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EXAMINATIONS ON THE ROLE OF SYNOPTIC CONDITIONS IN URBAN HEAT ISLAND DEVELOPMENT IN DEBRECEN

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ABSTRACT:

Thermal differences between settlements and their rural environment called urban heat island (UHI) have a remarkable impact on heating and cooling energy demand of buildings. UHI intensities are determined by buildup characteristics of settlements and synoptic weather conditions. In the present study effects of synoptic conditions are traced in the case of the city of Debrecen in East Hungary. Debrecen is situated on a nearly flat terrain, without rivers and lakes, what is favorable from the aspect of UHI development. Mobile techniques were used in order to get abundant comparable data for the settlement. On the base of the results, spatial characteristics of UHI in the settlement are described. Critical values of wind speed and cloudiness, which eliminates the development of UHI, have been determined.

1. Introduction

UHI is produced by modifications in the energy balance of buildup areas due to the special thermal behavior of artificial building and surface cover materials (Landsberg, 1981; Oke, 1987). Heat island intensities are determined mainly by the size, population and buildup structure (height and density of buildings and green areas) of settlements (Oke, 1973; Unger et al., 2001; Fernandez et al., 2003). Synoptic conditions can help or hinder the development of UHI. Strong heat islands can develop under anticylonic weather conditions with clear skies and calm winds, while passage of atmospheric fronts can destroy heat islands or prevent their development (Szymanowski, 2003; Piotrowski, 2003). For this reason, synoptic conditions, especially frontal activity, cloudiness, wind directions and wind speeds were taken into consideration also as determinant factors (Sundborg, 1950).

2. Study area and methods

UHI measurements were carried out in the city of Debrecen (212 000 inhabitants) in the Eastern region of Hungary (Figure 1.). In Debrecen the ratio of the artificial surface cover is the highest and the average distance of the buildings is the shortest in the city center, but the tallest buildings (highest H/W ratio) cannot be found there but in the housing estates. For this reason housing estates can act as subcenters of UHI. The structure of the city is rather inhomogeneous: houses with big gardens 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 not 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. On the base of these special features UHI show a bit special form.

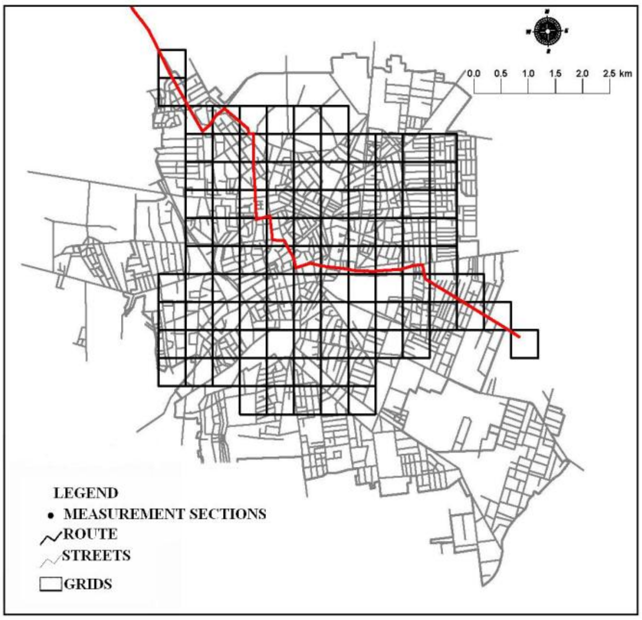

Fig. 1. The study area in Debrecen

Mobile techniques were used in order to get abundant comparable data on the spatial structure of the heat island. A digital thermometer was mounted on a car at a height of 170 cm (Unger et al., 2000). The thermometer had a thermal shield to eliminate the radiant heat from the engine of the car. Data were recorded on a digital data logger, the sampling interval was 10 seconds. In order to get comparable data for each measurement section the car visited each grid once on the way to the end of the rout and twice on the way back. This way we gained two values for each grid. Since on the way back we visited the grids in just the reversed order, calculating the averages for the grids we gained values for the same time (the reference time). 24 measurements were carried out during the measurement campaign. Synoptic conditions, low and high pressure systems, warm and cold fronts were taken into consideration as determinant factors as well.

Wind speeds were measured at a height of 2 meters using anemometers, while wind directions were determined visually at the beginning, the halfway and the end of the rout. Additionally, wind speed and wind direction datasets of the agrometeorological observatory of the University of Debrecen were used as well. Meteorological parameters of 72 hours before each measurement were taken into account also. Cloudiness was determined using datasets of the agrometeorological observatory as well.

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

3. Results and Discussion

Most of the 24 successful measurements were carried out under anticyclonic synoptic conditions, since strong frontal activity prevents the development of heat islands. However results show that in some cases 24-48 hours after a cold front with 10-15 mm of rain relatively strong heat islands developed in Debrecen. Different heat balance of the natural and artificial surfaces manifested more clearly under such circumstances. There were sharp drops in the intensity curves at the borders of those surface types. It means that fast moving cold fronts do not eliminate the development of UHI completely, but its intensity decreases. Slow moving warm fronts could eliminate the development of the UHI or could destroy a well developed UHI more effectively. During, or shortly after the passage of a strong warm front only weak heat islands were detected.

