2. Examples of lot area polygons. a:building; b: lot area; c: open area

The calculation of the above mentioned parameters were done for the area of these lot area polygons,e.g. BSF is the ratio of footprint area of building block located on the mentioned polygon and the footprint area of the lot area polygon itself.

Radiative, geometric and thermal parameters given by Stewart and Oke (2012) were determined with the exception of three properties – aspect ratio was omitted because it can be interpreted unequivocally only in the case of regular street network; thermal surface admittance and anthropogenic heat output was also omitted because we didn’t have any information about them.Lot area polygons were classified individually, according to the fit of their properties into the typical ranges given by Stewart and Oke (2012).

In line with the definition of LCZs, the lot area polygons classified (Fig. 3/A) into the same or similar LCZ classes were merged into zones of hundreds of meters to several kilometres (Fig. 3/B). In this case, we meet the minimum condition that final zones have to be large enough that the relatively homogeneous area constitutes an area with a radius of 250 m or greater.

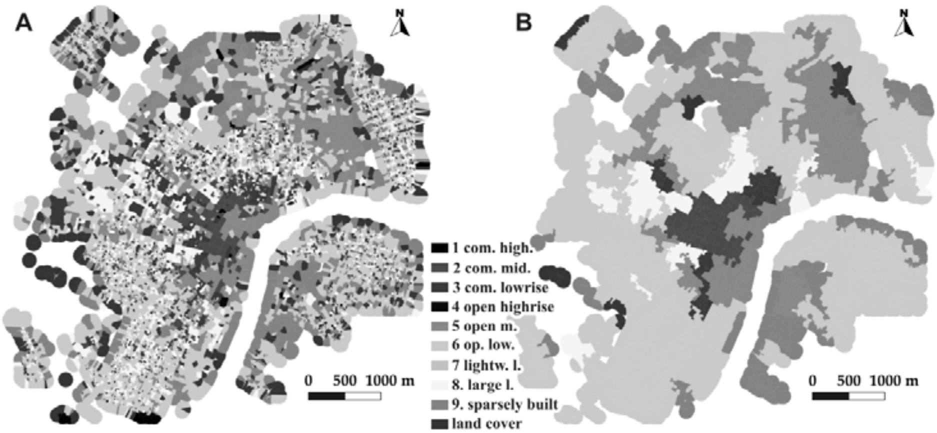

Fig. 3. (A) Classified lot area polygons; (B) Groups of aggregated polygons

Finally some manual corrections were made according to aerialphotographs and our local knowledge of the area, because of inadequate detachment of the zones. The most difficult task is the recognition of LCZ 8 (large lowrise) from the surface parameters. As a final result we obtained several LCZ polygons in ESRI shapefile format, what is suitable to produce maps or to extract spatial information as well.

4. APPLICATION OF AN EMPIRICAL TEMPERATURE FIELD MODEL

During the process of finding appropriate locations for the sites we wanted to take into account the field of air temperature.In order to get the pattern of temperature we applied an empirical model (Balázs et al., 2009). This model is based on our earlier mobile temperature measurements. These measurements were taken by cars at the same time after sunset on fixed return routes by several occasions during a one-year period (from April 2002 to March 2003) (e.g. Unger, 2004).

The aim of this model is to estimate the spatial distribution of the annual mean temperature surplus using just a few input parameters. It works on grids of 500 m × 500 m. Built-up ratio (artificially covered surface ratio, BR) of the cell and its neighbours and distance from a cell where BR = 0 are considered as independent variables from the viewpoint of the model equation. Temperature surplus is defined as the temperature excess of the built-up areas compared to the temperature of non-built areas. Temperature surplus of a grid cell (and its neighbour cells) without artificial cover is 0°C.

The modelled valuerefers to the grid cell centre, and characterizes the mean annual temperature surplus. Temperature surplus can be estimated by the following model equation (Balázs et al., 2009):

$$\Delta T = 0.001032 \cdot ln(BR_0) + 0.002455 \cdot ln(BR_1) + 0.002629 \cdot ln(BR_2)$$

where BR_0 is BR for the given grid cell itself, BR_1 is the average BR value of its directneighbours, and BR_2 is the average BR value of its second neighbours.

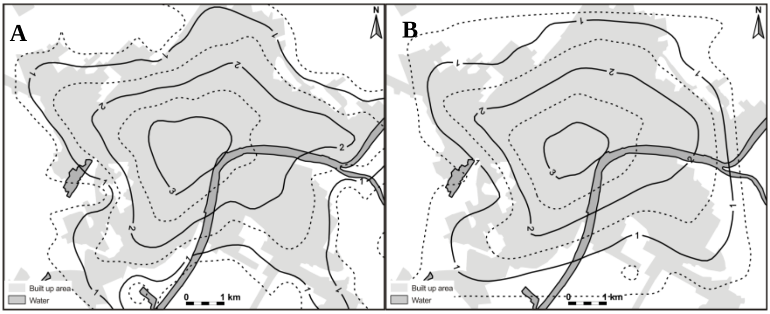

Fig. 4. Modelled (A) and interpolated (B) temperature surplus pattern (°C)

To test the ability of the network to represent the spatial distribution of the temperature we have interpolated the modelled values for the 24 planned station sites.Based on only these interpolated values of the stations the spatial distribution of the temperature was calculated for the whole study area. Calculation was performed with the method of linerar interpolation regarding 3 nearby data points after triangulation of the field.

