ACTA CLIMATOLOGICA ET CHOROLOGICA
Universitatis Szegediensis, Tomus 42-43, 2009, 151-158

IMPACTS OF URBAN GREEN SPACES ON THE SPATIAL STRUCTURE OF THE URBAN HEAT ISLAND IN DEBRECEN AND DIFFERENT SIZED SETTLEMENTS IN ITS NEIGHBOURHOOD

S. SZEGEDI and R. GYARMATI

Department of Meteorology, University of Debrecen, P.O. Box 13, 4010 Debrecen, Hungary
E-mail: szegedis@puma.unideb.hu

Summary – Small and medium-sized towns located near the city of Debrecen in Eastern Hungary were chosen for the present study on the development of the urban heat island (UHI) and park cool island (PCI). Mobile techniques were used in order to get abundant comparable data for all settlements. Besides the UHI, the existence of a park cool island (PCI) has been proved in Debrecen. On the basis of the results, the spatial characteristics of the UHI are described in various settlements. Characteristic maximal UHI intensities have been determined for the typical built-up types of the different settlements. The impacts of urban green spaces on the temporal and spatial dynamics of the development of the UHI in Debrecen and in the different sized settlements in its neighbourhood were determined. Annual and seasonal mean maximal PCI intensities were calculated for Debrecen. The cooling effect of the park Nagyerdő was traced in its urban environment in Debrecen.

Key words: urban heat island (UHI), park cool island (PCI), mobile techniques, settlement size, green spaces

1. INTRODUCTION

The main reason for the development of thermal differences between the settlements and their environment – the urban heat island (UHI) – is that built-up areas have an energy budget different from that of natural surfaces. Settlement size and structure are important factors from the aspect of the development of the heat island (Oke 1973, Unger et al. 2006). The higher the ratio of artificial surface cover, the stronger the heat island develops in the urbanized spaces (Oke 1997). However, UHI intensities are lower in urban green areas than in their urbanized neighbourhood, since these areas are characterized by a close-to-natural surface cover that have an energy balance more similar to that of natural surfaces. The phenomenon is called Park Cool Island (PCI). PCI intensities are determined on the basis of the thermal difference between the city centre and the park (Sproken-Smith and Oke 1998, Bacci et al. 2000). The features of the green spaces (the height and spacing of plants, irrigation) determine the degree and temporal dynamics of the thermal differences between the green areas and the built-up surfaces. Besides parks there are other types of green areas (cemeteries, agricultural areas, meadows, sport fields etc.) that behave more or less the same way from the aspect of the development of the UHI. In smaller settlements these are the dominant types of green areas in the urban environment.

2. STUDY AREA AND METHODS

Of the numerous methods of urban climate examinations mobile techniques were used in order to get abundant comparable data for Debrecen and the settlements involved in the research. A digital thermometer was mounted on a car at a height of 180 cm. The thermometer had a thermal shield to eliminate radiant heat from the engine of the car. Data were recorded on a logit digital data logger; the sampling interval was set to 10 seconds.

The results of two measurement campaigns are presented here. The first campaign (32 territorial measurements in Debrecen) was carried out between April 2002 and March 2003. In the second campaign, the comparative UHI observations in Debrecen and in its neighbourhood 24 measurements were carried out between September 2003 and 2004.

The built-up inner area of Debrecen (over 25 km^2) was divided into grid cells of 500 by 500 meters and two routes were established in the Northern and Southern part of the city (Fig. 1) for the first campaign. In the second campaign cross sections with measurement sections characteristic for the built-up types of the settlements were selected (Fig. 2).

