ACTA UNIVERSITATIS LODZIENSIS
FOLIA GEOGRAPHICA PHYSICA 3, 1998

Christos Balafoutis, Timoleon Makrogiannis

HEAT ISLAND AND BIOCLIMATIC INDEXES IN THE CITY OF THESSALONIKI

WYSPA CIEPŁA I WSKAŹNIKI BIOKLIMATYCZNE W SALONIKACH

The intensity of the heat island in the city of Thessaloniki, during the period 1950–1995, is studied. Daily data of minimum air temperature in one urban (AUTH) and one rural station (Macedonia air port) were used to estimate the monthly course of the heat island effect during the last 46 years. The resulting graphs show the existence of an intense heat island phenomenon in the city of Thessaloniki, as the daily temperature differences (Tu–Tr), in some cases exceed the ±6°C and the monthly magnitudes come up to ±4°C. Also, the monthly courses of the wind-chill temperature in the city of Thessaloniki, for a period of 50 years (1946–1995), is analyzed. The march of the wind-chill temperature shows that not any pronounced fluctuation exists during the warm period, probably due to the contrariwise behavior of the city on the magnitudes of the temperature and wind parameters, but during the colder months it exists a positive effect on the mildness of the city climate.

INTRODUCTION

The continued growth of the cities has spawned interest in environmental consequences by climatologists, atmospheric scientists, as well as urban planners (Changnon 1979). As a well documented man-induced temperature change, the urban heat island has left no doubt about its presence; however, its characteristics and causes do change spatially and temporally. This is because the urban heat island is controlled by a number of natural conditions and anthropogenetic effects, such as meteorological conditions, topography and the area of man-altered surface, which change over time (Landsberg 1981).

Very limited research has been undertaken on the study of the urban heat island and the changing characteristics of it in Greece. The majority of the papers deal with the distribution of the climatic elements over the city areas of Athens and Thessaloniki. Exclusively, referring to the city of Thessaloniki until now there is only one paper (Balafoutis 1985) dealing with the urban heat island, but there are a lot of papers analyzing many climatic and environmental parameters, and the majority of them has been published in a special edition (Thessaloniki Through 23 Centuries, 1985).

STUDIED AREA AND DATA USED

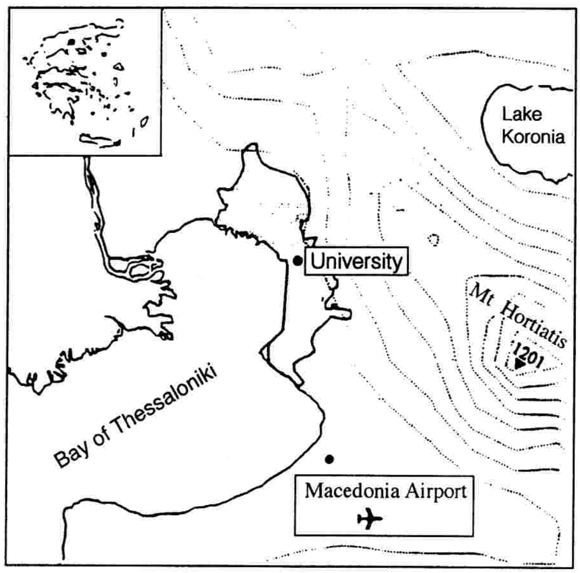


Fig. 1. Map of the area studied and the location of the stations used

Rys. 1. Mapa analizowanego obszaru i lokalizacja wykorzystanych stacji

Thessaloniki (40°37′N and 22°57′E) is a coastal town situated around the Golf of Thermaikos, in the northern part of the Aegean sea (Fig. 1). To the north of the town exists a chain of hills and mountains with an elevation ranging between 300 to 1200 meters, which protects the town from the northerly winds and results to a very high frequency of calms and weak winds (Balafoutis 1985).

The climate of the city is a typical Mediterranean climate with cool and wet winters and hot dry and sunny summers. A remarkable growth in the urbanization of Thessaloniki since the end of the Second World War has been observed. Its population rose from less than 300 000 inhabitants in 1951 to more than 1 000 000 in 1997. Population growth has accompanied by an increase in the size of the city and in the amount of the high buildings. The city is characterized by a high density of buildings, by very narrow and deep street canyons and by the lack of remarkable parks. The only significant green area, with a coverage of 30 km^2, is the wooded area on the urban fringes, of which the 50% has destroyed by a wildfire during the last summer.

This paper makes use of data collected over a large period of 46 years for the purpose of studying the condition of the urban heat island in Thessaloniki, on a monthly time scale. The records analyzed are extended to the period between 1950–1995 for the heat island effect and between 1946–1995 for the wind-chill temperature.

