Environmental Engineering and Management Journal

November 2014, Vol.13, No. 11, 2805-2808
http://omicron.ch.tuiasi.ro/EEMJ/

"Gheorghe Asachi" Technical University of Iasi, Romania

ROLE OF URBAN MORPHOLOGY IN DEVELOPMENT OF THE THERMAL EXCESS IN THE CITY OF DEBRECEN, HUNGARY

Sándor Szegedi*, Tamás Tóth, István Lázár

University of Debrecen, Department of Meteorology, Debrecen, Hungary

Abstract

The thermal excess in a settlement compared to its rural environment is called urban heat island (UHI). It has a significant effect on human comfort in open urban spaces and indoor environment. UHI intensities (the thermal difference between the settlement and its close-to natural environment) are determined by buildup characteristics of settlements as static endowments and synoptic weather conditions as dynamic factors. Effects of build-up characteristics are traced in the case of the city of Debrecen in East Hungary, in the present study. Debrecen is located on a nearly flat terrain, without rivers and lakes, which are favorable conditions from the aspect of UHI development. Mobile techniques were used in order to get abundant comparable data on the characteristics of the UHI in the city. On the base of the results spatial characteristics of UHI in Debrecen are described. Characteristic maximal UHI intensities have been determined for typical urban morphological units of the city.

Key words: city morphology, mobile measurements, spatial structure, urban heat island

Received: February, 2014; Revised final: October, 2014; Accepted: October, 2014

1. Introduction

As a result of urbanization boom, approximately three billion people – nearly the half of the population of the World – live in cities at the beginning of the third millennium. The acceleration of urbanization has triggered widespread environmental problems. These adverse effects impact on a dynamically growing population directly with the growth of cities. Meteorological and climatological consequences are among the most important issues. The altered physical characteristics of the artificial urban surfaces and the change of chemical composition of the air in the cities lead to deterioration of air quality and changes of each meteorological element compared to areas outside cities.

The term "urban climate" refers to the unique local climate of the built-up urban spaces, significantly different from the climate in rural areas. The present work deals with one of the most remarkable phenomena of urban climate, the thermal excess in cities compared to rural countryside, called urban heat island (UHI). Potential UHI intensities (the maximal thermal difference between cities and their unbuilt environment) are determined by the size, population and build-up structure (ratio of non-evaporating surfaces, sky view factor etc.) of settlements mainly (Oke 1987, Krüger and Emmanuel 2013). It means that great cities with compact build-up structures generate stronger urban climate with more intense heat islands than small ones (Oke, 1973).

Heat island development has a special diurnal and annual course. UHI intensities reach their maxima 3-5 hours after sunset. Strongest heat islands develop in the late summer-early autumn or in the winter depending on climate zones and regions (Landsberg 1981, Vardoulakis et al. 2013). On the other hand, meteorological conditions – cloud cover,

* Author to whom all correspondence should be addressed: szegedi.sandor@science.unideb.hu

wind speeds and precipitation – have a determinant impact on the development of heat islands at a certain moment (Szegedi et al., 2013; Unger, 1996; Unger et al., 2001).

Main objective of the examinations presented here was to identify the most important features of the structure the UHI of Debrecen. On this base an attempt is made to determine characteristic UHI intensities in the various morphological types of Debrecen during the maximal development of the heat island.

2. Study area and methods

Since the aim of the research was to trace the spatial pattern of the maximal development urban heat island, only favorable conditions for heat island formation were taken into consideration during the campaign: measurements were carried out under anticyclone conditions with clear skies and calm weather. The area of the city was divided into grids of 500 by 500 meters.

Measurements were carried out along a cross-section of the city selected from the grid network established for the campaign. It crosses the characteristic land use and build-up types of Debrecen from the rural grasslands to the city center (Fig. 1). Units of the measurement rout that belong to different grids were identified as measurement sections. The city was divided into 7 morphological types: rural areas outside the city, low-, medium- and high density residential areas, industrial areas, public intitutions with large green areas and the city center. The measurement rout crosses some representative units of all types. From the numerous methods developed for urban climate examinations mobile techniques were used in order to get abundant comparable data for Debrecen. A digital thermometer was mounted on a car at a height of 170 cm. The thermometer had a thermal shield to eliminate radiant heat from the engine of the car. Data were recorded on a digital data logger; sampling interval was set to 10 seconds.

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 40 minutes, which is a considerable time span from the aspect of the change of the temperatures in the different parts of the city. 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.

