IDŐJÁRÁS
Quarterly Journal of the Hungarian Meteorological Service
Vol. 96, No. 4, October–December 1992

Diurnal and annual variation of the urban temperature surplus in Szeged, Hungary

J. Unger

Department of Climatology, József Attila University,
P.O. Box 661, H-6722 Szeged, Hungary

(Manuscript received 26 June 1992; in final form 2 November 1992)

Abstract—This paper examines the temperature increasing effect originating from the climate modification effects of the city *Szeged* situated on a plain territory of Hungary.

It can be stated that there is a correspondence between the measure of the increase of temperature and the urban morphological type. The data used here were obtained from several stations representing the different built-up areas of the city. The examination is based on the differences of monthly temperature means between the given stations and the reference-station at all observation times.

The temperature surplus of the urban heat island sometimes exceeds even 4°C and its maximum is in early autumn during the evening.

Key-words: Urban climate, temperature surplus, Szeged.

1. Introduction

By establishing cities mankind has strongly modified natural surfaces. Since the albedo as well as the heat- and waterbalance depend more or less on the quality of surfaces these modifications have led to changes in meteorological elements, mainly temperature and humidity. The anthropogenic heat emission and the air pollution emitted in gaseous and aerosol phases in the territory of cities are of great importance as well. Due to these factors, specific local climate develops in the cities which in many respects, differs from the climate free from anthropogenic effects.

In bigger cities the climate changes are more obvious. However, modification can be observed even in the case of medium size cities (*Oke,* 1973, 1979; *Nkemdirim* and *Truch,* 1978; *Park,* 1987). This fact explains why much more attention should be paid to the climate modification effects from the mid 70's in Szeged. Research covering this topic was initiated by the Department of Climatology of Szeged University. Only small part of the enormous quantity of data received at that time has been processed (*Károssy* and *Gyarmati,* 1980; *Pelle,* 1983; *Unger,* 1992). This paper aims to reduce this deficiency.

Due to the powerful development of Szeged during the last 15 years, the explored features of the city climate have become much more remarkable until now.

2. The investigated area, data and methods

Szeged is situated in the south-east and the lowest plain (69 m a.s.l.) territory of Hungary, free of orographical effects. Thus its geographical situation is favourable to have relatively undisturbed city climate. The number of the inhabitants of the city counted up to 175000 in the investigeted term, in 1978 (*Sindely,* 1978). Thus it is considered to be a city of medium size, the temperature surplus of which can be shown comparing to its surroundings.

The research of urban climate in Szeged was begun in 1974 by cross section measurements, comparison between climates of different housing estates. Afterwards a station network was established where in 10 microclimatological stations measurements were taken between 1977 and 1980. Air temperature, humidity, maximum and minimum temperature and precipitation were measured. With possibilities taken into consideration, the stations represented several types of built-up areas of the city. Each station had a thermometer shelter with an Assmann-type psychrometer, minimum- and maximum thermometers inside and a pluviometer outside. The measurements were taken, at some stations 4-times, at other stations 3-times a day, by observers.

The present research used the data of the five stations, which were most characteristic from urban climatological points of view (*Zsiga,* 1983; *Pelle,* 1983). The reference-station was the Aerological Observatory which is situated outside the city, near the Airport. Its location is free of urban climatic effects and here the north-west wind prevails. *Fig. 1* illustrates the location of stations and the morphological types of the city.

The Station 2 was set up at the city centre influenced freshly by climate modification effects of the town, at a paved square bounded by more storeys building. The Station 3 was set up at a new housing estate with 5-10 storeys buildings built by prefabricated concrete slabs. The Station 4 was set up beside the 3 storey building of the University—in this way it represented the climate of streets with more storeys buildings built by traditional architectural technics. The Station 5 was set up at the grovy garden of the Children's Hospital bounded by busy streets. The Station 6 was set up at the suburb.

The measurements were taken at the first four stations four times a day (01, 07, 13 and 19, Central European Time), while at the last two stations three times (07, 13 and 19, CET). In this way, the investigation of data of the Stations 2, 3 and 4 provides a more comprehensive picture about the diurnal variation of the temperature surplus in the city than the investigation of the data of the Stations 5 and 6.

