THE DEVELOPMENT OF THE URBAN HEAT ISLAND UNDER VARIOUS WEATHER CONDITIONS IN DEBRECEN, HUNGARY

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Abstract

In this paper the results of the examinations on the effects of various weather conditions on the development and spatial pattern of the urban heat island in Debrecen are presented. Measurements were carried out using mobile technique. Examinations proved the existence of the UHI in Debrecen. Under favorable conditions the heat island showed some unique spatial characteristics. Most regular heat islands developed in cases when Hungary was situated between weak high and low pressure systems. Under anticyclonic conditions strong heat islands formed, but their shape was usually deformed by the prevailing winds. Strong cyclonic activity eliminated the formation of the UHI, while under weak cyclonic activity regular, but weak heat islands developed.

Key words: Urban heat island (UHI), Mobile measurements, synoptic conditions.

1. INTRODUCTION

The UHI can develop only under favorable synoptic weather conditions. Anticyclonic conditions presumably are more advantageous for the formation of the heat island because of the undisturbed radiation. Wind can influence the form – or even "blow away" – the heat island. In this study we examine the role of the different synoptic conditions on the formation of the heat island in Debrecen.

Under favorable conditions the build up characteristics of the city govern the development of the urban heat island. The intensity is in close relationship with the size of the city (Oke, 1973) and its form is determined by the spatial pattern of the build up types.

2. THE STUDY AREA

Debrecen (21°31' East, 47°38' North) 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 Northeast region of the country.

In the development of the urban heat island the build up characteristics of the cities play an important role. The important factors are the ratio of the artificial surface cover and the average height and distance of the buildings. On the base of their special characteristics every city's heat island differs from the general scheme.

In Debrecen this specialty lies in that the structure of the city is irregular. In the Eastern sector, detached and semi detached houses with gardens are dominant; the ratio of the artificial surface cover is between 25 and 50% (Figure 1). Near the geometrical center of the city, in the downtown the ratio of the artificial surface cover is the highest (60-80%) and the average distance of the buildings is the shortest, but the highest buildings cannot be found there but in the housing estates. In the Western sector can be found the large housing estates of Debrecen with 10-14 storey buildings. The ratio of the artificial surface cover is not very high (40-60%), but there are the most extensive vertical active surfaces. Since the houses are built in N-S rows the distance of the buildings in that direction is minimal (only a few meters) they form quasi-homogenous active surfaces oriented to the East and West. In the N-S direction the imbalance is more visible than in the E-W direction (Figure 1). In the South there is the industrial belt of the city, where the ratio of the artificial surface cover is between 60 and 80%. On the other hand, in the Northern sector can be found the forest of the "Nagyerdő", which is the first nature conservation area of Hungary. Its urban part, which belongs to the study area, is an extensive urban park forest (1.75 km²) with sports-grounds, the stadium, the amusement park, the zoo, the clinics and the campus of the University of the city.

Another specialty 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 flakes of detached houses with gardens alternate with extensive green areas (the ex Soviet airbase, sporting grounds and the forest of the "Nagyerdő) along the borders of the city.

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3. METHODS

Measurements were carried out in ten days intervals under various synoptic weather conditions (except the 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. The campaign began in the April of 2002 and finished in the March of 2003.

The area of the city was divided into grids of 500 by 500 meters and two routes were established in the Northern and Southern part of the city (Figure 2). 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. The difference between the first and the last grid is 90 minutes, which is a considerable time span from the aspect of the change of the temperature in the different parts of the city. For this reason in order to get comparable temperature data during the measurements we visited each grid once on the way to the end of the route 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 reverse order calculating the averages for the grids we gained values for the same time (the reference time). The reference time was four hours after sunset since according to the literature (Landsberg, 1981b; Unger et al., 2001) the Heat Island intensity reaches its maximum 3-5 hours after sunset.

Digital thermometers were mounted on cars at a height of 160-170 cm. The thermometers had a thermal shield to eliminate the radiant heat from the cars engine. The data were recorded on a logit data logger, the sampling interval was 10 seconds. The datasets were processed using Excel for Windows maps were made using Surfer for Windows software using the kriging interpolation technique.

4. RESULTS

4.1 Spatial pattern of the UHI of Debrecen

Measurements have proved the existence of the heat island in Debrecen. The mean maximal Urban Heat Island intensity was 2.3 °C. The absolute maximal intensity in the studied period was 5.8 °C, which falls behind the values calculated using the Oke’s formula (6.6-6.7 °C) based on the population of the city (Oke, 1973).

