ACTA CLIMATOLOGICA ET CHOROLOGICA
Universitatis Szegediensis, Tom. 34-35, 2001, 5-14.

URBAN TEMPERATURE EXCESS AS A FUNCTION OF URBAN PARAMETERS IN SZEGED, PART 1: SEASONAL PATTERNS

J. UNGER[1], Z. SÜMEGHY[1], L. MUCSI[2], V. PÁL[3], E. KÁDÁR[4] and I. KEVEI-BÁRÁNY[1]

[1]*Department of Climatology and Landscape Ecology, University of Szeged, P.O.Box 653, 6701 Szeged, Hungary*
E-mail: unger@geo.u-szeged.hu
[2]*Department of Physical Geography, University of Szeged, P.O.Box 653, 6701 Szeged, Hungary*
[3]*Department of Geography, Juhász Gyula Teacher's Training College, University of Szeged, Hattyas sor 10, 6725 Szeged, Hungary*
[4]*Department of Cartography, Eötvös University, Pázmány Péter sétány 1/A, 1117 Budapest, Hungary*

Összefoglalás - A tanulmány a beépített városi felszín és a felszínközeli légtér hőmérsékleti eloszlása közötti kapcsolatot elemzi egy közepes méretű város, Szeged esetében. A város sík, alföldi területen fekszik és lakosainak száma 160 ezer. Az adatgyűjtés különböző időjárási helyzetekben, mobil mérésekkel történt 1999. március és 2000. február között. A vizsgálat célja az átlagos maximális városi hősziget területi szerkezetének megállapítása kriging eljárással megszerkesztett izovonalak segítségével az egy éves periódusban, valamint az ezen belül megkülönböztetett fűtési és nem fűtési időszakokban. Az eredmények szerint a városi hőmérsékleti többlet izotermái meglehetősen szabályos, méghozzá a külterülettől a belváros felé növekedő koncentrikus alakot vesznek fel, de a hősziget erősségében megfigyelhető egy évszakos változás. A legnagyobb érték az egész időszakban több mint 2,6°C, a nem fűtési periódusban több mint 3,1°C és a fűtési periódusban pedig több mint 2,1°C. A szabályosságtól való eltérések szoros kapcsolatban vannak a beépítettség mértékével.

Summary - This study examines the influence of urban factors on the surface air temperature field of the medium-sized city of Szeged, Hungary, using of mobile measurements under different weather conditions between March 1999 and February 2000. This city with a population of about 160,000 is situated on a low, flat flood plain. The efforts have been concentrated on investigating the maximum development of the urban heat island (UHI). Tasks include the determination of spatial distribution of mean maximum UHI intensity, using of standard kriging procedure in the one-year study period, as well as in the heating and non-heating seasons. The results indicate isotherms increasing in regular concentric shapes from the suburbs toward the inner urban areas with a seasonal variation in the UHI magnitude. In the city centre, the mean maximum UHI intensity reaches more than 2.6°C, 3.1°C and 2.1°C, respectively. As the patterns show, strong relationship exists between urban thermal excess and built-up density.

Key words: maximum urban heat island, mobil measurements, spatial distribution, grid network, built-up density, heating and non-heating seasons

INTRODUCTION

The temperature-increasing effect of cities caused by urbanisation (the so-called urban heat island - UHI) is one of the most deeply examined field of climatology. Features of the UHI are well documented from different cities mainly from the temperate zone (*e.g. Oke*, 1997; *Kuttler*, 1998) and one of the most difficult aspect of this phenomenon is studying of its peak development during the diurnal cycle.

Counting all weather conditions except rain, the main purpose of this study is to investigate the effects and interactions inside the city on the surface air temperature, a few hours after sunset when the UHI effect is most pronounced. To achieve this aim, we construct horizontal isotherm maps to show the average spatial distribution of maximum UHI intensity in the investigated period, as a whole and in the distinguished so-called heating and non-heating seasons. Then, we intend to reveal some obvious relationships between temperature patterns and urban factors using built-up (artifically covered surface) ratio within the city.

Further results - connected to the statistical elaboration of the same data set used in this study - can be found in the second part of our investigation (*Unger et al.*, 2001).