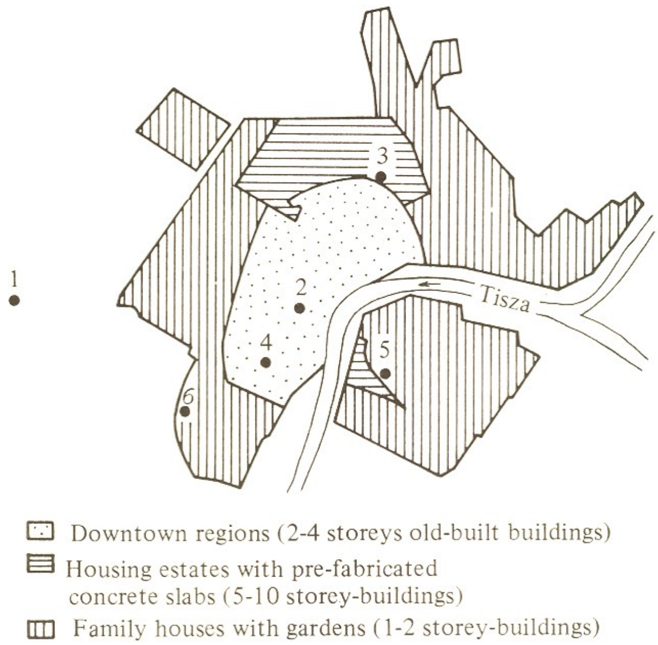

Fig. 1. The morphological types of Szeged and the used stations: 1. Aerological Observatory, 2. Restaurant of Napsugár, 3. Víztorony square, 4. Ady square, 5. Hospital for Children, 6. Department of Agriculture, Juhász Gy. Ped. Col.

The observations were taken during the whole year only from 1978 to 1980, therefore, the data of these 3 years were used in the examinations. The monthly and annual mean air temperatures were determined for each station at different observation times and then the differences of means from the corresponding mean values of the reference-station were examined.

On the basis of these differences, the annual variation of the temperature surplus can be drawn at the given observation times, while the monthly differences show the diurnal variation of the temperature surplus of the given month at several observation times. According to the different morphological types, the temperature increasing effect can be noticed on the basis of density of the built-up areas.

The examinations, mentioned above, suggest the average intensity of the city heat island known already in the literature (*Oke,* 1973, 1979; *Park,* 1987). It is denoted as ΔT_{u-r} and it provides the temperature difference between the city "core" (supposedly the warmest area of the city) and the reference-station in its surroundings.

As the examinations of other cities revealed (*Oke*, 1979, 1982), the maximum temperature difference occurs 3–4 hours after sunset. In the recent case, it means that almost throughout the year, the maximum difference can be expected between 19 and 01, because of the fixed observation times. The maximum temperature difference develops under clear and calm weather conditions and its value can be estimated by two different equations in the case of Europe. These equations depend on the population of the cities:

$$max\ \Delta T_{u-r} = 2.01 \log P - 4.06 \ (°C) \qquad (Oke,\ 1973)$$
$$max\ \Delta T_{u-r} = 1.92 \log P - 3.46 \ (°C) \qquad (Park,\ 1987),$$

where P is the population of the city.

On the basis of the first equation, this maximum difference in Szeged is 6.48°C, while on the basis of the second one it is 6.65°C (which do not significantly differ from each other).

3. Results and conclusions

Let's consider the temperature differences of the Station 2 representing the inner city (*Table 1*).

Table 1. The average temperature surplus of the Station 2 (°C)

Month	01h	07h	13h	19h	Month	01h	07h	13h	19h
Jan	1.35	1.93	1.13	2.83	Jul	4.03	2.03	0.70	2.00
Feb	1.63	2.20	0.73	1.50	Aug	4.50	1.97	0.53	2.40
Mar	2.93	2.43	1.50	2.60	Sep	4.77	2.87	0.43	1.20
Apr	3.53	2.10	0.70	2.40	Oct	3.83	3.30	0.33	2.80
May	3.60	1.40	0.67	1.77	Nov	1.93	1.67	1.03	2.03
Jun	3.73	1.90	1.90	1.80	Dec	1.60	2.13	0.77	2.10
					Year	3.12	2.16	0.87	2.12

By means of these data, the diagram of the temperature surplus can be drawn at all observation times and by months (*Fig. 2*). The figure shows that at 01 considerable temperature surplus can be pointed out which exceeds even 4°C in July, August and September. Since the data of the 01 observation is after the expected time of maximum difference, the value of September (4.77°C) shows good correspondence with the data received from the equations, mentioned above. The temperature differences are above 2°C during the greatest part of the year, while the smallest (but above 1°C) values are in the winter months from November to February.