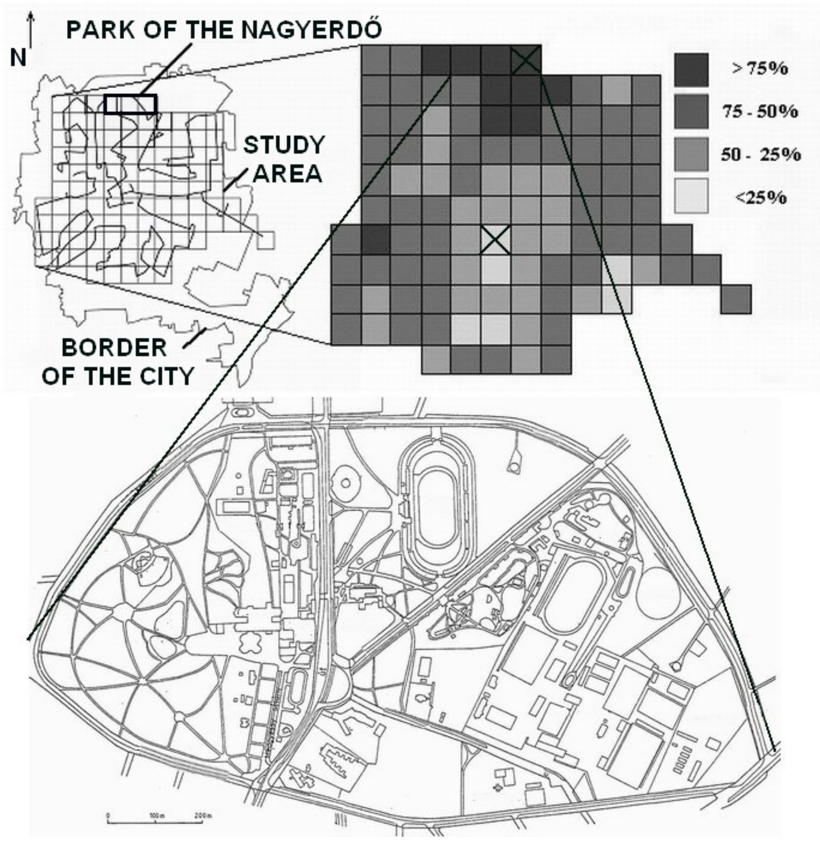


Fig. 1 The grid system with the two routes used during the first observation campaign and the location of the park of the Nagyerdő; the ratio of the green areas within the grid network. Grids in the city centre and the park used for the calculation of park cool island intensities are marked with exes