STUDY AREA AND METHODS

Szeged is located in the south-eastern part of Hungary on the Great Hungarian Plain (46°N, 20°E) at 79 m above sea level. The terrain of the city and its countryside is a large flat flood plain. The Tisza River passes through the city, otherwise, there are no large water bodies nearby. This geographical situation (no orographic climate influences) makes Szeged a good case for the study of a relatively undisturbed urban climate. Using Köppen's classification the area belongs to the climatic region *Cf*, which means a temperate warm climate with a rather uniform annual distribution of precipitation (*Table 1*). The regional climate of Szeged has, however, a certain Mediterranean influence. It appears mainly in the annual variation of precipitation, namely in every 10 years approximately 3 years show some Mediterranean (relatively high autumn-winter rainfall) characteristics (*Unger*, 1999).

The city's population of 160,000 (1998) lives within an administration district of 281 km^2 (*Firbás*, 1999). As for the city structure, its basis is a boulevard-avenue road system. Number of different land-use types are present including a densely built centre with medium wide streets and large housing estates of tall concrete blocks of flats set in wide green spaces. Szeged also contains areas used for industry and warehousing, zones occupied by detached houses, and considerable open spaces along the banks of the river, in parks and around the city's outskirts (*Fig. 1*).

Table 1 Monthly and annual means or sums of meteorological parameters in the region of Szeged (1961-1990)

Parameter	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Year*
Temperature (°C)	-1.8	1.0	5.6	11.1	16.2	19.2	20.8	20.2	16.4	11.0	5.1	0.6	10.4
Precipitation (mm)	29	25	29	40	51	72	50	60	34	26	41	40	497
Sunshine duration (h)	62	87	143	181	235	252	288	267	211	170	82	51	2029
Cloudiness (%)	70	68	63	60	58	54	45	42	45	49	69	76	58
Wind speed (ms^{-1})	3.3	3.4	4.0	3.7	3.2	2.9	2.9	2.7	2.6	3.0	3.0	3.7	3.2
Relative humidity (%)	85	82	73	68	66	67	65	67	70	73	83	87	74
Vapour pressure (hPa)	4.9	6.5	6.8	8.9	12.3	15	16	15.8	13.2	9.8	7.6	5.8	10.1

As the urban and suburban areas occupy only about 25-30 km^2, our investigation focused only on the inner part of the administration district (*Fig. 1*). This study area was divided into two sectors and subdivided further into 0.5 km x 0.5 km square grid cells (*Fig. 2*). The same grid size was employed, for example, in a human bioclimatological analysis of Freiburg, Germany, a city of similar size to Szeged (*Jendritzky and Nübler*, 1981) and in an other investigation of UHI in Seoul, Korea (*Park*, 1986). *Sailor* (1998) chose a 2 km x 2 km network for his hypothetical city, where he simulated the impacts of vegetative augmentation on the annual heating and cooling degree days.