The former fact can be explained by strong longwave heat emission originating from the surface after sunset, caused by the great daily input of solar radiation in summer. On the other hand, the latter fact can be explained by the weak longwave heat emission, caused by small daily input of solar radiation in winter, which can be counterbalanced by strong evening space heating only to a smaller extent.

The temperature difference is the smallest at 13 and it cannot be noticed at all in September and October (0.5°C). In the winter months, it is around 1°C, while it is the greatest in June (almost 2°C).

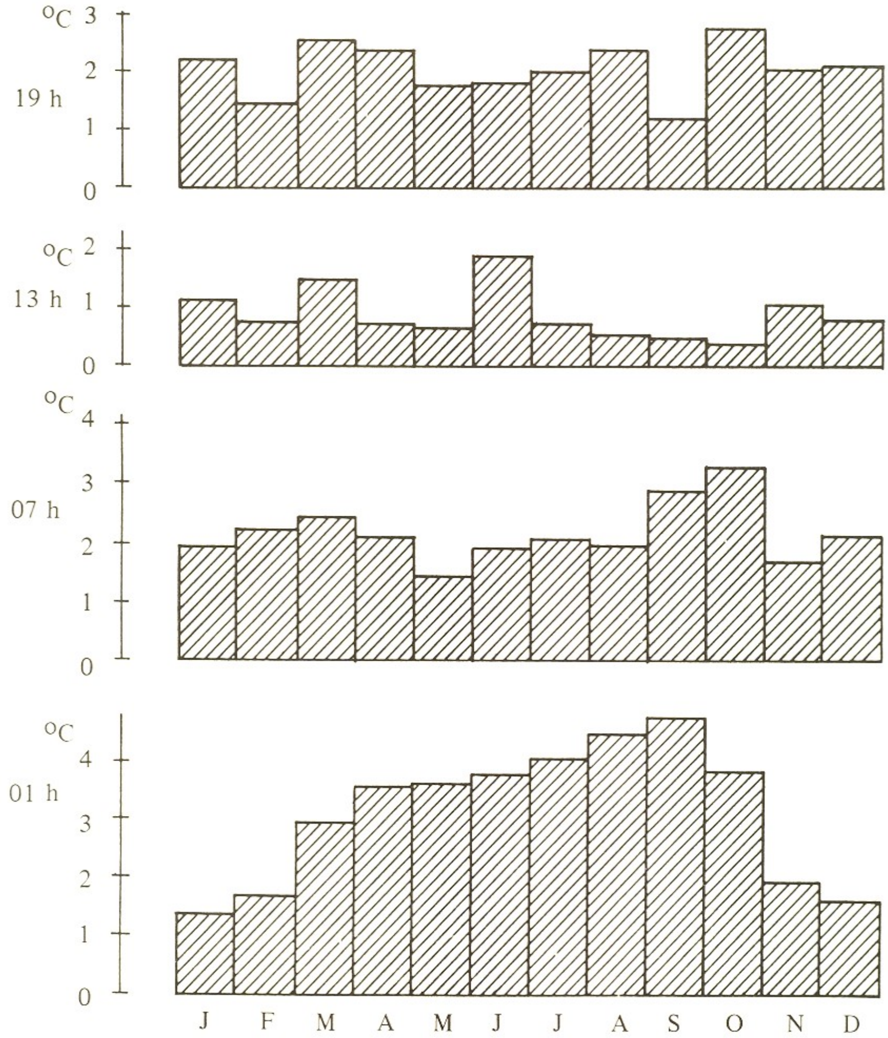

Fig. 2a. The annual variation of temperature surplus of the Station 2 (1978–80)

The temperature differences at 07 and 19 are almost the same during the year, they are about 2°C.

