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URBAN-RURAL DIFFERENCE IN THE HEATING DEMAND AS A CONSEQUENCE OF THE HEAT ISLAND

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Összefoglalás – A tanulmány alapjául szolgáló adatbázist egy szegedi városi-külterületi állomáspár 1978-1980 közötti mérésadatai szolgáltatták. Az első rész szerint a város klímamódosító hatásával kapcsolatos eredmények nem csak a szigorúan vett 3 éves vizsgálati periódusra, hanem hosszabb időszakra is érvényesek. A Student t-próba egy speciális esetének alkalmazása alapján a területnek az említett 3 évre és az 1961-1990-es periódusra vonatkozó klímajellemzői között nincs jelentős különbség. A második rész a városi hősziget néhány következményével foglalkozik. Az eredmények szerint a hősziget kifejlődése csökkenti a fűtési napok (*HD*) számát és a fűtési fokszámot (*HDD*), így csökkenti a fűtési idény hosszát és a felhasznált energia mennyiségét is. A városi és külterületi *HD*-k és *HDD*-k havi átlagai szerint Szegeden 3 héttel megrövidül a fűtési szezon és a fő fűtési időszakban az energia igény 10%-kal alacsonyabb, mint a külterületen.

Summary – The database of this study was provided by an urban-rural meteorological station-pair in the period of 1978-1980 in Szeged, Hungary. The first part shows that the results, related to the climate-modifying effect of the city, aren't strictly related to these three years, but they can be extended to a longer period as well. The climatic characteristics of the region in the mentioned three years and the period of 1961-1990 do not show significant differences, which is certified by the application of a special case of the Student t-test. The second part deals with some consequences of the urban heat island. According to the results, the development of the heat island reduces the number of heating days (*HD*) and heating degree-days (*HDD*) thus it reduces the duration of the heating season and the quantity of energy consumption in the city. Monthly means of the urban and rural *HD*s and *HDD*s show that in Szeged the heating season is shorter by more than 3 weeks and the energy demand is about 10% lower than in the rural areas in the main heating season.

Key words: urban climate, time extension of results, heating days, heating degree-days.

1. INTRODUCTION

The modification of the natural surface, the release of artificial energy and polluting materials into of the atmosphere over the cities alter the radiation and energy balance in the urban environments. As a result, a peculiar local climate, the so-called urban climate, develops. Its most obvious manifestation is the urban heat island, which means that, compared to the surroundings, warmer areas appear within the settlements (e.g. *Kuttler*, 2005). This heat excess has lots of practical consequences, which may influence our everyday life.

Szeged is a medium-sized city which had a population of 178,000 in a built-up area of approximately 46 km^2 in the investigated years (*Péter*, 1981). It is situated in Southeastern Hungary (46°N, 20°E) at 79 m above sea level on a flat plain (*Fig. 1*), so orographical effects do not modify the local climate of the city. The climate of the region is temperate with a continental character (*Cf* type by Köppen's classification).

In the late 1970s, an urban station network was established in Szeged for three years between 1978 and 1980; temperature and humidity observations were carried out 3 or 4 times a day. The continuous urban climatological observations of 10 stations in the city provided the possibility to examine the urban climate of Szeged. While some earlier investigations related to this urban station network dealt with the characteristics of the urban heat island, air humidity and alterations of human comfort sensation in the city (e.g. *Unger*, 1992, 1996, 1999), the second part of this paper discusses some further features and consequences of the urban heat island in Szeged.

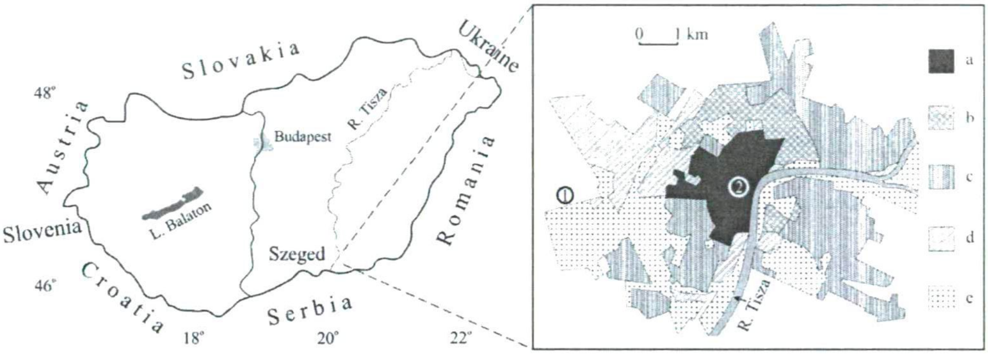

Fig. 1 Location of Szeged in Hungary, sites of rural (1) and urban (2) stations as well as built-up types of the city: a - centre (2-4-storey buildings), b - housing estates with prefabricated concrete slabs (5-10-storey buildings), c - detached houses (1-2-storey buildings), d - industrial areas, e - green areas