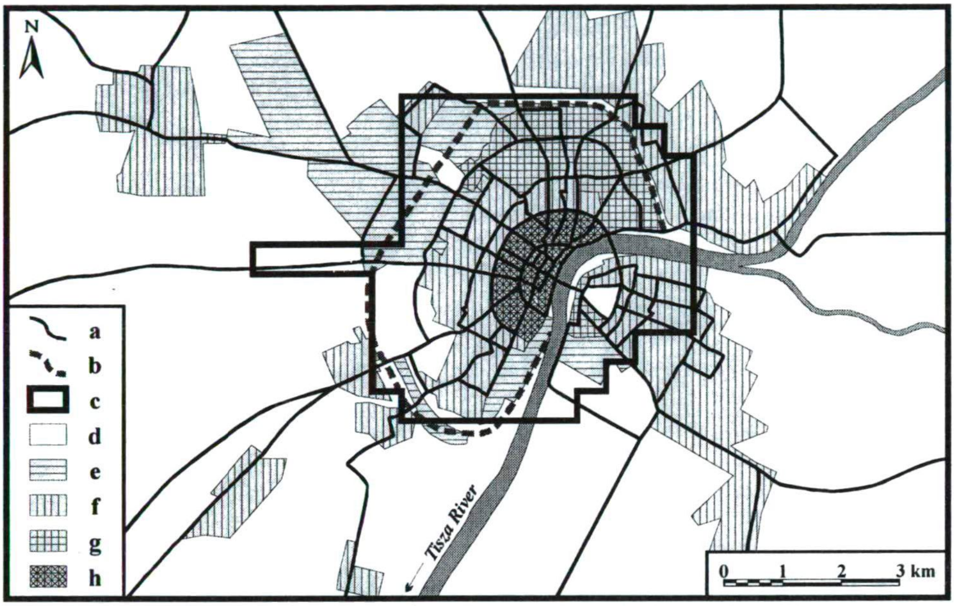

Fig. 1 Characteristic land-use types and road network in Szeged: (a) road, (b) circle dike, (c) border of the study area, (d) agricultural and open land, (e) industrial area, (f) 1-2 storey detached houses, (g) 5-11 storey apartment buildings and (h) historical city core with 3-5 storey buildings

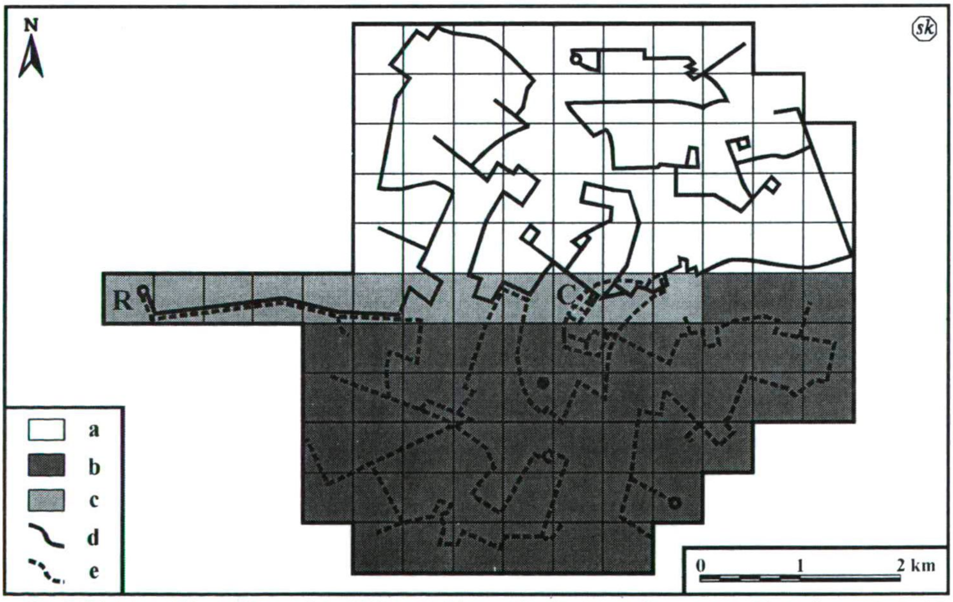

Fig. 2 Division of the study area into 0.5 km x 0.5 km grid cells: (a) northern sector, (b) southern sector, (c) overlap area and (d, e) measurement routes. The rural and central grid cell are indicated by R C, respectively and the permanent measurement site at the University of Szeged is indicated as •.

Therefore, our grid network can be regarded as a rather dense one. In the study area there are 107 grid cells totalling 26.75 km^2, covering the urban and suburban parts of Szeged (mainly inside of the circle dike that protects the city from floods caused by the Tisza River). The outlying parts of the city, characterised by village and rural features, are not included in the grid except for four cells at the western side of the area. These four cells are needed in order to determine the temperature contrast between urban and rural areas. The grid was established by quartering the 1 km x 1 km square network of the Unified National Mapping System (EOTR) that can be found on topographical maps of Hungary at the scale of 1:10,000.

The examination of the spatial and temporal distribution of surface air was based on mobile observations during the period of March 1999 - February 2000. In case of surface UHI and near surface air UHI investigations, the moving observation with different vehicles (car, tram, helicopter, airplane, satellite) is an often used process (e.g. *Johnson*, 1985; *Yamashita*, 1996; *Voogt and Oke*, 1997; *Klysik and Fortuniak*, 1999; *Tumanov et al.*, 1999).

In order to collect data on maximum UHI intensity (namely the temperature difference between urban and rural areas) at every grid cell, mobile measurements were performed on fixed return routes once a week during the studied period (altogether 48 times) to accomplish an analysis of air temperature over the entire area. This one-week frequency of car traverses secured sufficient information on different weather conditions, except for rain. *Table 2* contains the details of the one-year measurement campaign.

