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URBAN TEMPERATURE EXCESS AS A FUNCTION OF URBAN PARAMETERS IN SZEGED, PART 2: STATISTICAL MODEL EQUATIONS

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Összefoglalás - A tanulmány a városi felszín tényezőinek a hőmérsékleti mezőre való kvantitatív hatását elemzi egy közepes méretű város, Szeged esetében. Az adatgyűjtés különböző időjárási helyzetekben, mobil mérésekkel történt 1999. március és 2000. február között. A vizsgálat célja olyan statisztikus modellegyenletek felállítása, amelyek leírják ezeket a hatásokat az egy éves időszakban és az ezen belül megkülönböztetett fűtési és nem-fűtési periódusokban. A városi felszínparaméterek (beépítettség, vízfelület és a városközponttól való távolság egy négyzetes grid-hálózatban) hatását a városi hőszigetnek a napi meneten belüli legerőteljesebb kifejlődésére a többszörös korreláció- és regresszió-analízis alkalmazása tárja fel. Az eredmények szerint szoros kapcsolat létezik a városi hőmérsékleti többlet és a távolság, valamint a beépítettség mértéke között, viszont a vízfelületek szerepe ebben az esetben nem számottevő.

Summary - This study examines the quantitative influence of urban surface 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. Tasks include the determination of statistical model equations in the studied periods, distinguishing heating and non-heating seasons within the one-year period. Multiple correlation and regression analyses are used to examine the effects of urban surface parameters (land-use characteristics and distance from the city centre determined in a grid network) on the urban heat island (UHI) in its peak development during the diurnal cycle. The results indicate that strong relationships exist between urban thermal excess and distance, as well as built-up ratio, but the role of water surface is negligible in this case.

Key words: maximum urban heat island, built-up ratio, water surface ratio, distance, grid network, statistical analysis, regression equations

INTRODUCTION

The detection of real factors and physical processes generating the distinguished urban climate is extremely difficult because of the very complicated urban terrain (as regard surface geometry and materials) as well as artificial production of heat and air pollution. The simulation of these factors and processes demands complex and expensive instrumentation, and sophisticated numerical and physical models. Despite these difficulties, several models have been developed for studying small-scale climate variations within the city, including the ones based on energy balance (*Tapper et al,* 1981; *Johnson et al.*, 1991; *Myrup et al.*, 1993), radiation (*Voogt and Oke*, 1991), heat storage (*Grimmond et al.*, 1991), water balance (*Grimmond and Oke*, 1991) and advective (*Oke*, 1976) approaches.

The temperature alteration (urban heat island - UHI) caused by settlements is the most obvious and characteristic phenomenon of the urban climate. As an other solution of the above mentioned problems, utilisation of statistical models may provide useful tools, which give us quantitative information about the magnitude, as well as spatial and temporal features of the UHI intensity (defined as the temperature difference between urban and rural areas) by employing urban and meteorological parameters. Some examples of the modelled variables (surface and near surface air UHI intensity or even the possible maximum UHI intensity) and the employed variable parameters are gathered in *Table 1*.

Table 1 Survey of some statistical models with modelled UHI variables, employed parameters and authors

Modelled variable	***Employed parameters***	***Author(s)***
UHI intensity	wind speed, cloudiness	*Sundborg* (1950)
UHI intensity	population, wind speed	*Oke* (1973)
max. UHI intensity	population	
UHI intensity	wind speed, cloudiness, atmospheric stability, traffic flow, energy consumption, temperature	*Nkemdirim* (1978)
UHI intensity	wind speed, land-use type ratios	*Park* (1986)
max. UHI intensity	impermeable surface, population	
UHI intensity	cloudiness, wind speed, temperature, humidity mixing ratio	*Goldreich* (1992)
surface UHI intensity	solar radiation, wind speed, cloudiness	*Chow et al.* (1994)
UHI intensity	built-up area, height, wind speed, time, temperature amplitude	*Kuttler et al.* (1996)

The aim of this paper was to determine quantitative influences of the urban surface factors on the patterns of urban-rural temperature differences at the time of the strongest development during the diurnal cycle in the whole period, as well as in the so-called heating and non-heating seasons.

STUDY AREA AND METHODS

Features of the study area, method of the measurements, data base, grid network, determination of the land-use features and their ratios are described in details in the paper which contains the results of the first part of our investigation (*Unger et al.*, 2001).