The diurnal variation of the monthly mean temperature surplus shows characteristic feature from March to November (except June). It decreases typically from the maximum of 01 till 13, then it increases till 19. The values

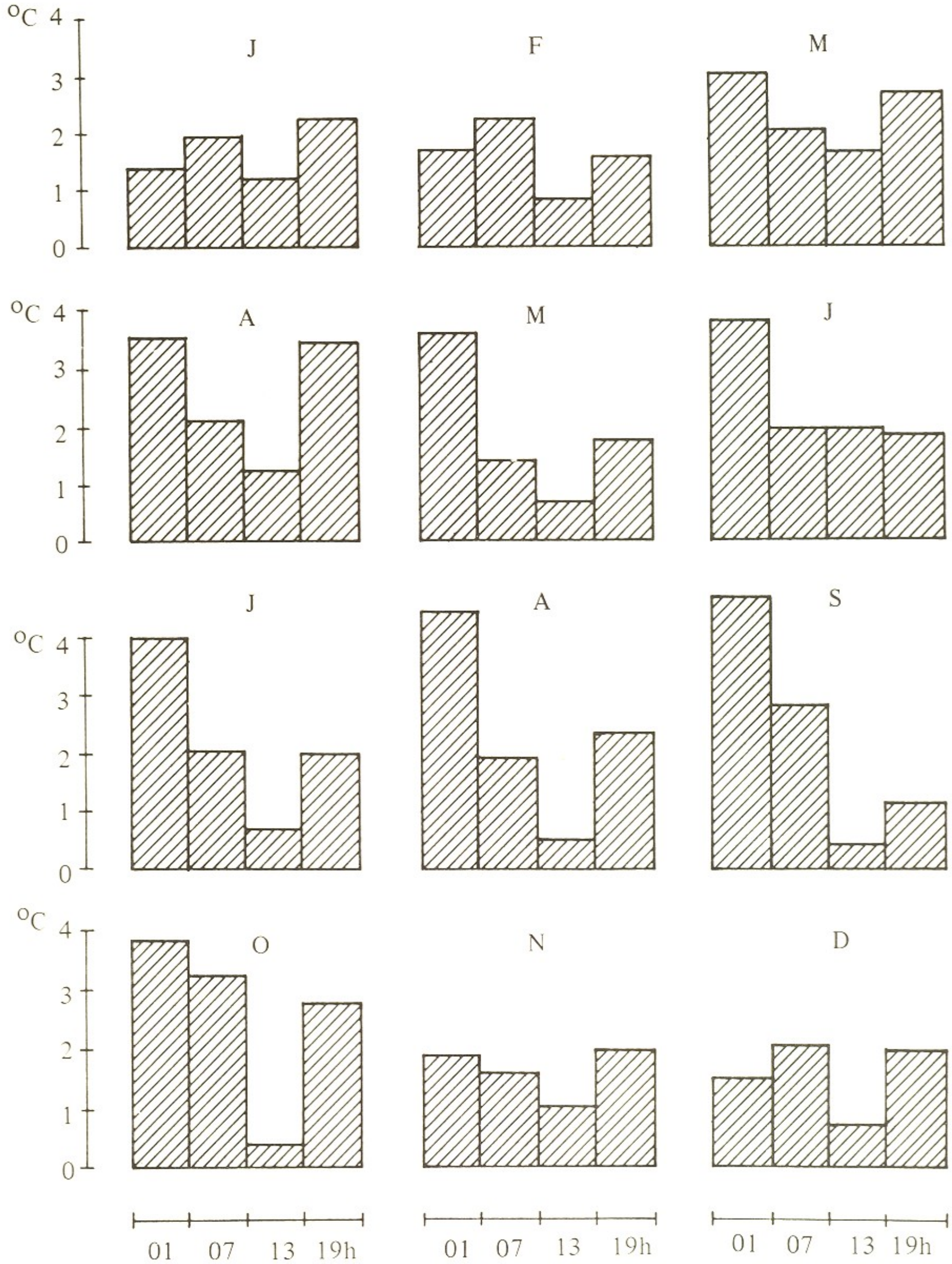

Fig. 2b. The diurnal variation of temperature surplus of the Station 2 (1978–80)

at 19 are lower than the ones at 01. The maximum at 01 reflects the heat reproduction of the solar radiation's absorption of the previous day, which decreases obviously by the morning. However, the temperature difference at 07 is considerable enough, which is in connection with the fact, that the energy of the morning solar radiation is used by the evaporation of dew in the surrounding country, while in the inner city because of the missing or less dew, it is used by the heating of the air. The minimum at 13 can be explained by the influence of the convection, advection and cloud development getting stronger and by the rural surface getting dry and well heated by that time.