The effect of urbanization on temperature characteristics in Thessaloniki is examined by comparing the temperature values of the urban station AUTH (37 m a.s.l.), located at the University campus, in the city center, and the rural station MAP (5 m a.s.l.), located at the Macedonia airport, about 15 km east of the city center (Fig. 1).

TEMERATURE DATA ANALYSIS

THE COURSE OF TEMPERATURE DIFFERENCES

The first step was the examination of the relative frequency of the heat island intensity for the entire 46-year period. The temperature categories were determined at 1°C steps and the results are demonstrated in Fig. 2.

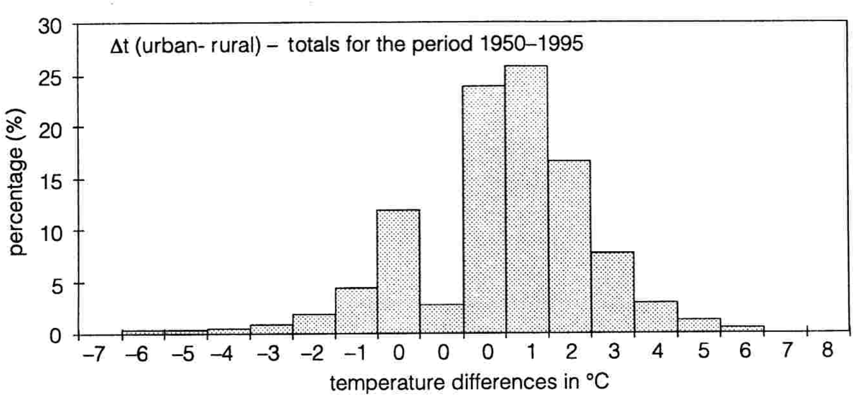


Fig. 2. Distribution of the relative frequencies of heat island intensity (1950–1995)

Rys. 2. Rozkład częstości intensywności wyspy ciepła (1950–1995)

The study of this figure shows that there is a positive kurtosis with a pick at the +2°C. The differences between the urban and rural daily minimum air temperatures range from –7 to +9°C, but these marginal values are very rare (0.015% of the total values). Thus, the heat island only exceeded 8°C twice during the entire period of 46 years. These values, due to their small frequency of appearance, are not presented in the graph. The "zero heat influence" is limited as it represents only the 2.5% of the total values. In four of five days (78.24%) exists a remarkable "positive heat influence" of the city, keeping these urban nights warmer than those of the rural area. An amount of 19.3% of the days presents a "negative" heat influence, showing that during those nights the town was colder than the outskirts of it. The lowest value of negative heat island fallen under –6°C only once. The mean annual course of the average monthly temperature differences for a sorter period (1950–1979) are demonstrated in Fig. 3.

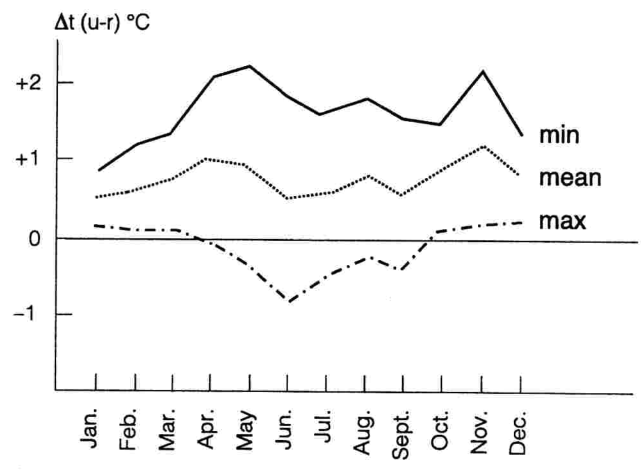


Fig. 3. Mean annual course of the mean, maximum and minimum air temperatures

Rys. 3. Średni roczny przebieg średniej, maksymalnej i minimalnej temperatury powietrza

The analysis of this Figure manifests the following:

a. All around the year the Δt (u–r) values of the minimum temperatures are positive, showing that the nights in the town – in an average – are warmer than in the airport. The higher differences appear during the months of April, May and November, when the radiation frosts are more frequent (Balafoutis 1977) and the lower values achieved in January.

b. The city positive heat effect is pronounced during all around the year as the mean monthly air temperature differences remain continuously above the zero value, confirming the permanent existence of the urban heat island effect.

c. The differences in the mean monthly maximum temperatures (urban--rural) are positive during the colder months November to March. In contrary, these differences are negative during the warmer months May to September. Finally, during the transitional months April and October these differences are almost zero.