The division of the study area into two sectors was needed because of the large number of grid cells. The northern and southern sectors consisted of 59 grid cells (14.75 km^2) and 60 grid cells (15 km^2) respectively, with an overlap of 12 grid cells (3 km^2). The lengths of the fixed return routes were 75 and 68 km in the northern and southern sectors, respectively and took about 3 hours to traverse (*Fig. 2* and *Table 2*). Such long and return routes were necessary to gather temperature values in every grid cell and to make time-based corrections. Temperature readings were obtained using a radiation-shielded LogIT HiTemp resistance temperature sensor (resolution of 0.01°C), which was connected to a portable LogIT SL data logger (DCP Microdevelopments and SCC Research) for digital sampling inside the car. Since the data were collected every 16 s, at an average car speed of 20-30 km h^{-1} the average distance between measuring points was 89-133 m. The temperature sensor was mounted 0.60 m in front of the car at 1.45 m above ground to avoid engine and exhaust heat. This is similar to the measurement system used by *Ripley et al.* (1996) in Saskatoon, Saskatchewan. The car speed was sufficient to secure adequate ventilation for the sensor to measure the momentary ambient air temperature (*Fig. 3*).

After averaging the measurement values by grid cells, time adjustments to the reference time were applied assuming linear air temperature change with time. This linear change was monitored using the continuous records of the permanent automatic weather station at the University of Szeged (*Fig. 2*). The linear adjustment appears to be correct for data collected a few hours after sunset in urban areas. However, because of the different time variations of cooling rates, it is only approximately correct for suburban and rural areas (*Oke and Maxwell*, 1975). The reference time, namely the likely time of the occurrence of the strongest UHI, was 4 hours after sunset (in CET - Central European Time, see *Table 2*), a value based on earlier measurements in 1998 and 1999 (*Boruzs and Nagy*, 1999). Consequently, every grid cell of 59 in the northern sector or every grid cell of 60 in the southern sector can be characterised by one temperature value for every measuring night. These temperature values refer to the centre of each cell.

Table 2 Survey of mobile measurements in the study area of Szeged (March 1999 - February 2000)

Sector	*No.*	*Date*	*Measuring period*	*Reference time (CET)*	*Number of measuring points*
northern	1	02.03.1999	2h 56m	2130	663
	2*	09.03.1999	-	2130	-
	3*	31.03.1999	-	2200	-
	4	15.04.1999	3h 09m	2230	708
	5	29/30.04.1999	3h 04m	2245	686
	6	13/14.05.1999	3h 05m	2300	692
	7	25/26.05.1999	3h 15m	2315	731
	8	09/10.06.1999	3h 16m	2330	736
	9	23/24.06.1999	3h 07m	2330	699
	10	05/06.07.1999	3h 12m	2330	700
	11	21/22.07.1999	3h 19m	2330	763
	12	03/04.08.1999	3h 01m	2315	666
	13	17/18.08.1999	3h 04m	2245	682
	14	29.08.1999	2h 59m	2230	669
	15	14.09.1999	3h 07m	2200	699
	16	29.09.1999	3h 12m	2130	719
	17	12.10.1999	3h 14m	2100	725
	18	26.10.1999	3h 12m	2030	717
	19	12.11.1999	3h 10m	2015	711
	20	06.12.1999	3h 08m	2000	701
	21	07.12.1999	2h 59m	2000	668
	22	04.01.2000	3h 08m	2000	704
	23	14.01.2000	3h 04m	2015	689
	24	19.01.2000	3h 05m	2030	691
	25	01.02.2000	3h 05m	2045	693
	26	15.02.2000	3h 06m	2100	694
southern	1	16.03.1999	3h 03m	2145	683
	2	23.03.1999	3h 00m	2200	673
	3	06.04.1999	2h 52m	2215	643
	4	20.04.1999	2h 55m	2230	652
	5	10/11.05.1999	2h 47m	2300	624
	6	19/20.05.1999	2h 47m	2315	624
	7	01/02.06.1999	3h 09m	2330	707
	8	15/16.06.1999	3h 18m	2330	695
	9	29/30.06.1999	2h 59m	2330	661
	10	13/14.07.1999	2h 56m	2330	657
	11	31.07/01.08.1999	3h 00m	2315	674
	12	09/10.08.1999	3h 02m	2300	673
	13	24.08.1999	2h 51m	2230	628
	14	07.09.1999	2h 54m	2215	650
	15	20.09.1999	2h 50m	2145	636
	16	07.10.1999	2h 59m	2115	670
	17	18.10.1999	2h 58m	2045	666
	18	02.11.1999	3h 04m	2030	689
	19	18.11.1999	3h 05m	2000	698
	20	01.12.1999	2h 57m	2000	659
	21	18.12.1999	2h 50m	2000	636
	22*	11.01.2000	-	2015	-
	23	25.01.2000	2h 48m	2030	630
	24*	03.02.2000	-	2045	-
	25	08.02.2000	2h 54m	2100	649
	26	22.02.2000	3h 00m	2115	672