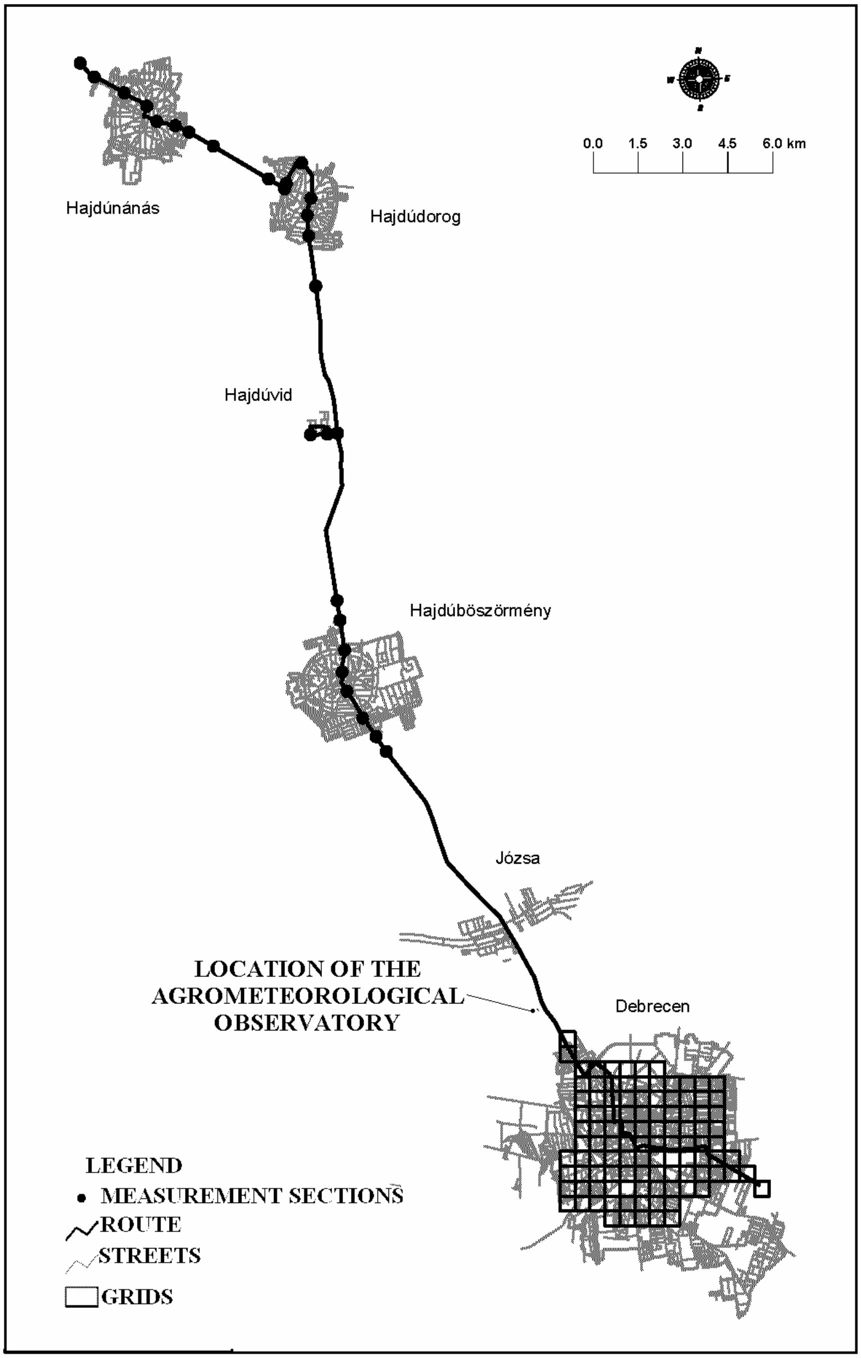


Fig. 2 The route of the second observation campaign with the settlements involved in the examinations; the grid system in Debrecen and the measurement sections in the other settlements

In Debrecen the ratio of the artificial surface cover is the highest and the average distance of the buildings is the shortest in the centre, but the highest buildings (highest H/W ratio) can be found in the housing estates. The structure of the city is rather inhomogeneous: houses with big gardens (the ratio of green areas is between 75-50%) are dominant in the eastern quarters, while the western sector is ruled by 10-14 storied blocks of flats in the housing estates. Another specialty is that there are no clear borders between the city and its environment: the density of the buildings decreases very gradually because spots of detached houses alternate with extensive green areas along the borders of the city.

The structure of the smaller settlements involved in the study are simpler than that of Debrecen. They have a rather regular circular structure, which is typical for the region. Only the smallest one has a regular quadrate structure. Only Hajdúdorog shows a bit irregular structure with an extensive, low-lying, wet green area near the centre, which makes its structure special from the aspect of development of the UHI. The studied settlements consist of peripheral green areas along their borders, vast areas of 1-2 storied houses with gardens and a relatively small centre with a ratio of green areas is about 50%. 3-4 storied blocks can only be found in the centres of the settlements.

An important problem was that measurements should be carried out in the same time in each grid. This is impossible using mobile techniques. The difference between the first and the last grid or measurement section is 90 minutes, which is a considerable time span from the aspect of the change of the temperature in the different parts of the cities. In order to get comparable temperature data during the measurements the cars visited each grid and measurement section twice: first on the way to the end of the route and the second time on the way back. This way we gained two temperature values for each grid and measurement section. Since on the way back the grids were visited in reversed order, calculating the averages for the grids and sections we gained values for the same time (the reference time). The reference time was four hours after sunset since according to the literature (Landsberg 1981a, 1981b) the heat island intensity reaches its maximum 3-5 hours after sunset.

UHI observations were carried out in ten-fourteen days intervals under various synoptic weather conditions (except rain, which eliminated the development of the UHI) in order to get information about the impact of the synoptic conditions on the development of the heat island.

International and Hungarian studies usually deal with metropolises and big cities; much less attention is paid to medium-size and small towns. For this reason the second campaign had focused on the development of the UHI in the typical-sized settlements in the Great Hungarian Plain (Table 1).

Table 1 Population of the settlements involved in the study (KSH 2003)

	Debrecen	Hajdúböszörmény	Hajdúnánás	Hajdúdorog	Hajdúvid
population	217.000	31.993	18.185	9.595	809

Wind speeds were measured at a height of 2 meters using anemometers, while wind directions were determined visually at the beginning, halfway and at the end of the route. Additionally, wind speed and wind direction datasets of the agrometeorological observatory of the University of Debrecen were used as well. Meteorological parameters of 72-hour-long periods before each measurement were also taken into account. Cloudiness also was determined using datasets of the agrometeorological observatory, located in the vicinity (500 meters) of the route between Debrecen and Hajdúböszörmény.