The above analysis shows that during the daytime and nighttime period the town of Thessaloniki is warmer than the rural area except of some midday hours during the warmer months.

WEATHER TYPES AND THE ΔT (URBAN-RURAL) TEMPERATURE DISTRIBUTION

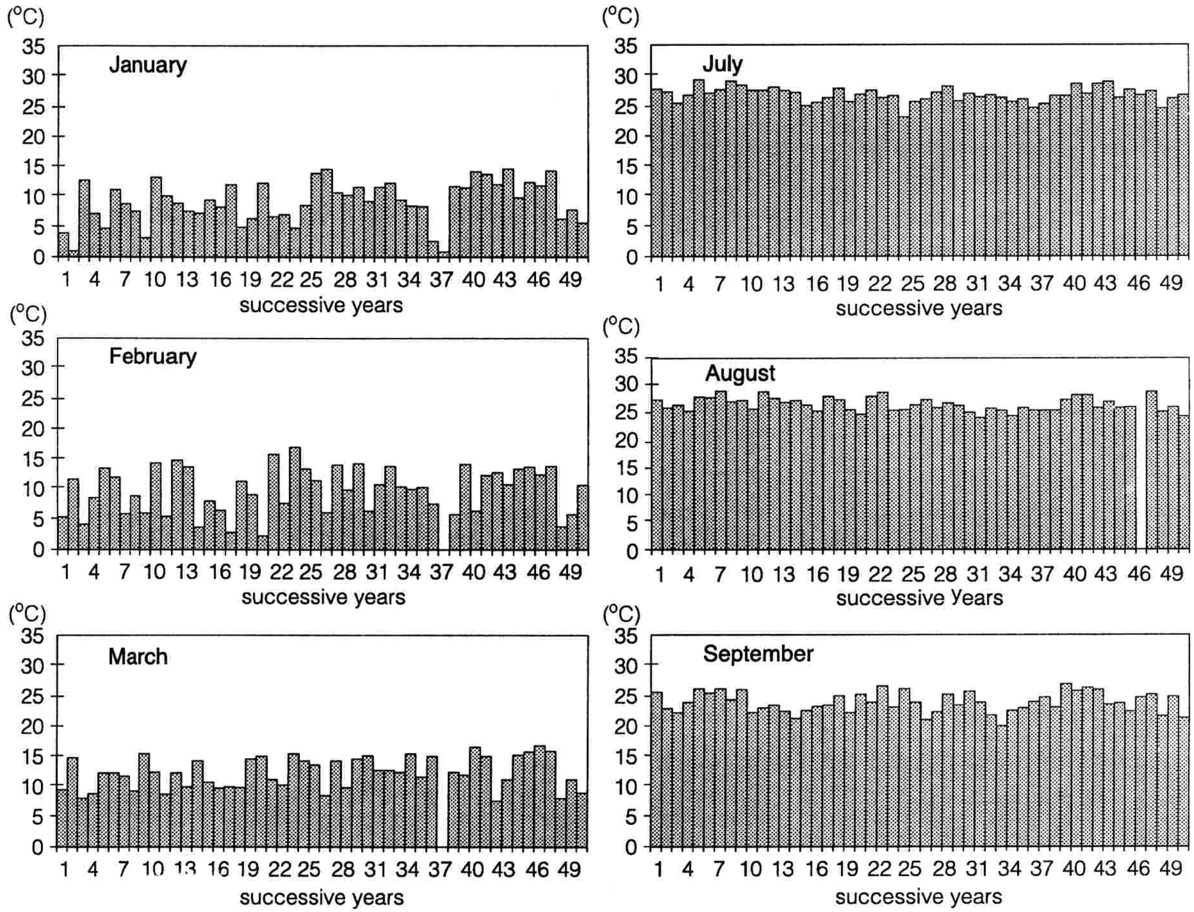
In order to investigate the relationship between urban heat island intensity and the prevailing weather conditions the Δt (u–r) daily data and the synoptic weather types were taken into account. The daily minimum temperature differences, only for the colder period from October to May, were classified according to the 13 weather types defined by L i v a d a s (1962). The frequencies and the average values of the minimum air temperature differences for each weather type are given in Tab. 1.

