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THE DEVELOPMENT OF THE URBAN HEAT ISLAND STUDIED ON TEMPERATURE PROFILES IN DEBRECEN

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Összefoglalás – A városi hősziget kialakulásának folyamatát tanulmányoztuk Debrecenben hőmérsékleti profilok segítségével, a Szegedi Tudományegyetem Éghajlattani és Tájföldrajzi Tanszékének kutatóival közös vizsgálatok keretében. A város jellegzetes beépítési típusait átszelő keresztmetszet mentén személygépkocsira szerelt termométerrel, havi rendszerességgel folytattunk adatgyűjtést. A profilok évszakos jellegzetességeinek vizsgálata során megállapítottuk, hogy a nem fűtési félévben erősebb és szabályosabb profilok alakultak ki. Az átlagos hősziget-intenzitás éjszakai időbeli változására vonatkozó adatok szerint sajátos jellegzetesség a város belső részein mutatkozó másodlagos maximum és minimum az intenzitási görbe menetében. A belső területek beépítési típusaiban a görbék hasonló lefutásúak, csak az ingadozások amplitúdója tér el, míg a város külső lakóövezetében a profilok meglehetősen laposak, hiányoznak róluk a jellegzetes elemek.

Summary – The development of the urban heat island (UHI) was studied in Debrecen, Hungary using temperature profiles. Mobile temperature measurements were carried along a cross section of the city. The route crossed the typical built up units of the city. The seasonal characteristics of the profile were determined. It was found that in the non-heating season stronger and more regular profiles formed. The measurements provided information on the temporal changes of the mean heat island intensities. A special feature is the occurrence of a secondary minimum and a maximum on the profile. In the inner parts of the city the profiles are similar only the amplitudes of the intensities are different, while in the peripheral sectors quite flat profiles were found.

Key words: UHI, temperature profiles, mobile measurements, Debrecen, Hungary

INTRODUCTION

Debrecen (21°38' E, 47°38' N) lies at a height of 120 meters above the sea level on the nearly flat terrain of the Great Hungarian Plain (relief is less than 20 meters / 1 km), which is favorable for studying the development of the urban heat island. It is the second city of Hungary and has a population of 220,000. Debrecen is the cultural and economic center of the north-east region of the country.

In the development of the urban heat island the built-up characteristics of the cities play an important role (*Oke*, 1987; *Voogt and Oke*, 1997; *Unger et al.*, 2001a). The important factors are the ratio of the artificial surface cover, the average building height and distance of the buildings from the center. In Debrecen the ratio of the artificial surface cover is the highest and the average distance of the buildings is the shortest in the center, but the highest buildings cannot be found there but in the housing estates (*Fig. 1*). Another speciality is that in most places there are not clear borders between the city and its environment: the density of the buildings decreases very gradually because spots of

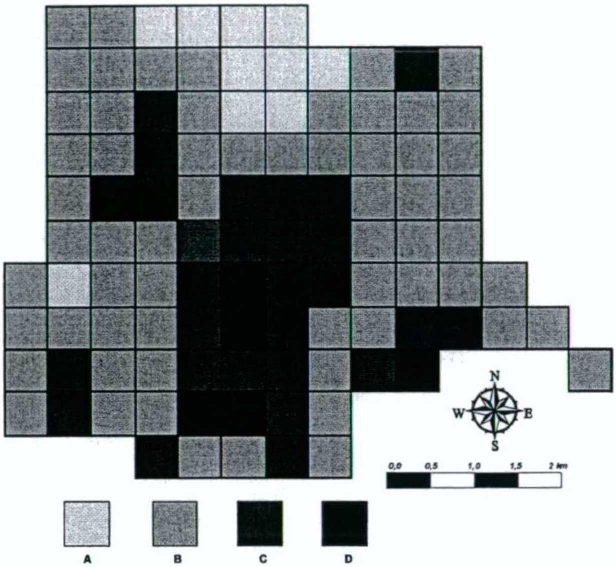

Fig. 1 Ratio of the artificial surface cover within the study area in percentage in Debrecen: **A**: <25% **B**: 25 – 50% **C**: 50 – 75% **D**: >75%

detached houses alternate with extensive green areas (e.g. the ex-Soviet airbase, sports-grounds and the forest of the "Nagyerdő") along the borders of the city.

