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EFFECTS OF THE SYNOPTIC CONDITIONS ON THE DEVELOPMENT OF THE URBAN HEAT ISLAND IN DEBRECEN, HUNGARY

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Összefoglalás – Cikkünkben a különböző nagytérségi időjárási helyzeteknek a hősziget kialakulására és térbeli szerkezetére gyakorolt hatását vizsgáljuk Debrecenben. A mobil méréseket gépkocsira szerelt műszerek segítségével hajtottuk végre. Az eredmények igazolták a hősziget meglétét Debrecenben. Kedvező körülmények között (anticiklonális helyzet, szélcsendes időjárás) a debreceni hősziget speciális jellegzetességeket mutatott. A legszabályosabb szerkezetű hőszigetek olyan esetekben alakultak ki, amikor Magyarország gyenge alacsony- és magasnyomású központok közt helyezkedett el. Anticiklonális helyzetekben erős hőszigetek fejlődtek ki, de az alakjuk rendszerint deformált volt az uralkodó szélirány szerint. Az erős ciklonális helyzetekben a hősziget nem jöhetett létre, míg gyenge ciklontevékenység esetén szabályos, de gyenge, 1ºC körüli intenzitású hőszigetek alakultak csak ki.

Summary – 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 (UHI) in Debrecen, Hungary are presented. Measurements were carried out using mobile technique with instruments that were mounted on cars. Examinations proved the existence of the UHI in Debrecen. Under favorable weather conditions (anticyclone activity, calm weather) 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 antycyclonic conditions strong heat islands formed, but their shape was usually deformed by the prevailing winds. Strong cyclone activity eliminated the formation of the UHI, while under weak cyclone activity regular, but weak heat islands of only about 1ºC developed.

Key words: UHI, mobile measurements, synoptic conditions, spatial distributions

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 built up characteristics of the city govern the development of the urban heat island (*Magee et al.*, 1999; *Runnals,* 1998). The intensity is in close relationship with the size of the city (*Oke*, 1973; *Feng and Petzold,* 1988) and its form is determined by the spatial pattern of the built up types.

THE STUDY AREA

Debrecen (21°31'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 (*Berényi*, 1930). 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.

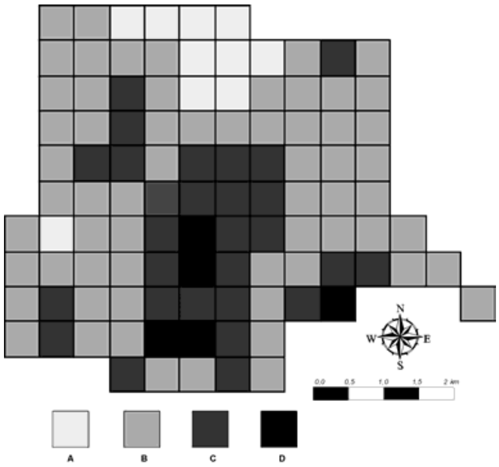

Fig. 1 Ratio of the artificial surface cover within the study area in percentage (**A**: <25% **B**: 25-50% **C**: 50-75% **D**: >75%)

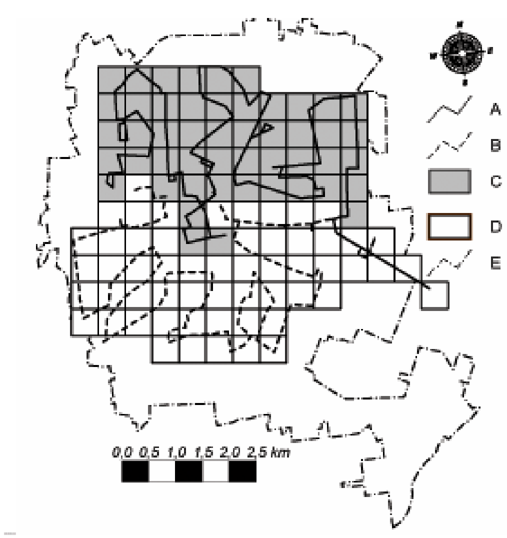

Fig. 2 Location of the study area in Debrecen. **A**: route of the measurement (north part), **B**: route of the measurement (south part), **C**: north part of the grid network, **D**: south part of the grid network, **E**: border of the city.

In the development of the urban heat island the built 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. Detached and semi detached houses with gardens are dominant in the Eastern sector, where the ratio of the artificial surface cover is between 25 and 50% (*Fig. 1*).