Datasets were processed using Excel for Windows; maps were made using Geomedia software.

3. RESULTS

On the basis of the results of the first measurement campaign the spatial characteristics of the UHI in Debrecen were determined first.

The mean maximal Urban Heat Island intensity was 2.3°C in the studied period. The spatial pattern of the UHI was basically determined by the structure of the city, while synoptic conditions had a strong impact on its intensities and air movements modified its shape (Fig. 3).

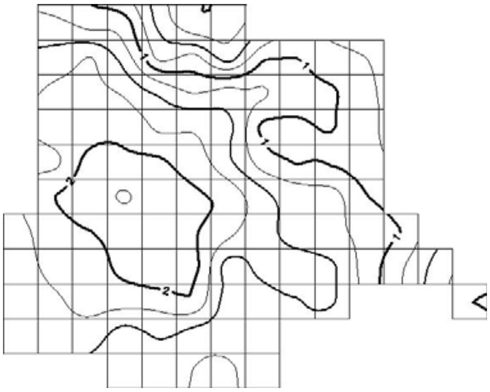


Fig. 3 The spatial structure of the UHI in Debrecen between April 2002 and March 2003. Intensities are in°C. (Szegedi and Kircsi 2003)

The highest UHI intensities should appear in the geometrical centre of the city. Instead of that, the structure is drifted south-westwards due to the prevailing northeastern wind directions and the special built-up characteristics of Debrecen with the dominance of high raised blocks of flats in the Western districts. Besides the city centre, housing estates and industrial areas, where the ratio of the vertical and horizontal active surfaces is high, are sub-centres of the UHI. Intensities increase gradually in the Eastern sector of the city towards the centre because the built-up density grows gradually as well. The steep horizontal temperature gradient called "cliff" is missing in that sector.

The park Nagyerdő in the north appears as a cool spot on the intensity maps (Fig. 3-5). The annual mean maximal intensity was around 0°C. The park makes its built-up environment cooler by 1-1.3°C on the average. The highest horizontal gradients (0.5°C/100 meters) were found there, namely the strongest "cliff" occurred in this part of the city. PCI intensities reached 1.9°C for the whole studied period (Table 2).

In the heating season the mean maximal UHI intensity was 2.1°C, which is lower than the annual mean and the non-heating season mean values. The reason for this is that in the winter period (especially in November and December) the cyclonic activity is strong in the Carpathian basin. North-eastern winds are less dominant in that period, which, on the other hand, results in more regular UHI structures. The city centre is the centre of the UHI, while housing estates and the industrial areas are sub-centres. The cool pool of the city is the forest Nagyerdő with intensities under 0°C on the annual average (Fig. 4).

In the non-heating season the mean maximal UHI intensity reached 2.5°C, which is higher than that of the whole period. The reason for this is that favourable radiation conditions in the summer play more important role in the formation of the UHI than anthropogenic heat input in the heating season. The south-westwards deformation of the UHI is stronger in the summer due to the prevailing 2-3 ms^{-1} north-eastern wind in the region of Debrecen (Fig. 5).

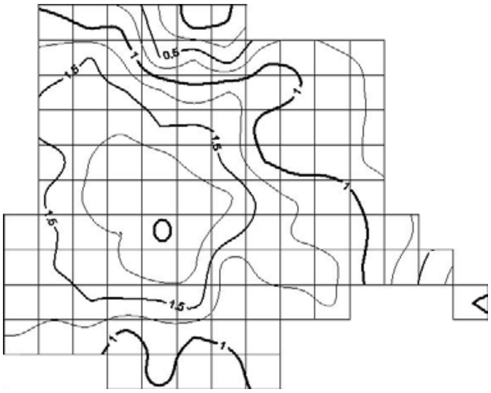


Fig. 4 Spatial structure of the UHI in Debrecen in the heating season. Intensities are in°C (Szegedi – Kircsi 2003)