As a result, we obtained two temperature patterns, the modelled and the interpolated one (Fig. 4). As it is shown, the modelled isotherms have a roughly concentric shapes and follow the shape of built-up area. The highest values are located in the most densely built-up central areas, as it can be expected. The interpolated field is necessarilyless detailed, due to its coarser spatial resolution.

With the comparison of the two temperature surplus fields, it can be seen, that absolute error is below 0.5°C on the 78% of the whole area. As Fig. 5 displays, bigger errors are connected to the outer regions of the study area – as the network is sparser on the edges – which is less important while the aim of the network is to monitor the human thermal comfort of the inhabited region.

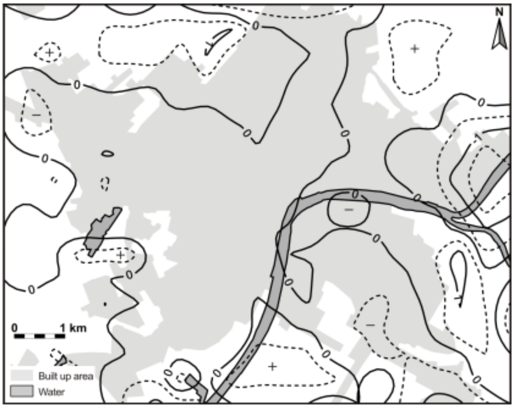

Fig. 5. Interpolated temperature surplus pattern (°C)

5. LOCATION OF THE MEASUREMENT SITES

For safety reasons the sensors have to be installed at 4 m a.g.l. on consolsfixed on the selected lamp posts. The effect of this height on the measured values is expected to be small as the air is generally well mixed instreet canyons (Nakamura and Oke, 1988).

As described in Section 3 and 4, location of the sites was selected preliminary considering the obtained LCZ map and the modelled air temperature field. Then after the experience of field surveys at the possible sites some adjustments were made. For example, the microenvironment of the site should be representative for the LCZ itself.

In addition, there are areas (mostly in the city centre) where there are no suitable places for a station as the public lamps hang on wire suspensions between the buildings, so these streets had to be omitted during the site selection process. There are also other sites with fixed place, e.g. at the existing WMO SYNOP station of the Hungarian Meteorological Service.

During the site selection, major criteria were (1) each station have to be surrounded by 250 meters wide homogeneous LCZ area, (2) number of the sites should be roughly proportional to the areas of different LCZs. Other additional criteria were (3) sites should be located near areas with local temperature maxima and stretches, (4) microenvironment of the site should be representative for that LCZ, (5) it should be placed on a lamppost which is appropriate for this purpose and hard to access for pedestrians.

As the result of the site selection process, 24 station sites were identified in the study area (Fig. 6). In LCZ 2 (compact midrise) and LCZ 3 (compact lowrise) there is 1 site, in LCZ 5 (open midrise) and LCZ 9 (sparsely built) there are 4 sites, in LCZ 6 (open lowrise) there are 10 sites, in LCZ 8 (large lowrise) there are 2 sites and in LCZ D (low plants) there are also 2 rural sites in the western and north-eastern parts of study area.

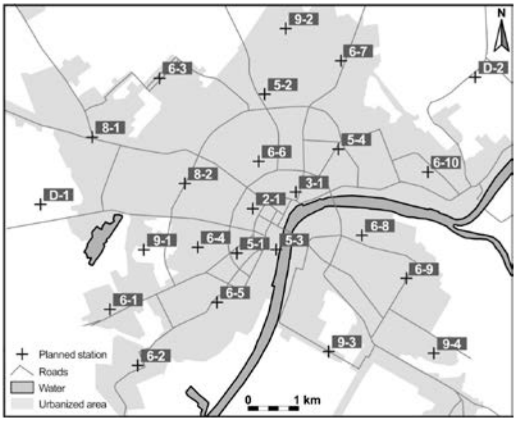

Fig. 6. Station locations of the urban monitoring network

Fig. 7 displays the immediate surroundings (with 250 m radius) of six typical stations representing the six built LCZ types occurring in the study area. These aerial photographs illustrate the clearly recognizable differences in e.g. building size and density and surface cover between the different LCZ types.

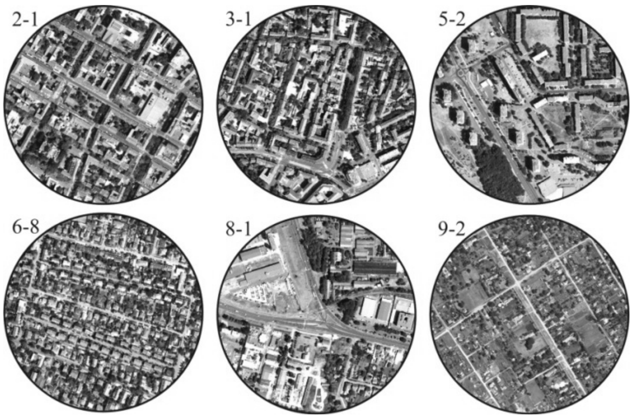

Fig. 7. Aerialphotographs of the250 m radius surroundings of six stations representing the six built LCZ types occurring in Szeged

6. CONCLUSIONS

In this study we were looking for appropriate locations for temperature and relative humidity measurement sites. They were determined after the delineation of built-up Local Climate Zones in the study area. Air temperature surplus pattern estimated by an empirical model was also regarded during the site selection, and during the estimation of geometric error due to the interpolation. After the experience of field surveys we selected 24 representative sites in the study area.

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