The ratio of the artificial surface cover is the highest (60-80%) and the average distance of the buildings is the shortest in the downtown near the geometrical center of the city, but the highest buildings cannot be found there but in the housing estates. The large housing estates of Debrecen with 10-14 storey buildings can be found in the Western sector. 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 and 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. The imbalance is more visible in the N-S direction than in the E-W direction (*Fig. 1*). The industrial belt of the city is in the Southern sector, where the ratio of the artificial surface cover is between 60 and 80%. On the other side, 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 km^2) 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 spots 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.

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 (*Unger et al.,* 2000). 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 (*Fig. 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 two times: first on the way to the end of the rout and the second time on the way back. This way we gained two temperature 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*, 1981a, 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 170 cm. The thermometers had a thermal shield to eliminate the radiant heat from the cars engine. Data were recorded on a Logit data logger, the sampling interval was 10 seconds. Datasets were processed using Excel for Windows, maps were made using Surfer for Windows softwares using the kriging interpolation technique.

RESULTS

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 2.3ºC. The absolute maximal intensity in the studied period was 5.8ºC, which falls behind the values calculated using the Oke’s formula (6.6-6.7ºC) based on the population of the city (*Oke*, 1973).

The city core and the housing estates in the western sector of the city belong to the center of the heat island (*Fig. 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 built-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 storey buildings. A belt of housing estates borders the 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 storey buildings (*Fig. 1*).

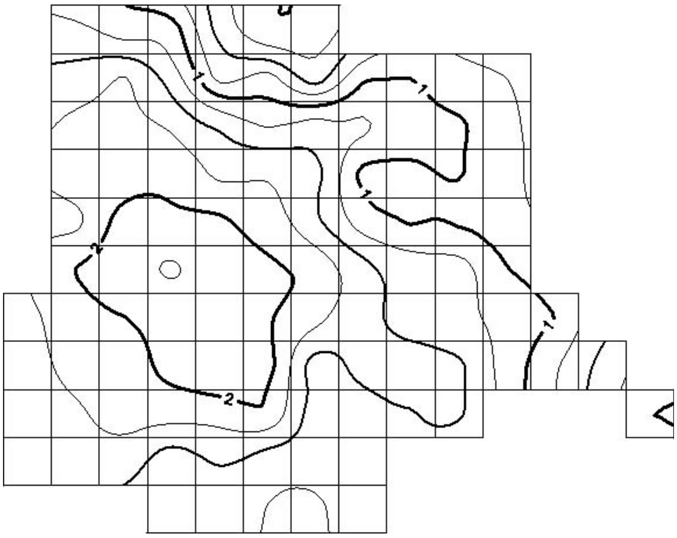

Fig. 3 Annual mean maximum UHI intensities in Debrecen (°C)

Intensities increase gradually in the Eastern sector of the city towards the center because the built up density grows gradually as well. The forest of the ”Nagyerdő” in the North is the coolest part of the city. The highest horizontal gradients (0.5°C/300 meters) were found there. This is in harmony with the spatial pattern of the natural and artificial surfaces. The ratio of the artificial surface cover is under 30% in the urban part of the forest of the ”Nagyerdő”. It is bordered by low intensity residential areas, the campus of the University of Debrecen and the clinics of the city. It is connected to the trunk of the forest outside the city in the North and for this reason it behaves like a cold fringe of that: it is cooler than its urban environment by 0.5-0.8ºC on annual average.

Seasonal variability – the effect of the synoptic conditions

In the non-heating season the mean maximal UHI intensity reached 2.5ºC, which is higher than that of the whole period (*Fig. 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 the high pressure system over the subtropical waters of the Atlantic governs the weather of Hungary in the summer 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 (*Justyák and Tar*, 1984). The wind speeds usually are between 2-5 ms^{-1}.

The absolute maximum was 5.8ºC 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 winds. Under such conditions the center of the heat island was drifted southwestward. This situation can clearly be seen in *Fig. 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 ms^{-1} during the measurements. Under cyclonic conditions, when the sky was cloudy the intensities hardly exceeded 1ºC.