As grids were visited in reversed order on the way back, we gained values for the same time (the reference time) by calculation of averages for the grids. The reference time was four hours after sunset, since according to the literature (Landsberg, 1981; Unger et al., 2001) the heat island intensity reaches its maximum between 3 and 5 hours after sunset.

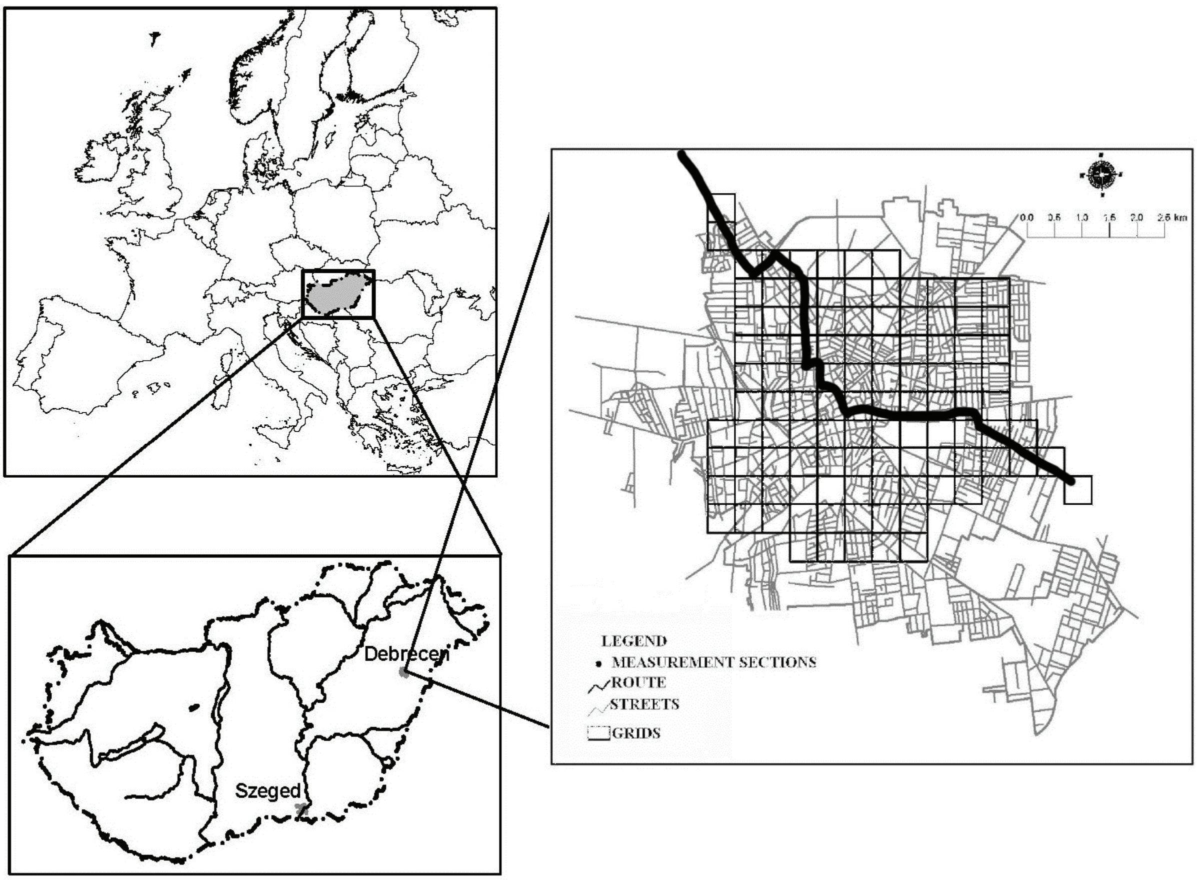

Fig. 1. Location of the study area with the grid network, the measurement rout and its sections

3. Results and discussion

The spatial pattern of the UHI in the case of Debrecen follows the typical cross-section described by Oke (1973) with characteristic parts of the profile as: “cliff”, “plateau” and “peak” in general. Beside these features some special characteristics appear (Fig. 2).

Measurement section 1 is the reference site. It is the Agrometeorological Observatory of the University of Debrecen. Temperatures measured there were subtracted from temperatures measured at urban measurement sites in order to gain UHI intensities instead of absolute temperatures. It is surrounded by a narrow forest strip and plough lands.