* no data available because of technical difficulties

Fig. 3 The measurement car with the temperature sensor (under the white cover)

We determined urban-rural air temperature differences (UHI intensity) by cells referring to the temperature value of the grid cell (the most western cell in the investigated area), where the synoptic weather station of the Hungarian Meteorological Service is located. This grid cell (labelled R) containing this station was regarded as rural (*Fig. 2*), because the records of this station were used as rural data in the earlier studies on the urban climate of Szeged (e.g. *Unger*, 1996, 1999). The 107 points (the above mentioned grid cell centerpoints) cover the urban parts of Szeged and they provide an appropriate basis to interpolate isolines. The isolines, therefore, can show detailed descriptions of thermal field within the city at the time of the strongest effects of urban factors. In order to draw the isotherms, a geostatistical gridding method, the standard kriging procedure was used.

The parameters of land-use for the grid cells were determined by GIS (Geographical Information System) methods combined with remote sensing analysis of SPOT XS images (*Mucsi*, 1996). Vector and raster-based GIS database were produced in the Applied Geoinformatics Laboratory of the University of Szeged. The digital satellite image was rectified to the EOTR using 1:10,000 scale maps. The nearest-neighbour method of resampling was employed, resulting in a root mean square value of less than 1 pixel. Because the geometric resolution of the image was 20 m x 20 m, small urban units could be assessed independently of their official (larger scale) land-use classification. Normalised Vegetation Index (*NDVI*) was calculated from the pixel values, according to the following equation:

$$NDVI = (IR-R)/(IR+R)$$

where *IR* is the pixel value in the infrared band and *R* is the pixel value in the red band. The range of *NDVI* values is from -1 to +1 indicating the effect of green space in the given spatial unit (*Lillesand and Kiefer*, 1987). Built-up, water, vegetated and other surfaces were distinguished according to the *NDVI* value. The spatial distribution of these land-use types of each grid element was calculated using cross-tabulation.

The ratio of the built-up area to the total area by grid cells in 25% increments is displayed in *Fig. 4*. This figure shows, that, for example, the location of the Tisza River (low built-up ratio) is clearly recognised with its east-to-south curve in the south-eastern part of the study area (see also *Fig. 1*).

SPATIAL DISTRIBUTION OF THE MAXIMUM UHI

In this part of the investigation not only the one-year period will be investigated, but within this period we distinguish the so called heating (between 16 October and 15 April) and non-heating (between 16 April and 15 October) seasons.

It can be seen in *Figs. 4, 5* and *6* that built-up density has a significant influence on the spatial patterns of the mean maximum UHI intensity (which is at 4 hours after sunset as supposed). The most obvious common features of these patterns are that the isotherms show almost regular concentric shapes with values increasing from the outskirts toward the inner urban areas. A vigorous deviation from this concentric shape occurs in the north-eastern part of the city, where the isotherms stretch toward the suburbs. This can be explained by the influence of the large housing estates with tall concrete buildings located mainly in the north-eastern part of the city with a built-up ratio higher than 75% (*Fig. 1*).

For the one-year period (*Fig. 4*), as it was expected, the highest differences (more than 2.5°C) are concentrated mainly in the densely built-up city centre (>75%) covered by about 2.5 grid cells (about 0.6 km^2). The strongest intensity (2.60°C) occurs in the central grid cell (C). A mean maximum UHI intensity of higher than 2°C indicates significant thermal modification. In this period in Szeged, the extension of the area, characterised by significant thermal modification, is about 19 grid cells (4.5-5.0 km^2), which is about 18% of the total investigated area.