METHODS

Measurements were carried out in monthly intervals under anticyclonic weather conditions in order to study the undisturbed process of the development of the urban heat island (*Unger et al.*, 2000; 2001b). The campaign began in April 2002 and finished in March 2003.

The area of the city was divided into 0.5 by 0.5 km grid squares (*Fig. 2*). Measurements were carried out along a cross-section of the city that crosses the characteristic land use and built-up types from the rural grasslands via the city center to the urban green areas. Grid No. 1829 is the rural reference area outside the city, where plough lands and grasslands can be found. Grids No. 1928, 1927, 2027, 2026, 2025 and 2125 belong to the low density residential areas, where detached houses with gardens (large ratio of close-to-natural surface cover) are dominant. Grids No. 2123 and 2124 are industrial areas. Grids No. 2122 and 2121 are high density residential areas, housing estates with 4-10 storey blocks of flats. The ratio of the artificial surface cover is over 50% there. Grids No. 2120 and 2220 belong to the city center. The ratio of the artificial surfaces is over 70%, but the buildings are only 3-4 storeys high.

Grids No. 2219, 2319, 2419 and 2519 are medium density residential areas. They are characterized by the alteration of 3-4 storey blocks of flats and spots of green areas. The ratio of the artificial surface cover is between 40 and 60%. In grid No. 2619 green areas are dominant: the forest of the "Nagyerdő" and the campus of the University of Debrecen is situated there. The ratio of the artificial surface cover is under 25%, while the ratio of the green areas is over 75% since in the absence of extensive water surfaces the ratio of the green areas can be interpreted as the inverse of the ratio of the artificial surface cover.

A digital thermometer was mounted on a car at a height of 160 cm. The sensor had a thermal shield to eliminate the radiant heat from the engine of the car. Data were recorded on a LogIT data logger with a sampling interval of 10 seconds. The datasets were processed using Excel for Windows; maps were made using Surfer for Windows softwares using the kriging interpolation technique.

An important problem is that measurements should be carried out in the same point of time in each grid. This is impossible using mobile techniques (*Conrads and van der Hage*, 1971). The sampling difference between the first and the last grid cell is 30 minutes, which is a considerable time span from the aspect of the temperature change in the different cells. For this reason in order to get comparable temperature data during the measurements we visited each grid two times: first on the way to the end of the route and second time on the way back. This way we gained two values for each cell. Since on the way back we visited the grids in reverse order calculating the averages for the grids we gained values for the same time (the reference time). In the non-heating season (16 April – 15 October) the measurements started in the hour of sunset and finished in the hour of dawn. In the heating season (16 October – 15 April) 10 measurements were carried out one night.

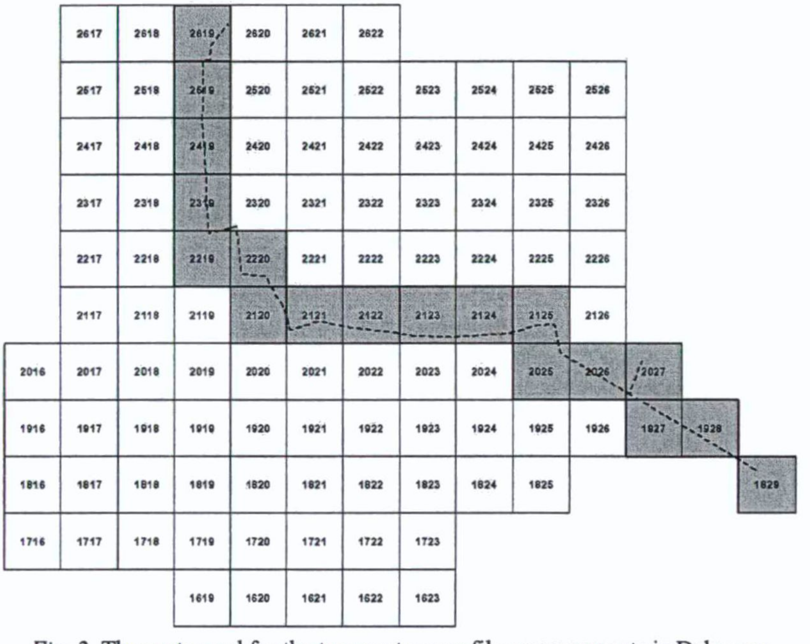

Fig. 2 The route used for the temperature profile measurements in Debrecen (April 2002 – March 2003)