Section 2 is a rural area as well. Usually lower temperatures have been found there, since that section lies on the alluvium of a small creek “Tócó” in a very shallow valley at a height of 116 meters above the sea level, while site 1 and 3 lies 4 meters higher. It clearly shows the effect of relief on microclimate. Development of a cold air lake has been observed at site 2. Cold air moves downwards the slopes slowly and fills up the bottom of the valley, forming a “cold air lake” in nights when skies are clear and winds are mild. This feature forms a “valley” near the edge of the urbanized areas on the cross-section (Fig. 2). The phenomenon is well developed in the non-heating season especially, when undisturbed radiation conditions are more frequent.

Temperatures show a steep drop known as the urban “cliff” through the next two sites. Sites 3-4 are situated in a low density residential area with gardens, detached and semidetached houses. UHI intensities increase slowly forming a short “plateau” in this zone beyond the “cliff” (Fig. 2).

Measurement section 5 has the most complex environment since it is situated on the edge of different urban climate zones. It is located in a Public institution with large green areas, the UD main campus with sports grounds, parks and high buildings. It is surrounded at close quarters by a low density residential area, 1-2 storied houses with gardens, a medium density residential area, a housing estate with high raised blocks of flats and the close-to-natural forest of the “Nagyerdő”.

Sections 6-7 can be found in a medium density residential area with close to set houses and ratio of artificial surface cover around 50 %. Section 6 is the end of the “plateau”, while intensities increase fast in section 7. Section 8-11 represents an intensely developed high density residential area with 3-6 storey very close set buildings. The intensity curve is almost as steep as in the case of the “cliff” what is a consequence of the special build-up characteristics of Debrecen: patches of 6-14 storey buildings of housing estates are scattered in traditional low density residential areas. Section 12 is situated in the city center, an intensely developed urban area with high raised buildings and an artificial surface cover ratio over 90%. This section represents the “peak”, what is best developed in the non-heating season, while it is just the highest point of a “high plateau” in the whole year and the heating season (Fig. 2), since differences in the energy balance of the city center and high density residential areas develop most strongly in the non-heating season what makes the intensity curve around the “peak” steep. Sites 13-14 belong to an intensely developed high density residential area again with 3-6 storey very close set buildings. UHI intensities decrease fast with the increasing distance from the center via these sections. Sections 15-16 represent an industrial area with large low buildings but an artificial surface cover ratio over 50%. Section 15 is a breakpoint in the curve: UHI intensities decrease moderately from this section towards the edge of the city (Fig. 2). Sections 17-22 belongs to a low density residential area with gardens, detached and semidetached houses. Intensities decrease smoothly through these sections center because the build-up density decreases gradually as well. Section 23 is the end point of the rout. It can be found in a semi-rural agricultural area with scattered houses. The steep horizontal temperature gradient called “cliff” is very weakly developed in the “whole year” and the “non-heating season”, or even missing in the heating season in that sector.

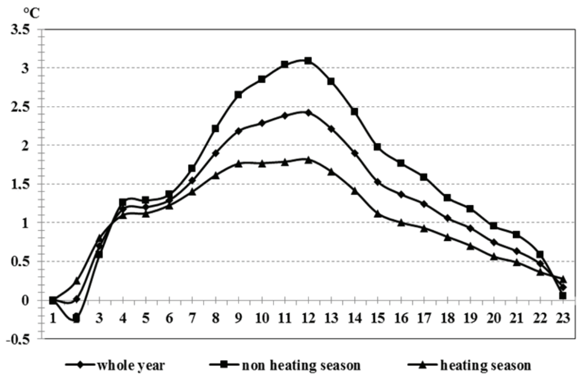

Fig. 2. Mean maximal UHI intensities in the heating- non-heating season and the whole studied period

The mean maximal Urban Heat Island intensity for the whole studied period was 2.4˚C. The spatial pattern of the UHI is determined by the structure of the city basically, while synoptic conditions have a strong impact on UHI intensities and air movements modify the shape. The absolute maximal heat island intensity was 5.8 ˚C in the non-heating season in Debrecen while in the heating season the absolute maximum reached 5.5 ˚C. Anyhow, there are significant differences in the conditions of the development and spatial structure of UHI between the two seasons.

Mean maximal UHI intensity was 1.8 °C in the heating season, which is lower than the annual mean and the non-heating season mean values. The reason for this is that cyclonic activity is strong in the Carpathian basin in the winter period (especially in

November and December). Northeastern winds are less dominant in that period what result in more regular UHI structures on the other hand.
Mean maximal UHI intensity reached 3.1 ˚C in the non-heating season, which is higher than that of the whole period. It proves that stronger heat islands develop in Debrecen in the non-heating season than in the heating season.