In order to assess the extent of the relationships between the maximum UHI intensity and various urban surface factors, multiple correlation and regression analyses were used. The selection of the parameters was based on their role in determining small-scale climate variations (*Adebayo*, 1987; *Oke*, 1987; *Golany*, 1996).

The selected urban parameters were percentage of built-up area (artifically covered surface - building, street, pavement, parking lot, etc.) and water surface by grid cells, as well as distance to the city centre (grid cell labelled C, see *Fig. 1*). This distance can be considered as an indicator of the location of a cell within the city. These three parameters are constants but not variables for the complete (one-year long) measurement period. However, in each cell their values vary from place to place within the city. They are constants temporally but variables spatially. Searching for statistical relationships, we will take into account that our parameters are at once variables and constants.

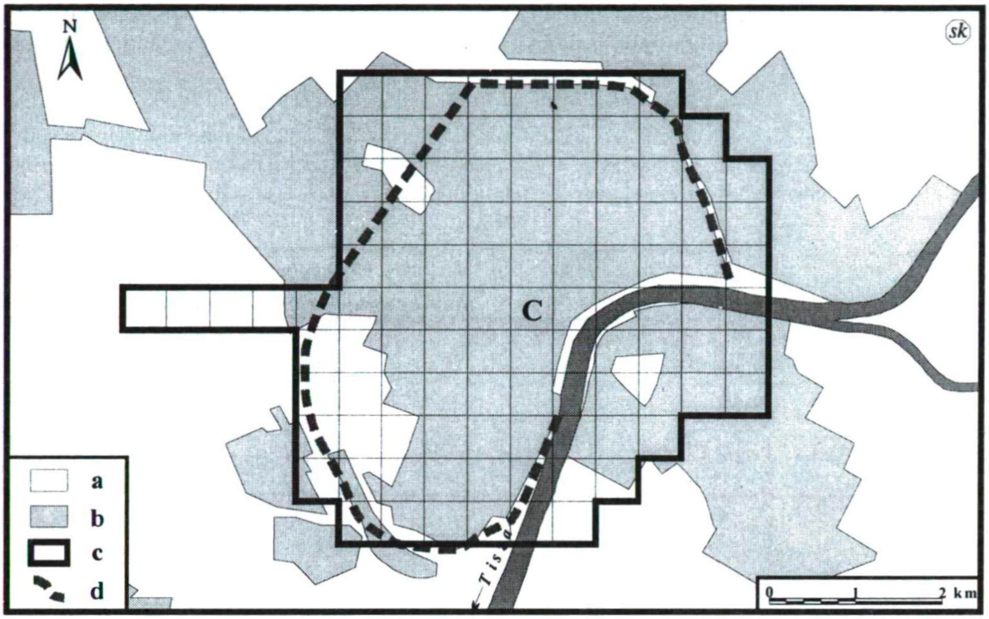

Fig. 1 Scheme of the urban area of Szeged and division of the study area into 0.5 km x 0.5 km grid cells (a: open land, b: urban area, c: border of the study area, d: circle dike). The central grid cell is indicated by C.

STATISTICAL RELATIONSHIPS

In this paper the one-year period, as well as the so-called heating (between 16 April and 15 October) and the non-heating (between 16 October and 15 April) seasons will be investigated.

In order to determine model equations for the maximum value of UHI intensity in the diurnal temperature course (ΔT) we use the earlier mentioned parameters (their labels are in brackets): distance from the central grid cell in km (D), ratio of built-up surface as a percentage (B) and ratio of water surface as a percentage (W). These parameters are variables spatially, namely by grid cells but constants temporally.

The bivariate analysis will be accurate if the total period averages of ΔT for each cell are correlated against each of the cell value of D, B and W, thus the time averages of the maximum UHI intensities vary by grid cells (the number of data pairs is $n = 107$).

Table 2 contains the results of the bivariate correlation analyses on ΔT against the urban surface parameters considered in this study. As the table shows, among the examined parameters D has the largest correlation coefficients ($r_{\Delta T,D}$). This fact support the establisment of *Unger et al.* (2001) on the regular concentric shapes of the UHI isotherms in szeged. The first two coefficients (D, B) are significant at 0.1% in all the three periods. The strong relationships between ΔT and D as well as B by periods can be seen also in the *Figs. 2, 3* and *4.* The ratio of water surface seems not to be important ($r_{\Delta T,W} < 0.06$ always, so it is not significant even at 10% level), for this reason it is not necessary to be used in the multiple regression equations. The explanation of this statistically insignificant role in the development of the maximum heat island in Szeged is that water surfaces can be found only in 39 grid cells from the total number of 107 and their ratio only a few percentage in most of the grids.