RESULTS

In general, the shape of the profile follows the typical one described by *Oke* (1987) with the characteristic parts as: "cliff", "plateau" and "peak". Beside these features some special characteristics appear. The "cliff" forms only during the maximum development of the heat island between 3-6 hours after sunset, later the "cliff" and the "plateau" take the shape of a "slope". Beside the city center the housing estates and industrial areas are sub centers of the urban heat island. This is due to Debrecen's special built-up characteristics: patches of 6-15 storey buildings of the housing estates are scattered in traditional low or medium density residential areas. Low-density residential areas in the NE part of the city usually have medium intensities. The forest of the "Nagyerdő" is spreading into the city from the north. It is surrounded by medium density residential areas, the Clinics of Debrecen, sports-grounds and parks. It behaves like a "cold fringe": it is warmer than the rural countryside, but cooler than its urban environment.

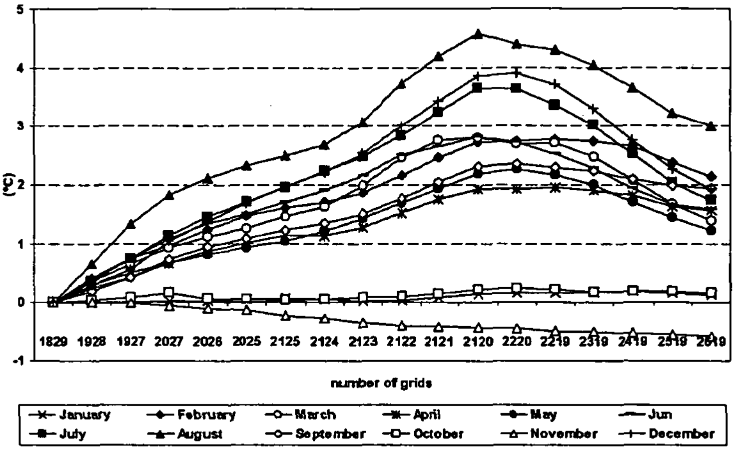

Fig. 3 Monthly changes of the UHI intensities during the temperature profile measurements in Debrecen (April 2002 – March 2003)

On annual average the mean intensity was 1.3°C and the maximum was 2.2°C. In the heating season the mean intensity was 1.0°C and the absolute maximum was 1.6°C. In the non-heating season 1.9°C was the mean intensity and 3.1°C was the maximum. The absolute maximum occurred in August with 2.9°C on the average and 4.6°C maximum intensity. It supports that the non-heating season is more favorable for the development of the urban heat island in Debrecen due to the prevailing anticyclone activity (clear skies and calmness) in that period. The weakest development was detected in November, when the average intensity was -0.3°C and the maximum was only 0.0°C. It was caused by the strong cyclone activity, which practically prevented the development of the heat island in that month in spite of the additional anthropogenic heat input.

In the non-heating season grid No. 2120, the geometrical center of the city was the warmest. In the heating season grid No. 2220 was another warm spot. This is due to the frequent southerly winds in the heating season. In the period between December and March the highest intensity was moving northward from the central grid and back. In the summer it stayed in the central grid and in the autumn it moved northward again (*Fig. 3*).

The highest intensities were found in the non-heating season (*Fig. 4*). Intensities are higher than in the case of the annual average and the heating season in each grid. The profile is the most regular in that season as well. The "cliff" is not very steep and is situated in grid No. 2027. The "plateau" between grids No. 2027 and 2123 ascends towards the peak with the exception of August. The "peak" is the most emphasized part of the profile in this season. It is situated in grid No. 2120 near the geometrical center of the city. In grids No. 2220, 2219, 2319, 2419 and 2519 from the city center towards the forest of the "Nagyerdő" there are relatively strong gradients despite that those grids are surrounded by medium density residential areas. Grid No. 2619 is in the forest, which is warmer than the reference grid by nearly 2.0°C and even the low density residential areas by 0.1-1.0°C, but cooler than the downtown by more than 1.0°C.