In the non-heating season, the spreading out of the isolines of 2.25°C and 2.5°C to the north-west of the centre, and the isolines of 1.5°C and 1.75°C to the south-west are also caused by the high built-up ratio of more than 75% (*Fig. 5*). The highest differences (more than 2.75°C) are concentrated in the densely built-up city centre (>75%) covered by about 8 grid cells (2 km^2). The greatest intensity (3.18°C) is to the north of the central grid cell (C) in an adjacent cell. The mean maximum UHI intensity of higher than 2°C relatively large compared to the size of the study area. It covers about 40 grid cells (10 km^2), which is about 37% of the investigated area.

In the heating season, the high built-up ratio of more than 75% also caused the streching out of the isoline of 1.5°C to the north-west, and the isolines of 1°C and 1.25°C to the south-west (*Fig. 6*). The highest differences (more than 2°C) are concentrated in the city centre (>75%), covered by less than 2 grid cells (0.5 km^2), which is only about 2% of the total area. The strongest intensity (2.12°C) occurs in the central grid cell (C).

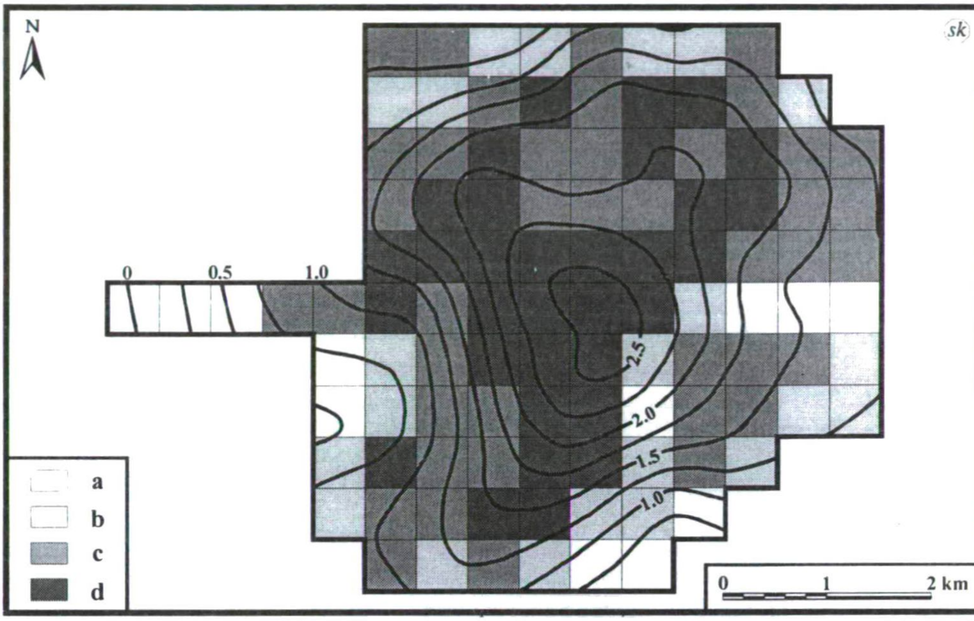

Fig. 4 Spatial distribution of the mean maximum UHI intensity (°C) and built-up density of the study area by grid cells (ratio of the built-up area to the total cell area: a/ 0-25%, b/ 25-50%, c/ 50-75% and d/ 75-100%) during the studied one-year period (March 1999 - February 2000) in Szeged