Moreover, it is also important to know whether the most significant climatic elements of these 3 years were characteristic for the climate conditions of the Szeged region. The aim of the first part of this study is to compare the climatic conditions (using the parameters such as temperature, vapour pressure, precipitation and wind speed) of these 3 years to a 30-year average (1961-1990) in order to demonstrate the possible deviations of the above-mentioned four climatic elements.

2. CLIMATOLOGY OF SZEGED AREA AND STATISTICAL COMPARISON

Tables 1, 2, 3 and *4* show the monthly and annual averages of temperature, vapour pressure, precipitation and wind speed in the Szeged region in the 3 years (1978-1980) of urban climate investigation and in the 30 years (1961-1990) which are relevant for the climate characterisation of the area using climatological normals.

Table 1 Monthly and annual averages of air temperature of Szeged (°C) (*CLINO*, 1996; *YHMS*, 1978-1980)

months	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*year*
1961-90	-1.8	0.9	5.6	11.1	16.2	19.2	20.8	20.2	16.5	11.0	5.1	0.6	10.5
1978-80	-2.2	1.2	6.7	9.2	14.8	19.5	19.2	19.3	15.6	10.4	3.8	1.8	10.0

Table 2 Monthly and annual averages of vapour pressure of Szeged (hPa) (*CLINO*, 1996; *YHMS*, 1978-1980)

months	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*year*
1961-90	5.0	5.6	6.9	8.9	12.3	15.1	16.0	15.8	13.2	9.8	7.6	5.8	10.1
1978-80	4.7	5.9	7.4	8.3	11.5	15.3	15.1	15	12.7	9.6	7.3	6.3	9.9

Table 3 Monthly and annual averages of precipitation of Szeged (mm) (*CLINO*, 1996; *YHMS*, 1978-1980)

months	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*year*
1961-90	29	25	29	41	51	72	50	57	34	26	41	40	495
1978-80	20	21	31	43	57	91	37	85	26	28	49	45	534

Table 4 Annual wind speed averages separated by directions in Szeged (ms^{-1}) (*CLINO*, 1996; *YHMS*, 1978-80)

directions	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WS	W	WNW	NW	NNW	N
1961-90	3.6	3.0	3.3	2.4	2.6	3.3	3.9	3.1	3.0	2.9	3.2	3.2	3.8	4.1	3.8	3.4
1978-80	3.4	3.0	2.6	2.5	2.8	3.2	3.8	3.2	2.8	2.7	2.7	3.1	3.6	4.0	3.6	3.2

In the comparison of the two (3 and 30-year long) databases, the traditional statistical methods could not be applied, because the first database is part of the second one.

In order to establish whether there is any significant change within a given time series of an optional climatic parameter, the Makra-test can be applied (*Tar et al.*, 2001; *Makra et al.*, 2002, 2004a, 2004b). The basic question of this test is whether significant difference can be revealed between the mean of an optional subsample of a given time series and the mean of the whole sample itself, namely that of the given time series. If the answer is yes (that is to say if there is significant difference between the two means), then it can be stated that significant change occurred in the climatic characteristics during the period given by the examined subsample of the whole time series.

The method itself is a special case of the Student t-test. Namely, it makes possible to determine if there is statistically significant difference between the expected values of not independent time series. The following probability variable was produced with $N(0;1)$ distribution:

$$\frac{\overline{M}-\overline{m}}{\sqrt{\frac{N-n}{N\cdot n}}\cdot\sigma}$$

for which $\overline{M}$ is the mean of the whole sample, $\overline{m}$ is the mean of the subsample, N is the number of the elements of the whole time series, n is the number of the elements in the subsample and σ is the standard deviation of the whole time series (it is supposed that the standard deviations of the subsample and the whole time series are equal). Now, from the table of the distribution function of the standard normal distribution an x_p value can be determined for a given $0 < p < 1$ number for which the following equation is true:

$$P\left(\left|\frac{\overline{M}-\overline{m}}{\sqrt{\frac{N-n}{N\cdot n}}\cdot\sigma}\right|>x_p\right)=p$$

If the absolute value of the above-mentioned probability variable with $N(0;1)$ distribution is higher than x_p then it is said that $\overline{M}$ and $\overline{m}$ differ significantly. The 0-hypothesis, according to which there is no difference between these two means, is fulfilled with a probability that is lower or equal to the critical p value. Being supported by this theoretical basis, significant difference can be revealed between the mean of an optional subsample of a given time series and the mean of the whole sample. This means that the period, that is to say the start and end, of the significant change of the examined climatic characteristics can be determined.