Table 1

Weather type frequencies and average minimum air temperature in Thessaloniki from October to May

Częstości typów pogody i średnia minimalna temperatura powietrza w Salonikach od października do maja

Weather type	Frequency (%)	Average Δt (°C)
Anticyclone (A-I)	21.9	1.62
Anticyclone (A-II)	12.8	1.92
Anticyclone (A-III)	2.6	1.53
Anticyclone (A-IV)	5.5	1.93
Anticyclone (A-V)	1.8	1.75
Cyclone (C-VI)	10.9	0.54
Cyclone (C-VII)	12.7	0.37
Cyclone (C-VIII)	3.6	1.00
Slack Pressure Field (SPF-IX)	6.7	1.61
Mixed (M-Xa)	0.7	0.05
Mixed (M-Xb)	9.0	0.32
Mixed (M-XI)	4.6	0.67
Mixed (M-XII)	7.2	0.78



(°C)
January
July
February
August
March
September
successive years
successive Years

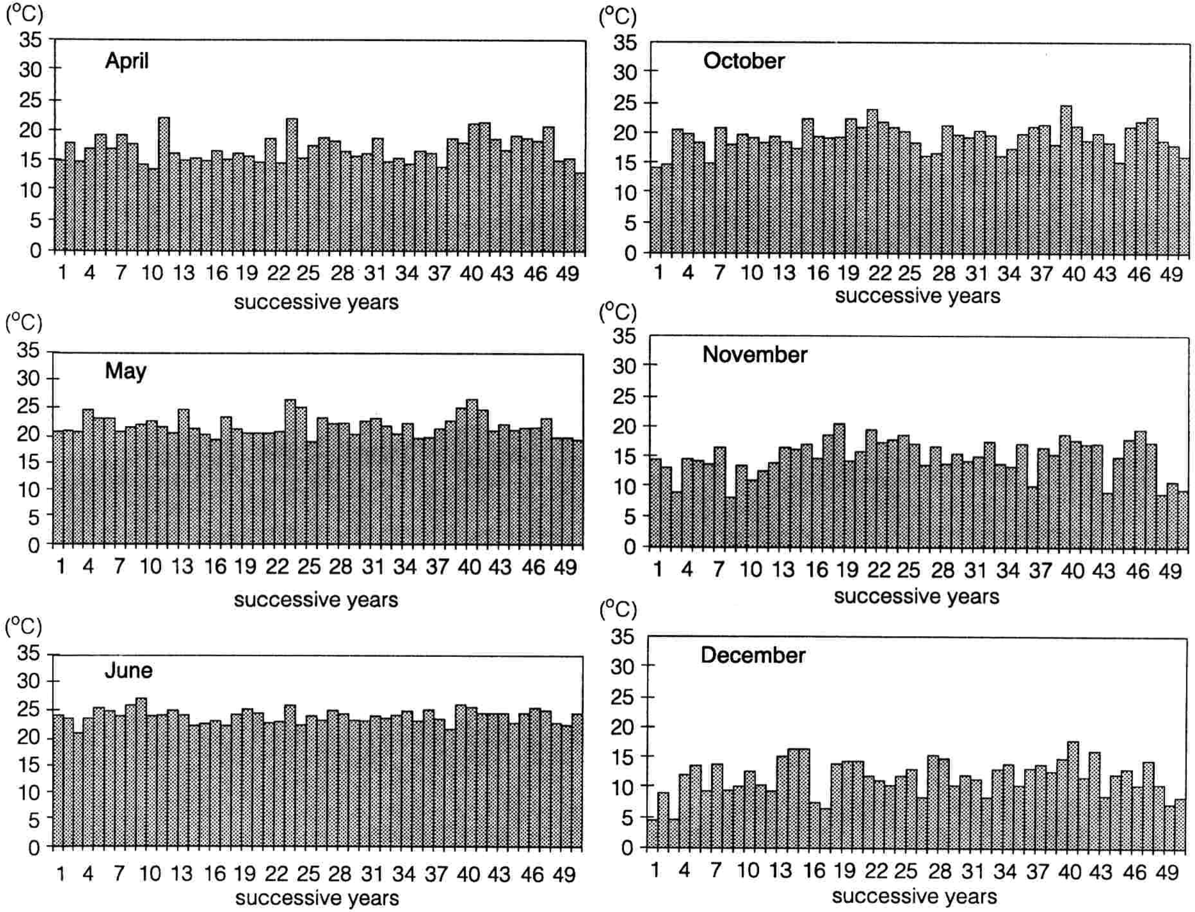


Fig. 4. The monthly year-to-year variation of the Δt (u–r) parameter in Thessaloniki

Rys. 4. Zmiany z roku na rok miesięcznych wartości parametru Δt (u–r) w Salonikach

The analysis of the results showing in the above Table, reveals the important role of the anticyclonic circulation on the formation of the urban heat island, as the higher average values of Δt, ranging between 1.93 to 1.62°C, appear under anticyclones or with slack pressure fields (1.61°C). Under cyclonic or mixed conditions the average values are enough lower. The highest value (1.93°C) is related with an anticyclone centered over the Mediterranean sea, south of Thessaloniki, and the lowest value of 0.05°C is related with strong NE winds resulting from a combination of a High over the Balkans and a Low over Asia Mirror.