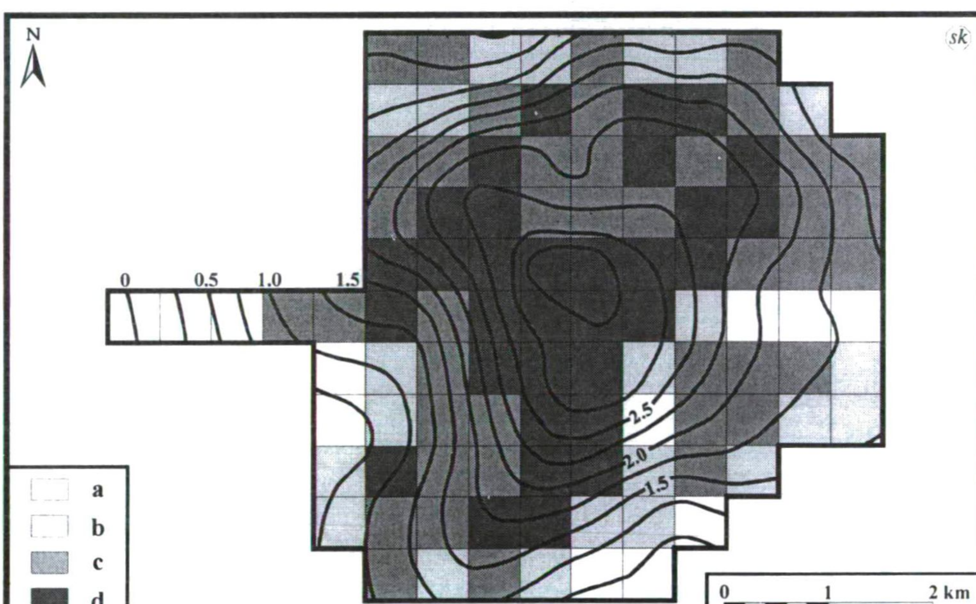

Fig. 5 Spatial distribution of the mean maximum UHI intensity (°C) during the non-heating season (16 April - 15 October) in Szeged

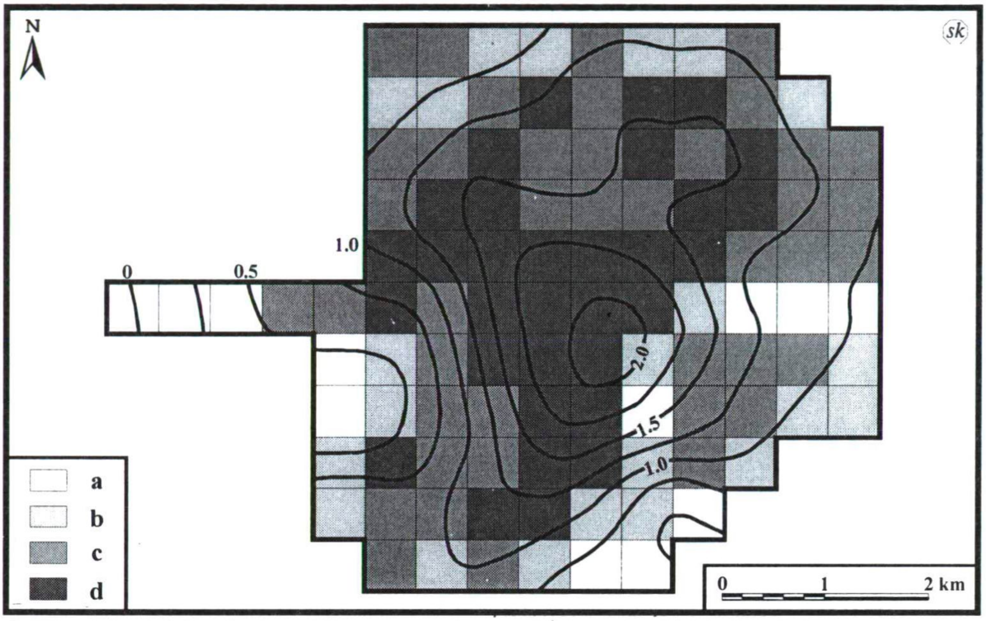

Fig. 6 Spatial distribution of the mean maximum UHI intensity (°C) during the heating season (16 October - 15 April) in Szeged

CONCLUSIONS

The seasonal spatial distribution of the maximum urban heat island and its relationship with built-up density is investigated in the present study. The results indicate that:

- The spatial patterns of the maximum UHI intensity have regular concentric shapes and the isotherms increase from the outskirts towards the central urban areas in all the three studied periods.
- The anomalies in the regularity are caused by the alterations in the built-up density.
- There are significant differences in the magnitudes of the seasonal (heating and non-heating) patterns. The area of the mean maximum UHI intensity of higher than 2°C - indicates significant thermal modification caused by urbanisation - is 18 times larger in the non-heating than in the heating season (2% and 37%, respectively).