In the winter months, on the basis of the results, mentioned above, the maximum of the temperature surplus can be observed not at 01, but in the morning or in the evening, while the minimum can be found at 13 similarly to the rest of the year.

The diagrams of the Fig. 2 are summarized in a figure by the help of isoplates (*Fig. 3*). Using the Fig. 3 with the consideration of the formerly mentioned restrictions, it can be seen how warmer the inner city is as compared to its surroundings, that means, how intensive the heat island is at any month and at any time of the year.

As the Station 2 is situated in the inner city and supposedly it represents the area of the heat island in the best way, so the results for this station were interpreted in the most detailed way.

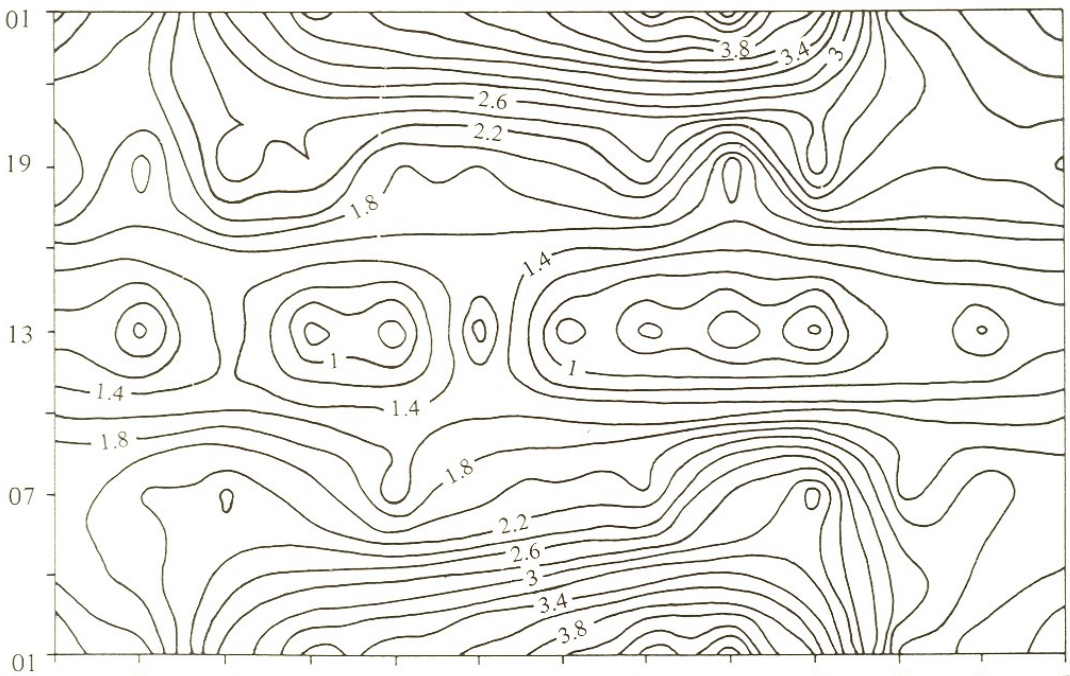

Fig. 3. The isopletes of the temperature surplus of the Station 2 (1978–80)

The examination concerning the next four stations is not so detailed, however, it can be stated that apart from a few monthly means of difference of the Station 6, all the other differences are positive (although not to the same extent as in the inner city). This unambigously proves that it is warmer in the city than in its surroundings. The Station 6 is situated in the outskirts, therefore, it cannot be said to be a representative city station.

In the case of the Station 3 and 4 the values of the temperature surplus are summarized in tables (*Table 2* and *3*). On the basis of these data isoplates, showing clearly the annual and diurnal variation of temperature surplus, which are similar to the Fig. 3, can be constructed.