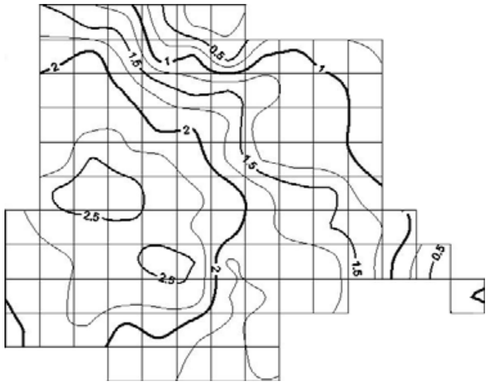


Fig. 5 Spatial structure of the UHI in Debrecen in the non heating season. Intensities are in°C (Szegedi – Kircsi 2003)

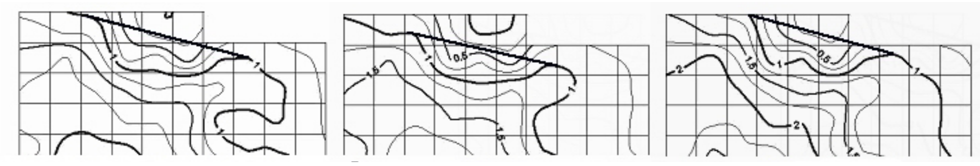
For the whole heating season the highest horizontal thermal gradients reached 0.2°C/100 m at the Nagyerdő (Table 2). The cold pool of the city was the park Nagyerdő with intensities around 0°C in the Northern grids. Weak PCI-s were found during the frequent weak UHI-s in the heating season: PCI intensities reached 1.8°C in that period. For instance, a PCI with an intensity of only 0.75°C was detected during a weak UHI with an intensity of 1°C (Table 2).

Table 2 Maximal and occasional maximal horizontal temperature gradients and park cool island intensities (in°C) at the park Nagyerdő for the whole second observation campaign, in the heating and non-heating season; under favourable (21 08 2003) and unfavourable (05 03 2003) conditions

	year	Non-heating season	Heating season	21 08 2002	05 03 2003
Horizontal temperature gradients (°C/100m)	0.20	0.20	0.20	0.50	0.10
PCI intensities (°C)	1.90	2.00	1.80	3.50	0.75

The coldest sector of the city was the park Nagyerdő again in the non-heating season, although it is less cold than the outer parts in that period. The diurnal course of temperatures is more even under the tree canopies (one active surface), since cooling rates in the night, which are responsible for the development of the UHI and PCI, are much lower there than in the open outer spaces (plough lands/grasslands). Therefore, in the non-heating season the park behaved more like the built-up area, there weren't any cases when intensities were under 0°C. In the coldest, northernmost grid cells that belong to the park Nagyerdő intensities under 0.3°C were observed. The maximal horizontal thermal gradient for the whole season was 0.1°C/100 m only, but it reached 0.5°C/100 m under favourable conditions (Table 2).

The spatial extent of the cooling effect of green spaces on the neighbouring built-up areas was examined as well. For this, the position of the 1°C isotherm was used for the whole studied period, the heating and the non-heating seasons (Fig. 6), because it shows the strongest break at the park Nagyerdő. Connecting the first and the final points of the arc of the break of the isotherm we can draw the line what the isotherm would take if there was not a green space. After that, the average distances between the two lines were measured on the three maps. The cooling effect could be traced within a distance of 300-500 meters.



a b c

Fig. 6 The real and the calculated position of the 1°C UHI intensity isotherm for the whole first observation campaign (a), the heating (b) and the non-heating seasons (c)

Stronger UHI-s caused stronger PCI-s in the non-heating season; weaker heat islands had weaker cooling effect in the heating season. The highest intensities reached 2.0°C (Table 2). There were no significant differences in the absolute PCI intensity maxima for the whole year, the heating and the non-heating seasons similarly to UHI intensities. However in one case (21 08 2002) when an UHI of 4.5°C was measured, a PCI of 3.5°C was observed under favourable synoptic conditions.

Results of the second measurement campaign made it possible to compare the development of the heat island in different sized settlements around Debrecen.

There are significant differences in the UHI intensities in the same built-up types of the different settlements (Table 3). Differences of the characteristic intensities between the settlements within the same built-up types increase from the peripheral areas towards the centres. Intensities in each settlement and each type are in strict correlation with the distance of the given built-up type area from the geometrical centre of the settlement, indirectly the size of the settlement and the decreasing ratio of green areas towards the centre. It shows the complex impact of the settlement size, built-up structure and green areas on the development of the UHI.