To trace the impact of cloudiness on the development of the UHI is rather complicated, because − with the exception of irradiative stratus (St) clouds – they usually appear in windy weather. From the cloud genera detected during the measurements St has proved to be most effective in preventing the formation of UHI. A St cover of 90-100% 12-20 hours before the measurements could completely eliminate the thermal differences between the natural and artificial surfaces. cirrus (Ci) type clouds had the weakest impact. In cases when favorable synoptic conditions prevailed within 48-72 hours before the measurements, but during the measurement cloudiness reached 50% strong UHI could not develop, while over 75% only weak UHI could form in Debrecen. Over 90% there were no heat islands found.

Wind speed had a strong impact on the strength of the heat island, while wind directions affected the shape merely. It was found that winds of 1-1.5 m/s (measured at a height of 2 meters) made intensity curves asymmetric as the heat island was pushed towards the lee side. In the case of stronger 2.5-3 m/s winds, Weak UHI could develop only. The intensity in such cases (2-3 °C) reached only about the half of the characteristic intensity for ideal circumstances. The shape was usually drifted strongly lee wards. Over a wind speed of 3 m/s at a height of 2 meters heat island could not develop in Debrecen.

Results emphasize the importance of the synoptic conditions of 2-3 day long periods before the measurements. Since artificial surfaces accumulate significant amounts of heat from one day to another, the development of a strong heat island is a several day long process. For this reason a short unfavorable weather event (e.g. a cold front without a heavy rainfall) can not eliminate completely a well developed heat island. On the other hand, after a 2-3 day long period of disadvantageous synoptic conditions, only medium intensities were found in the studied cases within a 24 hour long favorable period.

Table 1. UHI intensities in the heating season, the non-heating season, the whole studied period and the absolute maximum in Debrecen

Heating season	1.8 °C
Non heating season	3.1 °C
Whole studied period	2.4 °C
Absolute max.	4.5 °C

Figure 2. shows the mean maximal UHI intensities in Debrecen during the whole studied period, in heating and non-heating seasons and in a case, when weather conditions were favorable for the development of the UHI.

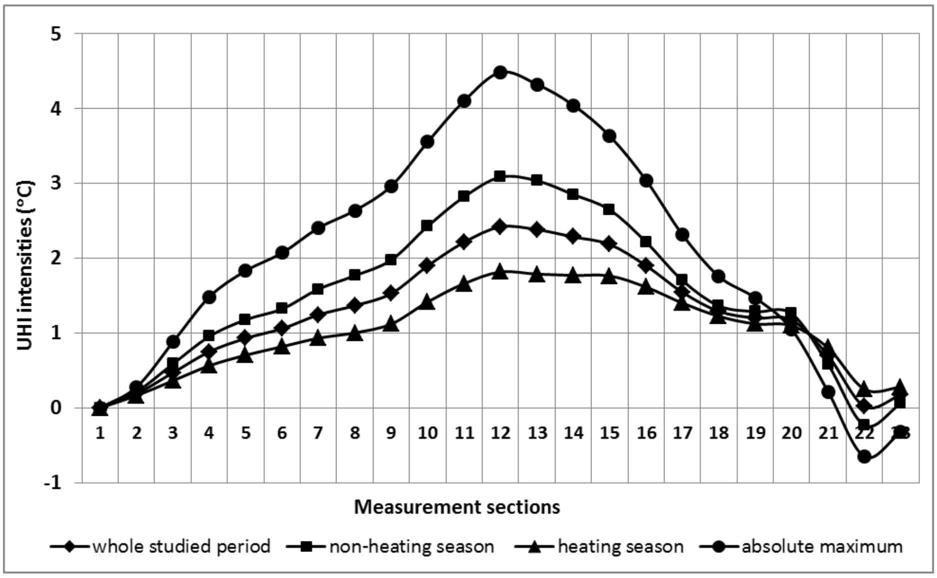

Fig. 2. Mean maximal UHI intensities in Debrecen

Intensity curves of Debrecen, are similar in the three periods and in the case of the absolute maximum (Figure 2.), only the amplitudes are different. Therefore the characteristics of the curves are independent from the seasons. There are clear differences between the heating and the non-heating seasons. Heat island intensities were 25-50% higher in that period, than in the heating season (Table 2.).

4. Conclusions

- Synoptic conditions have proved to have a determinant impact on the formation of the UHI.
- Slow moving warm fronts with thick cloud cover have proved to be more effective than fast moving cold fronts in preventing the formation of UHIs.

- Wind speeds and directions have a strong, combined impact on the intensity and shape of UHI, since wind pushes leeward the urban boundary layer what modifies the shape of the UHI remarkably.
- There are critical wind speeds, where the UHI gets deformed or the development of the heat island becomes impossible: winds of 1-1.5 m/s made intensity curves asymmetric; 2.5-3 m/s winds allowed the formation of weak UHIs only, while a wind speed of 3 m/s could completely eliminate the development of a heat island in Debrecen.
- Cloudiness during, and 24-72 hours before the measurements have a determinant effect on the intensity or the existence of UHI, since artificial surfaces accumulate significant amounts of heat from one day to another.
- Stratus type clouds have proved the most effective in preventing the formation of UHI, while Cirruses have the weakest effect. A stratus cover of 90-100% 12-20 hours before the measurements could completely eliminate the thermal differences between the natural and artificial surfaces.
- The non heating season proved to be more advantageous for development of UHI. Heat island intensities were 25-50% higher in that period, than in the heating season.

Acknowledgments

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