Table 2. The average temperature surplus of the Station 3 (°C)

Month	01h	07h	13h	19h	Month	01h	07h	13h	19h
Jan	0.90	0.93	0.57	0.80	Jul	2.77	1.30	1.00	0.70
Feb	0.20	1.07	0.57	1.17	Aug	2.53	1.23	0.20	0.90
Mar	1.85	1.53	0.87	1.47	Sep	2.95	1.85	0.77	1.93
Apr	1.95	1.30	0.63	1.27	Oct	2.15	1.87	0.53	1.77
May	2.00	0.77	0.70	0.70	Nov	0.80	0.77	0.77	1.13
Jun	2.35	1.03	1.10	0.93	Dec	1.10	1.13	0.53	1.10
					Year	1.80	1.39	0.69	1.16

Table 3. The average temperature surplus of the Station 4 (°C)

Month	01h	07h	13h	19h	Month	01h	07h	13h	19h
Jan	1.23	1.33	0.73	1.40	Jul	1.90	1.73	1.17	0.73
Feb	1.10	1.25	0.65	1.05	Aug	2.10	0.53	1.53	0.90
Mar	0.90	1.15	0.25	1.15	Sep	2.07	1.30	1.20	1.10
Apr	1.25	0.70	0.90	0.80	Oct	1.77	2.13	0.57	1.20
May	1.47	0.57	1.40	0.67	Nov	0.05	0.95	0.30	0.60
Jun	1.67	0.40	1.70	0.43	Dec	0.70	1.15	0.40	0.70
					Year	1.35	1.10	0.90	0.89

In the case of the Station 5 and 6 the tables are given, isoplates cannot be drawn precisely on the basis of the data from only three observation times (*Table 4*).

As the tables and figures show, the temperature surplus is the greatest at 01—with maximum in summer and autumn—, considerably in the case of Station 3 situated in housing estate with pre-fabricated concrete slabs.

Table 4. The average temperature surplus of the Station 5 and 6 (°C)

	Station 5			Station 6		
Month	07h	13h	19h	07h	13h	19h
Jan	0.67	0.47	1.57	0.07	0.17	−0.23
Feb	0.63	0.47	0.60	0.30	0.27	−0.17
Mar	1.10	0.67	0.90	0.70	0.23	0.40
Apr	0.67	0.70	0.80	0.73	0.33	0.60
May	0.37	0.43	0.47	0.27	0.47	0.73
Jun	0.07	0.70	0.43	0.13	0.53	0.40
Jul	0.40	0.23	0.70	0.27	0.20	0.23
Aug	0.70	0.20	0.10	0.33	0.33	0.67
Sep	1.17	0.20	1.63	0.70	0.07	1.00
Oct	1.53	0.50	1.30	0.63	−0.13	0.30
Nov	0.90	0.87	1.13	−0.07	−0.07	−0.07
Dec	0.97	0.83	1.03	0.03	−0.10	−0.37
Year	0.76	0.52	0.89	0.34	0.19	0.28

The differences at 01 and at the other observation times can be said to be more moderate than the ones in the inner city in the following decreasing order:

Station 3: 5—10-storey buildings with concrete slabs,
Station 4: untight built-up inner city,
Station 5: border between family houses and 5—10-storey buildings with concrete slabs,
Station 6: outskirts.

It can be stated for all stations, that the size of the temperature surplus is reflected adequately by the density of the given built-up area, moreover, the minimum of the temperature surplus is at 13, in each case.

References

Károssy, Cs. and *Gyarmati, Z.*, 1980: The development of the heat island in the air space of Szeged (in Hungarian). *Scientific Proceedings of Juhász Gy. Ped. Col. Szeged, 112-120.*

Nkemdirim, L. C. and *Truch, P.*, 1978: Variability of temperature fields in Calgary, Alberta. *Atmos. Environ. 12,* 809-822.

Oke, T. R., 1973: City size and the urban heat island. *Atmos. Environ. 7,* 769-779.

Oke, T. R., 1979: Review of urban climatology 1973-76. *WMO Technical Note 169,* Geneva.

Oke, T. R., 1982: The energetic basis of the urban heat island. *Quart. J. Roy. Meteorol. Soc. 108,* 1-24.

Park, H. S., 1987: Variations in the urban heat intensity affected by geographical environments. *Environ. Research Center Papers 11,* Ibaraki.

Pelle, L., 1983: City climate measurements in Szeged (in Hungarian). *Légkör 28,* 10-12.

Sindely, P., 1978: Differences in temperatures and humidity between Szeged and its surroundings (in Hungarian). *Doctoral Thesis,* Szeged.

Unger, J., 1992: The seasonal system of urban temperature surplus in Szeged, Hungary. *Acta Clim. Univ. Segediensis, Tom. 24-26,* 49-57.

Zsiga, A., 1983: Relationships between the city morphological types and the city temperature in Szeged (in Hungarian). *Scientific Proceedings of Juhász Gy. Ped. Col. Szeged,* 95-102.