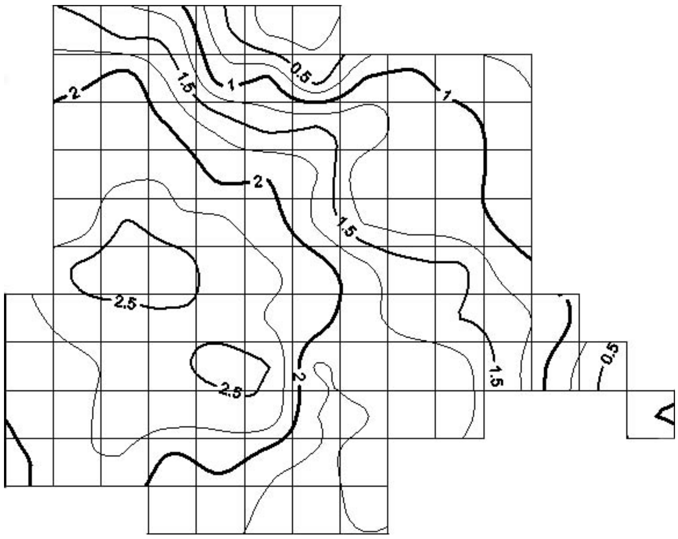

Fig. 4 Mean maximum UHI intensities in Debrecen (°C) in the non-heating season

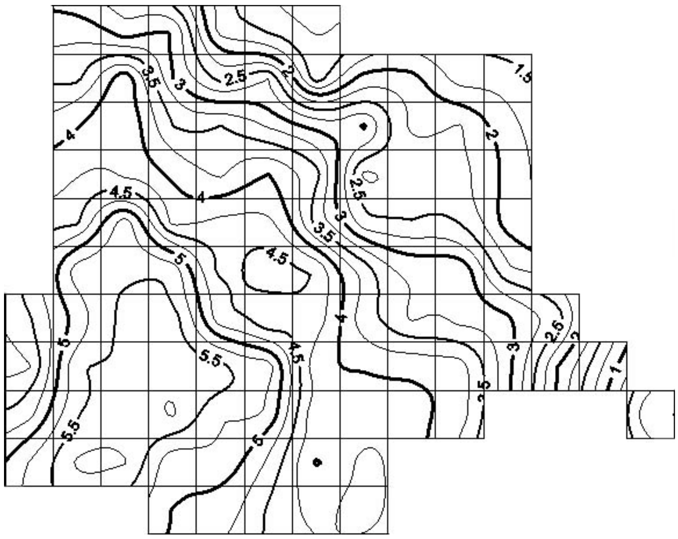

Fig. 5 The UHI intensitiy in Debrecen on 26 June 2002 (°C)

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 *Fig. 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 4.8ºC developed. Its shape followed the built-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.

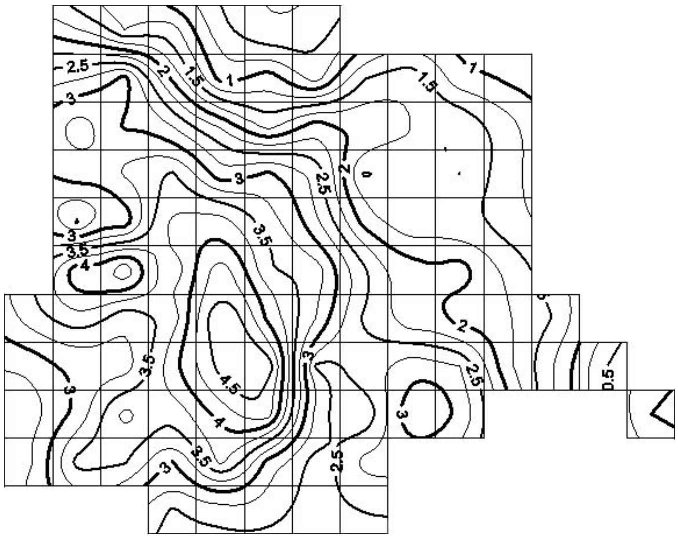

Fig. 6 The UHI intensity in Debrecen on 21 August 2002 (°C)