The seasonal differences may be formed rather as a consequence of different weather characteristics in the two seasons than as a consequence of heating or non-heating of inhabitants. This explanation is supported by *Klysik and Fortuniak* (1999) who found similar differences in the UHI intensities between warm and cold seasons in Lódz, Poland. As in Poland, in Hungary (particularly in the Szeged region) the climate conditions in winter, conducive to the formation of UHI, are less common (*Table 1*). Thus, the role of appropriate weather conditions (stronger solar radiation income, more frequent clear sky and weak wind in the warmer, therefore non-heating season) is more pronounced in the development of UHI than the building heating in urban areas. Consequently, in case of Szeged, the significance of artifical heating in the development of UHI is rather limited.

Acknowledgements - The research was supported by the grants of the Hungarian Scientific Research Fund (OTKA T/023042) and the Ministry of Education (FKFP-0001/2000.). The authors wish to give special thanks to the students (M. Fegyveres, S. Fogarasi, A. Kiss, L. Kovács, P. Purnhauser, J. Sass, I. Sódar, R. Szalóki and B. Tárnok) who took part in the measurement campaigns.

REFERENCES

Boruzs, T. and Nagy, T., 1999: *Urban Influence on the Climatological Parameters* (in Hungarian). MSc thesis, University of Szeged, Szeged.

Firbás, Z. (ed.), 1999: *City Atlas of Szeged* (in Hungarian). Firbás-Térkép Kiadványszerkesztő és Térképgrafikai Bt., Szeged.

Jendritzky, G. and Nübler, W., 1981: A model analysing the urban thermal environment in physiologically significant terms. *Arch. Met. Geoph. Biol. Ser.B. 29*, 313-326.

Johnson, D.B., 1985: Urban modification of diurnal temperature cycles in Birmingham. *J. Climatol. 5*, 221-225.

Klysik, K. and Fortuniak, K., 1999: Temporal and spatial characteristics of the urban heat island of Lódz, Poland. *Atmos. Environ. 33*, 3885-3895.

Kuttler, W., 1998: Stadtklima. In *Stadtökologie* (eds: *Sukopp, H. und Wittig, R.*). Gustav Fischer, Stuttgart-Jena-Lübeck-Ulm, 125-167.

Lillesand, T.M. and Kiefer, R.W., 1987: *Remote Sensing and Image Interpretation*. J. Wiley & Sons, New York.

Mucsi, L., 1996: Urban land use investigation with GIS and RS methods. *Acta Geographica Univ. Szegediensis 25*, 111-119.

Oke, T.R. and Maxwell, G.B., 1975: Urban heat island dinamics in Montreal and Vancouver. *Atmos. Environ. 9*, 191-200.

Oke, T.R., 1997: Urban climates and global environmental change. In *Applied Climatology* (eds: *Thompson, R.D. and Perry, A.*). Routledge, London-New York, 273-287.

Park, H-S., 1986: Features of the heat island in Seoul and its surrounding cities. *Atmos. Environ. 20*, 1859-1866.

Ripley, E.A., Archibold, O.W. and Bretell, D.L., 1996: Temporal and spatial temperature patterns in Saskatoon. *Weather 51*, 398-405.

Sailor, D.J., 1998: Simulations of annual degree day impacts of urban vegetative augmentation. *Atmos. Environ. 32*, 43-52.

Tumanov, S., Stan-Sion, A., Lupu, A., Soci, C. and Oprea, C., 1999: Influences of the city of Bucharest on weather and climate parameters. *Atmos. Environ. 33*, 4173-4183.

Unger, J., 1996: Heat island intensity with different meteorological conditions in a medium-sized town: Szeged, Hungary. *Theor. Appl. Climatol. 54*, 147-151.

Unger, J., 1999: Urban-rural air humidity differences in Szeged, Hungary. *Int. J. Climatol. 19*, 1509-1515.

Unger, J., Bottyán, Z., Gulyás, Á. and Kevei-Bárány, I., 2001: Urban temperature excess as a function of urban parameters in Szeged, Part 2: Statistical model equations. *Acta Climatologica Univ. Szegediensis 34-35 (this issue)*, 15-21.

Voogt, J.A. and Oke, T.R., 1997: Complete urban surface temperatures. *J. Appl. Meteorol. 36*, 1117-1132.

Yamashita, S., 1996: Detailed structure of heat island phenomena from moving observations from electric tram-cars in metropolitan Tokyo. *Atmos. Environ. 30*, 429-435.