The above-mentioned statistical procedure was applied in this study, in order to detect if there was significant difference between the monthly and yearly mean temperatures of the period 1978-1980 and that of 1961-1990 (*Table 5*).

Table 5 Probability variables for determining the significance of differences between the mean temperatures of the whole samples (1961-1990) and the subsamples (1978-1980)

months	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*year*
pr.var.	0.22[1]	0.13[1]	0.84[1]	2.20[2]	1.79[1]	0.40[1]	2.45[2]	1.49[1]	0.94[1]	0.74[1]	1.07[1]	1.14[1]	1.39[1]

[1] not significant
[2] significant at 5% significance level.

According to *Table 5*, it can be stated that the monthly average temperatures of April and July in the period of 1978-1980 differ significantly from those of the whole period (1961-1990). For the whole year and the rest of the months there are no significant differences. According to these results, the above-mentioned short period (1978-1980) can be considered as a representative for characterizing the whole time series (1961-1990). Namely, statistical characteristics coming from the whole time series can be applied for the subsample as well.

3. DATA AND METHODS FOR THE APPLICATION

The location of Station 1 was nearly free from urban modifying effects (Aerological Observatory of the Hungarian Meteorological Service) and it was situated at a distance of 4.4 km west to the city centre. The urban stations represented, more or less, the different types of built-up areas. Among them Station 2 was considered to represent the central urban area (*Fig. 1*).

In this part of the study in order to compare the urban (Station 2) and rural (Station 1) thermal conditions between 1978 and 1980, daily mean temperatures have been used.

The development of the urban heat island has certain influence on the duration of the heating period and the quantity of heating energy consumption. For human comfort there is a need of space heating below a critical temperature level. The more extreme the conditions, the more energy is consumed. Winter conditions can be illustrated through the examination of the number of heating days and the heating degree-days. They are only functions of air temperature and a given critical threshold. The number of heating days (*HD*) is defined as the number of days, on which, according to Hungarian standards, the daily mean temperature (t_i) is below 12°C. The heating degree-days (*HDD*) are calculated by the following formula:

$$HDD = \sum (T - t_i)$$

where T is the required room air temperature (20°C) and the summing up refers to the heating days in a heating season. This method assumes that average space heating losses of buildings are proportional to average degree-days and it is used for estimating the energy demand of space heating in buildings (*Harrison et al.*, 1984; *Sailor*, 1998; *Livada et al.*, 2002). Cumulative degree-days are, thus, a direct indicator of the overall thermal climate for a heating season. The ratio of the energy consumption at two sites can be considered equal to the ratio of *HDD*s (*Probáld*, 1974; *Bründl and Höppe*, 1984; *Soule and Suckling*, 1995). It has also to be noted that the number of the heating days is a simpler approach to the climate differences instead of taking the heating degree-days into account, which reflect the amount of heating energy demand as a function of the mean daily temperature.

4. RESULTS AND DISCUSSION

The comparison of the monthly means of urban and rural *HD*s show that the heating season begins in October and lasts until May (*Fig. 2*). Except for the two coldest months (December and January), the monthly means of *HD* in the rural areas exceed those in urban areas and the differences are between 0.7 and 8.7 days in February and October, respectively. As a result, the heating season in the city is more than 3 weeks shorter than in rural areas.

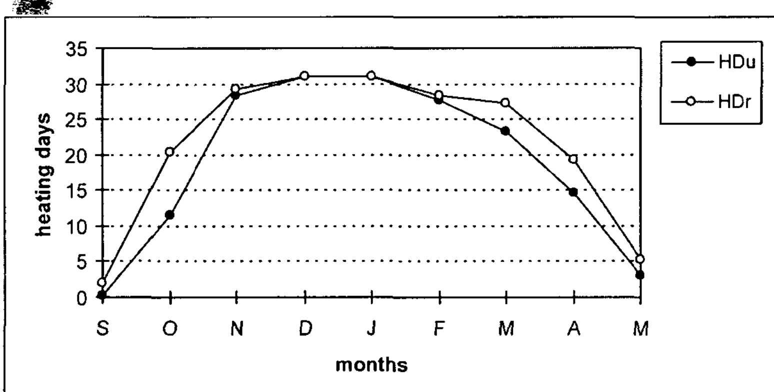

Fig. 2 Monthly mean numbers of urban (*HDu*) and rural (*HDr*) heating days in Szeged (1978-1980)