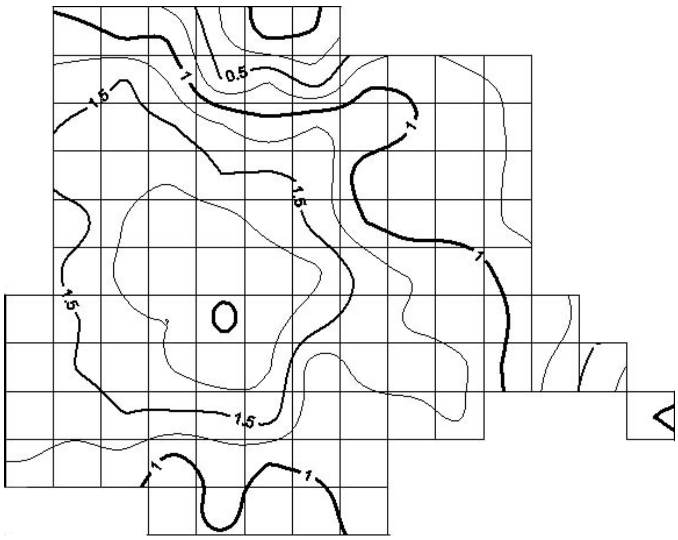

Fig. 7 Mean maximum UHI intensities in Debrecen (°C) in the heating season

In the heating season the mean maximal UHI intensity was 2.1ºC, which is lower than the annual mean and the non-heating season mean value (*Fig. 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.

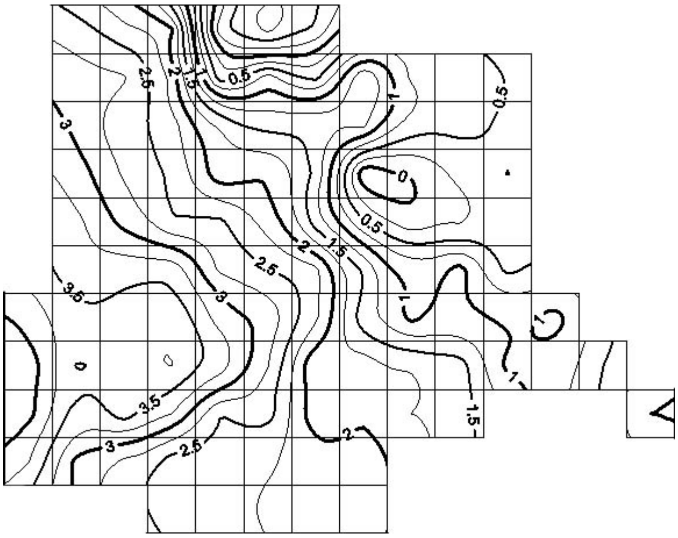

Fig. 8 The UHI intensity in Debrecen on 18 November 2002 (°C)

Strong heat islands developed under anticyclonic weather conditions with clear skies and weak NE winds (*Fig. 8*). The absolute maximum in the central and in the South and SW grids reached 5.5ºC which is not significantly lower than that in the heating season. In the Northern part intensities were usually under 4ºC. From the aspect of the absolute maxima there is not a deep gap between the heating and non-heating season.

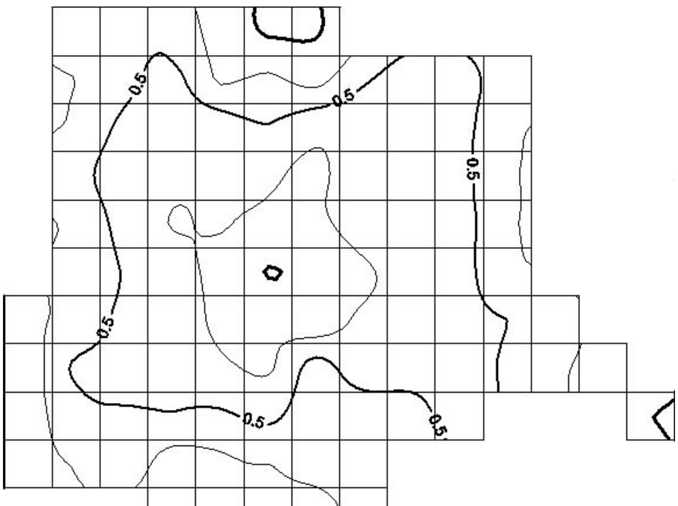

Fig. 9 The UHI intensity in Debrecen on 5 March 2003 (°C)

When snow covered the ground and only walls 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 1ºC (*Fig. 9*).

During frontal activity Western winds prevailed therefore the center of the UHI was pushed to the East. This situation is presented in *Fig. 10*.