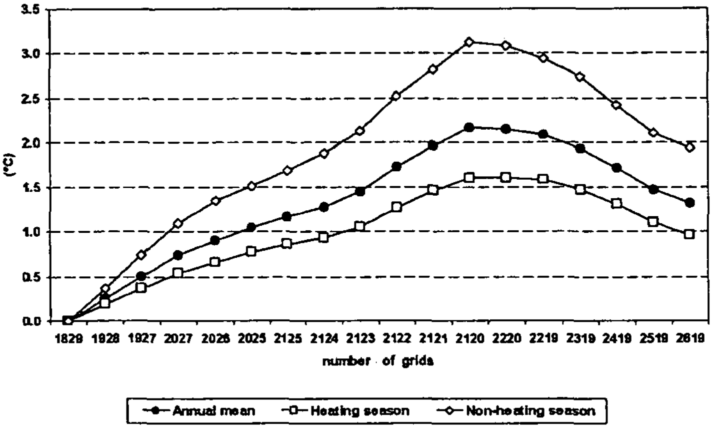

Fig. 4 Changes of the UHI intensities in the heating and non-heating season, and in the whole year during the temperature profile measurements in Debrecen (April 2002 – March 2003)

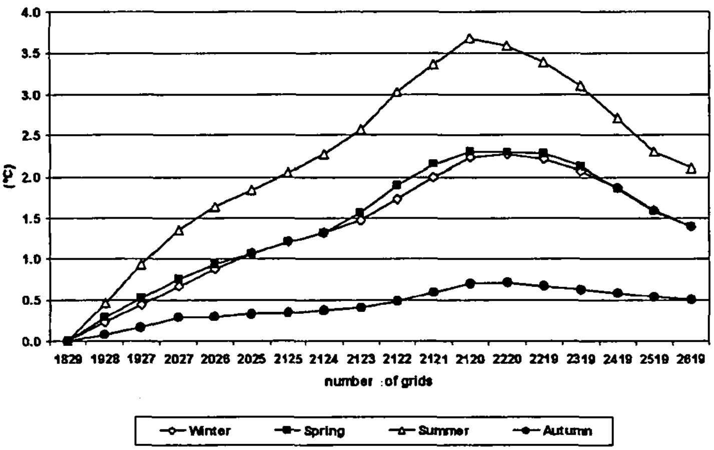

Fig. 5 Changes of the UHI intensities in the four seasons during the temperature profile measurements in Debrecen (April 2002 – March 2003)

In the heating season and in the whole year profile a very weak "cliff" can be found in grid No. 2027. As it can be seen in *Fig. 5*, in the autumn the profile is rather flat without any of its characteristic parts, while in the winter months stronger heat islands developed. The most clearly visible part of the profile in the whole year and in the heating season is the "plateau", which can be found between grids No. 2027 and 2123. In the profile of the whole year the "peak" is a bit more emphasized. In the heating season a flat "high plateau" lies between grids No. 2120, 2220 and 2219 in the place of the "peak".

This phenomenon is clearly visible in the winter and the spring profile as well (*Fig. 5*). The "slope" can be found between grids No. 2319, 2419 and 2519. The "weak relief" can be explained by the strong cyclone activity in the autumn on one hand. As it can be seen from *Fig. 3*, in October and November very flat profiles were detected. On the other hand, in December and February stronger heat islands developed (*Fig. 3*), but the characteristic parts were not emphasized. It was caused probably by the snow cover, which eliminated the horizontal active surfaces and this way only the vertical walls could play the role of the active surfaces. The spatial distribution of the vertical active surfaces is much more uniform in the grids from No. 2123 to 2519 than that of the horizontal active surfaces.