Table 2 Values of bivariate correlation coefficients between the average of maximum UHI intensity (ΔT) in °C and urban surface parameters (D - distance from the city centre in km, B - ratio of built-up area as a percentage and W - ratio of water surface as a percentage) by grid cells in different periods in Szeged (n = 107)

	March 1999 - February 2000		***16 April - 15 October (non-heating season)***		***16 October - 15 April (heating season)***	
Bivariate correlation coefficient (n = 107)	***Value***	***Significance level***	***Value***	***Significance level***	***Value***	***Significance level***
$r_{\Delta T,D}$	-0.837	0.1%	-0.861	0.1%	-0.760	0.1%
$r_{\Delta T,B}$	0.685	0.1%	0.675	0.1%	0.674	0.1%
$r_{\Delta T,W}$	0.044	-	0.056	-	0.020	-

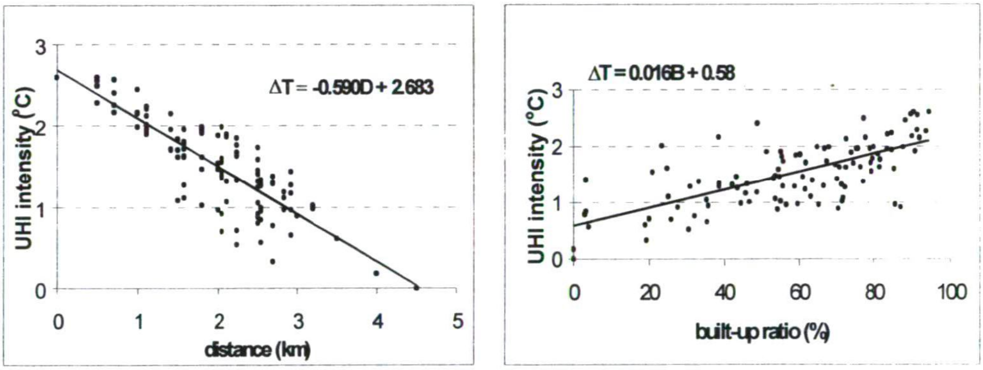

Fig. 2 Maximum UHI intensity (ΔT) as a function of the distance from the centre (D) and built-up ratio (B) with the best fit regression lines in the one-year period (March 1999 - February 2000) in Szeged

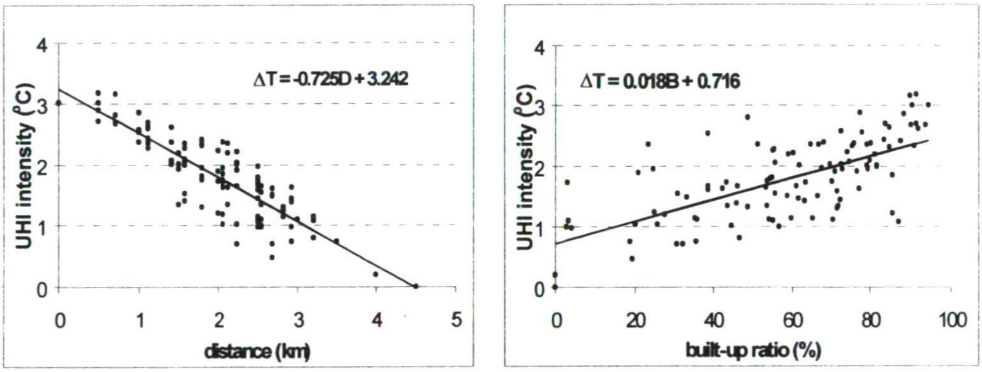

Fig. 3 Maximum UHI intensity (ΔT) as a function of the distance from the centre (D) and built-up ratio (B) with the best fit regression lines in the non-heating season (16 April - 15 October) in Szeged