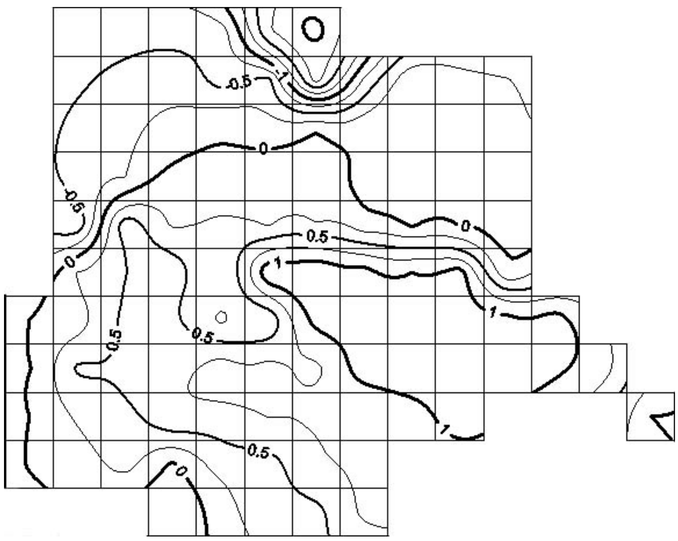

Fig. 10 The UHI intensity in Debrecen on 15 April 2002 (°C)

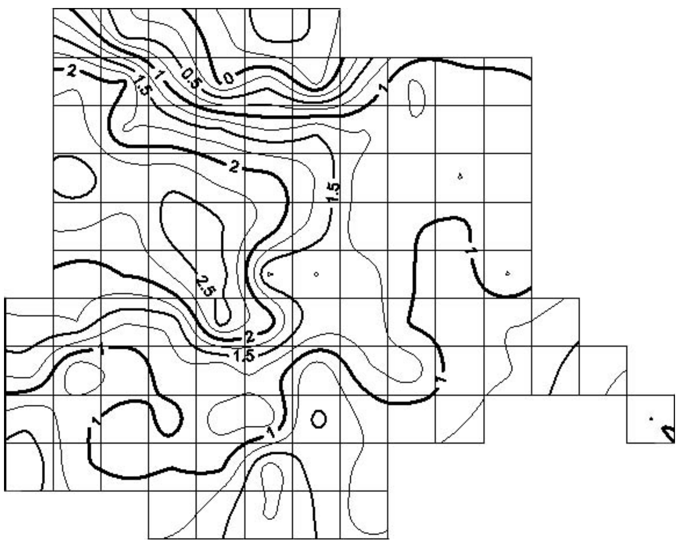

Fig. 11 The UHI intensity in Debrecen on 6 May 2002 (°C)

In the spring under anticyclone activity clear skies combined with high wind velocities. Usually weak, asymmetric heat islands developed under such conditions (*Fig. 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 (*Fig. 12*).

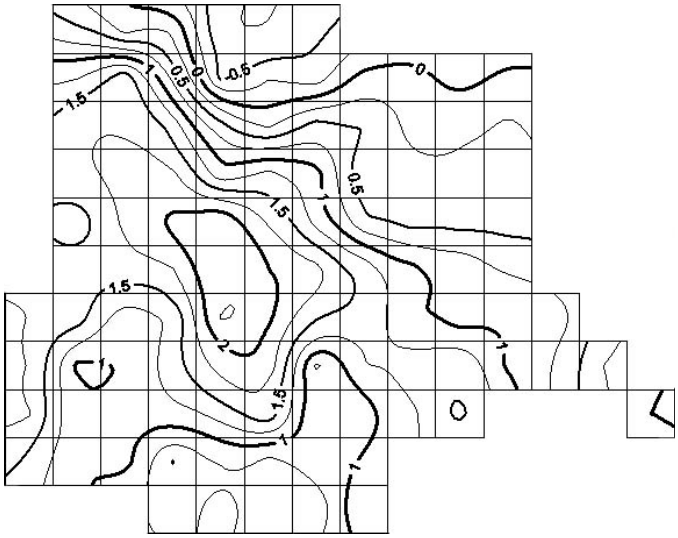

Fig. 12 The UHI intensity in Debrecen on 14 October 2002 (°C)

CONCLUSIONS

The mean maximum urban heat island intensity was 2.3ºC, while the absolute maximum heat island intensity was 5.8ºC 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 primarily determined by the built-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 0.5-0.8ºC on the annual average. In the non-heating and the heating season as well strong heat islands developed under anticyclonic conditions, but their shape was 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.

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