The city center and the housing estates in the Western sector of the city belong to the center of the heat island (Figure 3). According to Oke’s terminology (Oke, 1987) the geometrical center of the city should appear as the “peak”, but here the peak is missing and the city center and its neighborhood takes the shape of a broad and very flat “plateau”. The special build up characteristics of Debrecen can explain this phenomenon: the buildings and consequently the ratio of the vertical active surfaces is not much higher in the city center than in its environment. The ratio of the artificial surfaces is high (70-80%) in the city center, but there are 4-5 story buildings. A belt of housing estates borders the city center of Debrecen from the West, where the ratio of artificial surface cover is still relatively high (over 50%), and there are large vertical active surfaces of the 10-14 story buildings (Figure 1).
4.2 Seasonal variability — the effect of the synoptic conditions

In the non-heating season the mean maximal UHI intensity reached 2.5°C, which is higher than that of the whole period (figure 4). It proves that in Debrecen in the non-heating season stronger heat islands develop than in the heating season. The reason for this is that in the summer the high pressure system over the subtropical waters of the Atlantic governs the weather of Hungary except June. The radiation conditions are favorable for the formation of the UHI. The high pressure center cause a Northern air flow in the Carpathian Basin, which is altered by the relief to NE direction in the region of Debrecen. The wind speeds usually are between 2-5 m/s.

The absolute maximum was 5.8°C what was the highest value within the whole studied period. Under anticyclonic conditions strong heat islands developed but the shape often were deformed by the prevailing NE wind. Under such conditions the center of the heat island was drifted southwestward. This situation can clearly be seen in Figure 5. The heat island in that case developed under strong anticyclone activity: skies had been clear for more than a week with strong irradiance and NE winds blew with a speed of 3 m/s during the measurements. Under cyclonic conditions, when the sky was cloudy the intensities hardly exceeded 1°C.

Since anticyclone activity cause windy weather and cyclones bring clouds the most favorable conditions for the development of regular heat islands are those, when Hungary lies between weak high and low pressure systems. Such situation is presented in Figure 6. In that case a shallow low pressure system formed the weather in Western Europe, while a weak high pressure ridge was situated over the Baltic Sea and Poland. The isobaric gradient was weak; the weather was clear and calm. In that situation a strong UHI of 4.8°C developed. Its shape followed the build up pattern of the city: The geometrical center of the city was the primary center of the UHI, while the housing estates in the West and the industrial areas in the SE were the sub centers.
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 value (figure 7). The reason for this is that in the winter period (especially in November and December) the cyclonic activity is strong in the Carpathian basin due to the influence of the low pressure system of Iceland.

Strong heat islands developed under anticyclonic weather conditions with clear skies and weak NE winds (figure 8). The absolute maximum intensity in the central and in the South and SW grids reached 5.5 °C which is not significantly lower than that in the heating season. In the Northern part intensities were usually under 4.0°C. From the aspect of the absolute maxima there is not a deep gap between the heating and non-heating season. When snow covered the ground and only vertical surfaces played the role of the active surfaces the spatial pattern was more uniform. Cloudy weather conditions prevented the development of the heat island only anthropogenic heat input generated weak heat islands of 1°C (figure 9). During frontal activity Western winds prevailed therefore the center of the UHI was pushed to the East. This situation is presented in figure 10.

In the spring under anticyclonic conditions clear skies combined with high wind velocities. Usually weak, asymmetric heat islands developed under such conditions (figure 11).

The autumn is not very windy in Debrecen, the wind velocity reaches its annual minimum, which is favorable for the development of strong heat islands. The weather was cloudy in 2002 therefore regular, but weak heat islands were formed usually in the autumn (figure 12).

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5. CONCLUSIONS

The mean maximal Urban Heat Island intensity was 2.3°C. The absolute maximal heat island intensity was 5.8 °C in the studied period in Debrecen. In the non-heating season stronger heat islands were detected than in the heating season, although there was not a significant difference between the absolute maxima of the two periods. The spatial pattern is primary determined by the build up characteristics of the city. The intensities are not much higher in the city center than in the housing estates and the industrial areas, which are sub centers of the heat island. The cool pole of the city is the forest of the Nagyerdő, which is cooler than its urban environment by 0.5-0.8 °C on the annual average. In the non-heating and the heating season as well strong heat islands developed under anticyclonic conditions, but their shape were usually deformed by the prevailing NE or W winds. Frontal activity connected to mid latitude cyclones usually prevented the formation of the heat island in both periods. The most regular heat islands developed in situations, when Hungary was situated between weak high and low pressure systems and the for this reason the isobaric gradient force was weak.

ACKNOLEDGEMENTS

The authors thank the National Scientific Research Foundation for its support. The research was supported by the program OTKA T/034161.

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