The heating degree-day is a more exact measure for the comparison of the heating energy consumption. According to *Fig. 3* the heating season characterized by significant heating demand begins in October and lasts until April with the highest values in January at both sites. The most significant difference appears in October (more than 100°C less in urban than in rural!). While in the coldest winter months the differences are only about 50°C, great differences occur in March and April (65°C and 80°C, respectively). Consequently, the decreasing effect of the city on the heating energy demand is stronger in the transitional months than in other periods of the heating season.

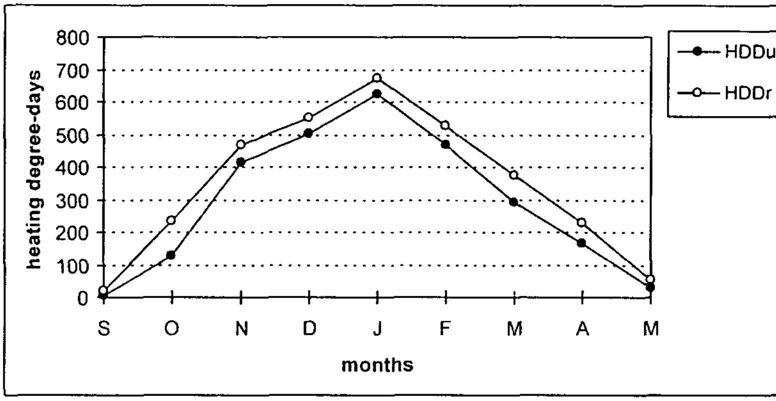

Fig. 3 Monthly means of the urban (*HDDu*) and rural (*HDDr*) heating degree-days (°C) in Szeged (1978-1980)

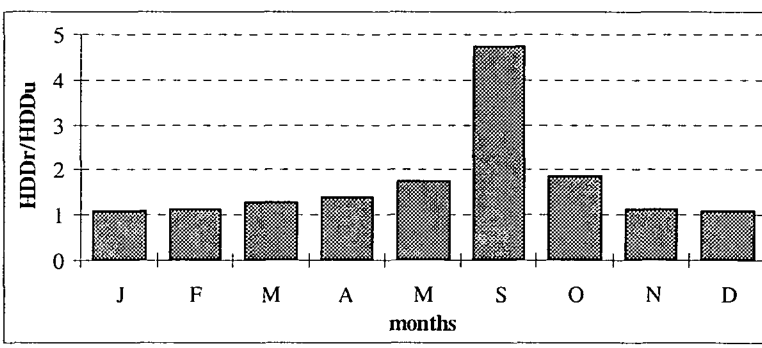

Fig. 4 Ratios of the monthly means of rural and urban heating degree-days (*HDDr/HDDu*) in the heating season in Szeged (1978-1980)

This establisment is supported by the ratios of the monthly means of rural and urban heating degree-days (*Fig. 4*). Except for the value of September (in this month the heating demand is insignificant at both sites, so the ratio is not important), the ratios fluctuate between 1.08 and 1.85 with a minimum in January and a maximum in October, respectively. Thus, in October, the heating energy demand is almost twice as much in rural areas as in the centre. In the winter months the ratios are about 1.1 which means that the energy demand in case of similar buildings is about 10% lower in the city centre than in rural areas in the main heating season. Considering the whole heating season, the difference is already 19%. This result is in good accordance with the values of similar investigations using the heating degree day method for estimation of urban-rural difference in heating demand: 12% in Budapest (*Probáld*, 1974), 20% in Tokyo (*Kawamura*, 1985), 30% in Athens (*Santamouris et al.*, 2001). This fact shows that the urban heating effect results very significant energy and cost savings even in the case of a medium-sized city like Szeged.

5. CONCLUSIONS

The climate modifying effect of the urban heat island in a medium-sized city located in the temperate climate region causes significant thermal alterations which are revealed by our simple measures. These alterations are mostly advantageous for the inhabitants because of the remarkable reduction of the heating season in the winter half year and the reduction of the quantity of heating energy demand in the city centre compared to the rural areas. Therefore, we may conclude that our results can provide useful information for the decision-makers of the local authorities and companies to handle the green areas and to plan the yearly heating energy supply in the urban area of Szeged.

Furthermore, our results about the urban modification effects are valid not only for the 3 years used in urban climatological investigation, but for a longer time period as well.

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