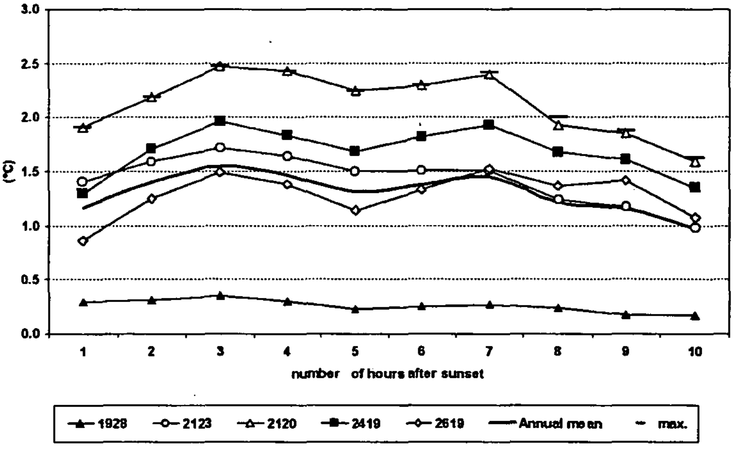

Fig. 6 The temporal changes of the annual mean UHI intensities in some typical grids of the profile during the night in Debrecen (April 2002 – March 2003)

Fig. 6 shows that the temporal changes of the annual mean intensities in each typical grid in point of view of land-use have two minima and maxima, only the amplitudes are different. There is a first order maximum is in the third hour after sunset and a second order one in the seventh hour. A second order minimum occurred in the fifth hour and the absolute minimum around dawn. The first order maximum is caused by the different cooling rates of the natural and artificial surfaces. The intensity minimum at 5 hours after sunset might be caused by the slight increase of the temperatures in the reference grid caused by the formation of dew, when the latent heat is released. Since dew formation is much weaker in the urban grids that process could cause the decreasing thermal difference between the urban grids and the reference grid. Intensities increased again due to the faster cooling in the reference grid at 7 hours after sunset. Intensities decreased as the thermal differences between the city and its environment diminished from 8 hours after sunset. The heat island became very weak but did not disappear around dawn. The amplitudes of the fluctuation are highest in the central grid (No. 2120) and in the high and medium density residential areas. In the peripheral grid No. 1928, which is characterized by houses with large gardens the profile is similar to the reference grid: intensities are low and the curve is very flat. The urban park forest of "Nagyerdő" (grid No. 2619) behaves more like other urban grids: intensities are lower than in any other inner grids but the shape of the curve is quite similar to those.

CONCLUSIONS

- The profile is best developed between 3-6 hours after sunset. In that time the "cliff", the "plateau" and the "peak" appear. Later the "cliff" disappears and the "slope" forms instead of the "plateau".
- The best profiles were found in the non-heating season, especially in August due to the prevailing anticyclonic weather conditions. In the heating season much weaker profiles were detected. In October, November and January rather flat profiles were found.
- There is a second order minimum of the intensities in the inner part of the city at 5 hours after sunset and a second order maximum at 7 hours after sunset. The second minimum is caused by the thermal excess in the reference grid due to the strong dew formation there, while the second intensity maximum can be interpreted as a consequence of the faster cooling outside the city in the second half of the night.
- The shape of the profile is quite similar in the inner parts of the city, even in the urban park forest, while in the outskirts the shape is rather flat.

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REFERENCES

Conrads, L.A. and van der Hage, J.C.H., 1971: A new method of air-temperature measurement in urban climatological studies. *Atmos. Environ. 5*, 629-635.

Oke, T.R., 1987: *Boundary layer climates.* Routledge, London - New York.

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

Unger, J., Bottyán, Z., Sümeghy, Z. and Gulyás, Á., 2000: Urban heat island development affected by urban surface factors. *Időjárás 104*, 253-268.

Unger, J., Sümeghy, Z. and Zoboki, J., 2001a: Temperature cross-section features in an urban area. *Atmos. Res. 58*, 117-127.

Unger, J., Sümeghy, Z., Gulyás, Á., Bottyán, Z. and Mucsi, L., 2001b: Land-use and meteorological aspects of the urban heat island. *Meteorol. Applications 8*, 189-194.

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