The reason for this is that favorable radiation conditions play more important role in the formation of the UHI in the summer than anthropogenic heat input in the heating season. The southwestward deformation of the UHI is stronger in the summer due to the prevailing 2-3 m/s Northeastern winds in the region of Debrecen.

There are significant differences in the UHI intensities in the urban morphological types of the city (Table 1). Characteristic UHI intensities of build-up types increase from the peripheral areas towards the center. Intensities in each type are in strict correlation with the distance of the given build-up unit from the geometrical center of the settlement (indirectly the size of the settlement). That shows the complex impact of the settlement size and build-up structure on the development of the UHI.

Table 1. Characteristic mean maximal UHI intensities of the urban morphological types of Debrecen

Urban morphological types	*UHI intensities*
Rural	0.0-0.3°C
Public institutions with large green areas	1.2°C
Low density residential	0.3-1.3°C
Industrial areas	1.2-1.6°C
Medium density residential	1.2-1.6°C
High density residential	1.7-2.3°C
City center	2.4°C

4. Conclusions

UHI intensity curves in the case of Debrecen show the general characteristics described by Oke ("cliff", "Plateau" and "peak"). Beyond these similarities they have some unique features as well. Due to the microclimatic effects of the relief the “valley” appears. The existence of urban “cliff” depends on whether the edge between rural and urbanized areas is sharp or it is not. It can be identified in places where a sudden change in buildup density and artificial surface cover ratio occurs.

UHI intensities grow gradually towards the city center in low density residential areas. This part of the curve appears as a “slope” instead of a “plateau” in the eastern sector of Debrecen, because of the gradual increase of build-up density and the large green areas along the borders of the city. The “cliff” is often missing in these areas.

Best developed UHI intensity curves were detected during the non-heating season probably because the different heat budget of the natural and artificial surfaces manifests under such circumstances more clearly.

It is noticeable that intensity curves of the “whole year” and “heating season” run together, but the winter curve is less steep at the most characteristic parts (the “cliff” and the slope of the “peak”). It can probably be explained by that during winter observations cloudiness and snow cover weakened the impacts of the differences in the surface cover of horizontal active surfaces on the energy balance of different areas, so intensities reflect the effects of anthropogenic heat emissions more strongly in that period. As a consequence, intensities increase parallel with the decreasing distance from the geometric center of the city.

There are characteristic mean maximal UHI intensities for each urban morphological type, what support our hypothesis that urban morphology has a basic impact on conditions of potential UHI development.

UHI intensities presented in table 1 are characteristic for the maximal development of the thermal excess in Debrecen. However, diurnal, heating-, non-heating season and annual mean UHI intensities are more informative from the aspect of heating/cooling energy demand. In order to gain such kind of UHI intensity time series we have launched continuous temperature measurements using automatic weather stations established in the urban morphological types of Debrecen.

Acknowledgements
The publication is supported by the TÁMOP-4.2.2.A-11/1/KONV-2012-0041 project. The project is co-financed by the European Union and the European Social Fund.

References

Landsberg H.E., (1981), *The Urban Climate*, Academic Press, New York-London-Toronto-Sydney, San Francisco.

Oke T.R., (1973), City size and the urban heat island, *Atmospheric Environment,* **7**, 769-779.

Oke T.R., (1987), *Boundary Layer Climates*, Routledge, London-New York.

Oke T.R., (2004), *Urban Observations*, World Meteorological Organization, IOM Report N_81, WMO/TD n_1250.

Szegedi S., Tóth T., Kapocska L., Gyarmati R., (2013), Examinations on the factors of urban heat island development in small and medium-sized towns in Hungary, *Carpathian Journal of Earth and Environmental Sciences,* **8**, 209-214.

Unger J., (1996), Heat island intensity with different meteorological conditions in a medium-sized town: Szeged, Hungary, *Theoretical and Applied Climatology,* **54**, 147-151.

Unger J., Sumeghy Z., Gulyas A., Bottyan Z., Mucsi L., (2001), Land-use and meteorological aspects of the urban heat island, *Meteorological Applications,* **8**, 189-194.

Vardoulakis E., Karamanis D., Fotiadi A., Mihalakakou G., (2013), The urban heat island effect in a small Mediterranean city of high summer temperatures and cooling energy demands, *Solar Energy,* **94**, 128-144.