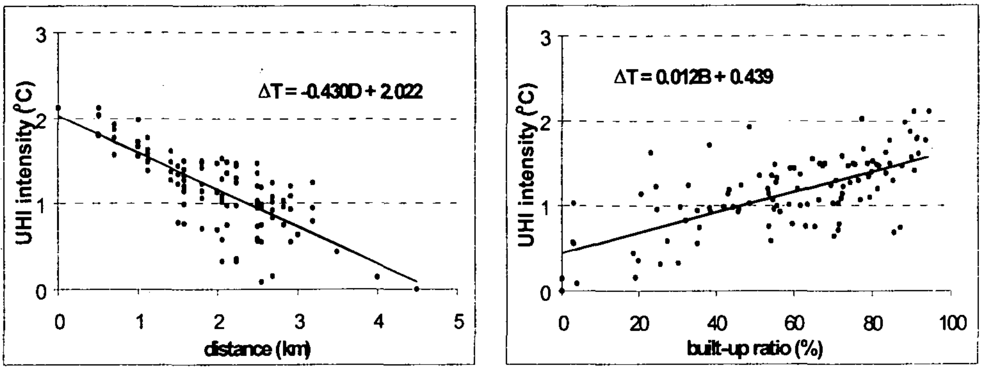

Fig. 4 Maximum UHI intensity (ΔT) as a function of the distance from the centre (D) and built-up ratio (B) with the best fit regression lines in the heating season (16 October - 15 April) in Szeged

The sequence of the parameters, entered in the multiple stepwise regression, was determined with the help of the magnitude of the bivariate correlation coefficients. *Table 3* contains the results of this stepwise regression on ΔT against the urban surface parameters in the three investigated periods. As the results show the distance from the city centre is most pronounced, but the role of the built-up density is also important. The improvements in the explanation caused by the entering of B, namely the differences as a percentage in the correlation coefficients in the fourth column of the table (Δr^2) of 6.8%, 5.3% and 8.9% cannot be neglected. The moderate large values of Δr^2 can be explained by the fact that D and B in a city structure are not entirely independent from each other.

Table 3 Values of the stepwise correlation of maximum UHI intensity (ΔT) and urban surface parameters by grid cells in different periods in Szeged (n = 107)

Period	*Parameter entered*	*Multiple* $\lvert r \rvert$	*Multiple* r^2	Δr^2
March 1999 - February 2000	*D*	0.837	0.701	0.000
	B	0.877	0.769	0.068
16 April - 15 October (non-heating season)	*D*	0.861	0.742	0.000
	B	0.892	0.795	0.053
16 October - 15 April (heating season)	*D*	0.760	0.577	0.000
	B	0.816	0.666	0.089

Referring to the investigated periods *Table 4* contains the model equations which describe ΔT in the best way. The absolute values of the multiple correlation coefficients (r) between the maximum UHI intensity and the parameters are 0.837 and 0.877 for the one-year period, 0.861 and 0.892 for the non-heating season and 0.760 and 0.861 for the heating season (they all are significant at 0.1% level) (*Tables 3* and *4*). The corresponding squares of these multiple correlation coefficients (r^2) provide explanations of 70.1% and 76.9%, of 74.2% and 79.5 and of 57.7% and 66.6% of the variance, respectively.

Table 4 Best fit model equations for the average of maximum UHI intensity (ΔT) using urban surface parameters in different periods in Szeged ($n = 107$)

Period	*Parameters*	*Multiple linear regression equations*	*Sig. level*
March 1999 - February 2000	D	$\Delta T = -0.590D + 2.683$	0.1%
	D, B	$\Delta T = -0.466D + 0.007B + 2.016$	0.1%
16 April - 15 October	D	$\Delta T = -0.725D + 3.242$	0.1%
	D, B	$\Delta T = -0.593D + 0.008B + 2.533$	0.1%
16 October - 15 April	D	$\Delta T = -0.430D + 2.022$	0.1%
	D, B	$\Delta T = -0.315D + 0.007B + 1.406$	0.1%

CONCLUSIONS

The results indicate that statistical type of modelling of spatial distribution of maximum urban heat island, based on urban surface factors, is an appropriate process. As the correlation coefficients of the parameters show, a short distance from the city centre and a high built-up ratio, which prevail mostly in the inner parts of the city, play important roles in the increment of the urban temperature.

Consequently, our preliminary results prove that the statistical approach which determines the behaviour of the UHI intensity in Szeged is promising and this fact urge us to make more detailed investigations. We are planning to extend this project by modelling urban thermal patterns as they are affected by weather conditions with a time lag. We intend to employ the same parameters used in this study, as well as additional urban and meteorological parameters, to predict the magnitude and spatial distribution of the maximum UHI intensity on the days characterised by any kind of weather conditions (apart from the ones with precipitation) at any time of the year without recourse to extra mobile measurements. These tasks require longer-term data sets, so we intend to gather data for a period of more than one year.

The results will be of practical use in predicting the pattern of energy consumption inside the city. They can be used to forecast and plan the energy demand, particularly in cold and warm periods of the year when energy consumption of heating and cooling, respectively, is highest.

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