Table 3 Characteristic UHI intensities (°C) of the built up types of the different sized settlements

Built up type	Debrecen	Hajdúböszörmény	Hajdúnánás	Hajdúdorog	Hajdúvid
Peripheral	0.3-0.5	0.4-0.5	0.1-0.4	0.1	0
Houses with gardens	0.7-1.3	0.7-0.8	0.4-0.6	0.1	-
Green areas	1.3	-	-	0.1	-
Blocks of flats	2.3-1.7	-	-	-	-
High raised blocks of flats	1.3-2.3	-	-	-	-
Industrial areas	1.3-1.5	0.3-0.5	0.4	-	-
Centre of the settlements	2.5	0.9	0.7	0.2	0.1

The built-up structure of the smaller settlements is rather uniform with the dominance of houses with large gardens; the ratio of green areas is over 50%. Higher buildings are characteristic for the centres of the settlements only. On the one hand there are no sectors that could be identified as green areas with the exception of Hajdúdorog. On the other hand the decrease of the spatial extent of green spaces from over 75% to 50% from the outskirts towards the centre is one of the governing factors of the development of the heat island in those settlements.

The maximal UHI intensities in the different settlements are most strongly determined by the size of the settlements. Beyond these similarities the shape of the intensity curves is characteristic for each settlement, originating from the characteristic spatial distribution of the built-up types within the settlements. For example the drop of the curve near the centre of Hajdúdorog is due to a vast green area (meadow) close to the centre of that town.

4. CONCLUSIONS

The most important conclusions of the observations on the impact of the green spaces on the development of the UHI in Debrecen and the neighbouring settlements can be summarized as follows:

- Beside the UHI, existence of the park cool island (PCI) has been proved in Debrecen.
- Annual mean maximal PCI intensities reached 1.9°C, in other words, the park Nagyerdő was cooler than its urban environment by 2°C on the average during the measurements.
- Mean maximal PCI intensities reached 1.8°C in the heating season and 2.0°C in the non-heating season, which are close to each other, but under favourable conditions PCI intensities reached 3.5°C.
- Mean maximal horizontal thermal gradients for the whole year, the heating and the non-heating seasons were 0.1°C/100 m, but they reached 0.5°C/100 m in the case of strong UHI-s.
- The cooling effect of the park could be traced within a distance of 300-500 meters in its urban environment.

Acknowledgements – The authors thank the National Scientific Research Foundation for its support. The research was supported by the program OTKA T/034161 and K-68248. The work of the first author was also supported by the Bólyai János Scholarship of the Hungarian Academy of Sciences (BO/00047/02).

REFERENCES

Bacci L, Morabito M, Rapi B, Battista P (2000) Analysis of urban heat island in the Florentine area (Italy) and application of different biometeorological indexes. 3rd European Conference on Applied Climatology – Tools for the environment and man of the year 2000. CD-ROM

Központi Statisztikai Hivatal (2003) Hajdú-Bihar-megye statisztikai évkönyve 2003. [Statistical Yearbook of Hajdú-Bihar county 2003. (in Hungarian)]

Landsberg HE (1981) The Urban Climate. Academic Press, New York–London–Toronto–Sydney–San Francisco. 83-126

Oke TR (1973) City size and the urban heat island. Atm Environ 7:769-779

Oke TR (1997) Urban climates and global environmental change. In: Thompson RD and Perry A (eds) Applied climatology. Routledge, London–New York. 273-287

Spronken-Smith RA, Oke TR (1998) The thermal regime of urban park sin two cities with different summer climates. Int J Remote Sens 19(11):2085-2104

Szegedi S, Kircsi A. (2003) The Development of the Urban Heat Island under Various Weather Conditions in Debrecen, Hungary. In: Klysik K, Oke TR, Fortuniak K, Grimmond CSB, Wibig J (eds) Proceed. ICUC-5. Lodz, Poland. Vol 1:139-142

Unger J, Balázs B, Sümeghy Z, Gál T (2006) Multiple variable model for estimating the maximum UHI using 2 and 3 dimensional surface parameters. In: Preprints ICUC-6. Göteborg, Sweden. 334-337