THE INTER-ANNUAL COURSE OF THE AIR MINIMUM TEMPERATURE DIFFERENCES

The course of the minimum air temperature differences, separately for each month of the year are presented in Fig. 4, for the entire period 1950–1995. The results show that all the average monthly differences for every individual year do not exceed the 4°C. During the colder months October to March, in the beginning of the studied period, the urban heat effect was not so intense and in many cases it was negative, as the relevant graphs show. During these months the urban heat effect becomes positive at the end of 50s and this situation remains until 1990. After that year negative values of the urban effect appeared during some cold months.

An inter-annual fluctuation of the minimum temperature differences is remarkable for all months, with the highest values preferring to appear during the period 1972 to 1980. Before that period the differences are enough lower, but, during the warmer months, they are usually higher if they compared with the corresponding values of the recent 6 or 7 years. Indeed, during the 90s the temperature differences are smaller showing, maybe, a weakness of the heat island effect. After that it is useful to explain this ascertainment. Of course there are many reasons for it. The most serious is a change of the atmospheric circulation, but there are not enough signals to accept this interpretation. Among a number of other reasons the most convenient are the following: First, the inner park of the University Campus has shown a remarkable change during the last 20 years, as at the year 1972 a planting program was started. The vegetation now is very dense and tall deciduous trees cover the area around the meteorological station, leading to a substantial change on the microclimatic environment of the urban station. Second, the observation technique and the data collecting hours have entirely changed at the university station during the last decade and third, a small change in the airport microclimate is apparent due to the airport extension. Finally, this point still remains a problem under farther investigation.

A CASE STUDY OF THE TEMPERATURE DISTRIBUTION

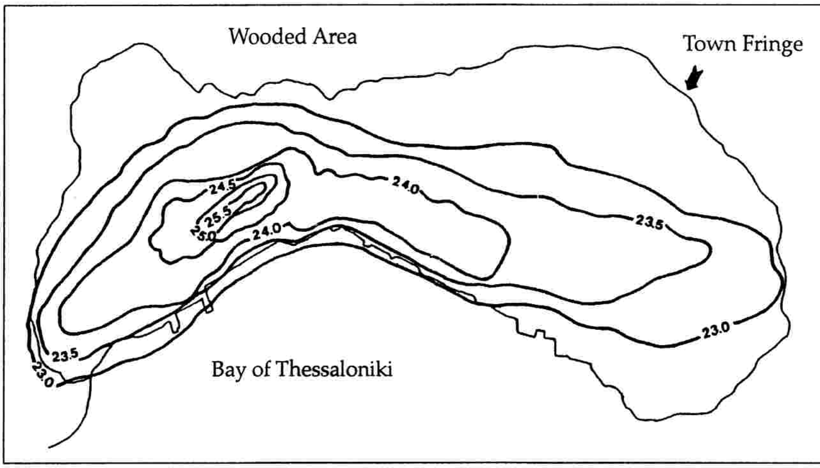


Fig. 5. The distribution of air temperature at 20.00 UTC on 12 October 1997 in Thessaloniki

Rys. 5. Rozkład temperatury powietrza o godz. 20.00 dnia 12 października 1997 r. w Salonikach

The heat effect of the city can be established by meteorological networks of stations. These permit a very good estimate of the average differences and they also integrate over-all weather conditions. In Thessaloniki due to the lack of a meteorological network the knowledge about the city climate derives from traverses. Figure 5, shows the distribution of the air temperature during an occasional traverse in the night on 12 October 1997 at 20.30 UTC. This night was clear and the southerly winds, coming from the seaside, were very weak with speeds up to 3 m/sec. As Fig. 5 shows, the temperature gradient is more intense around the city center, and it becomes more weak far of the downtown.

The increase of the air temperature from the urban fringes to city center was greater than 2.5°C, almost four hours after sunset. Thus it is pronounced that the urban area is enough warmer than its surrounding few hours after sunset as it is, for example, pointed out in many relevant papers (i.e. O k e et al. 1975).

Generally, it is known that the inhabitants of urban areas show a much greater disaffection for the climate in the summer season in contrast to inhabitants of the rural areas. Beyond the common reasons of the reflection and the back radiation of the concrete walls, warm nights are indicators of sensible climate during the summer months.

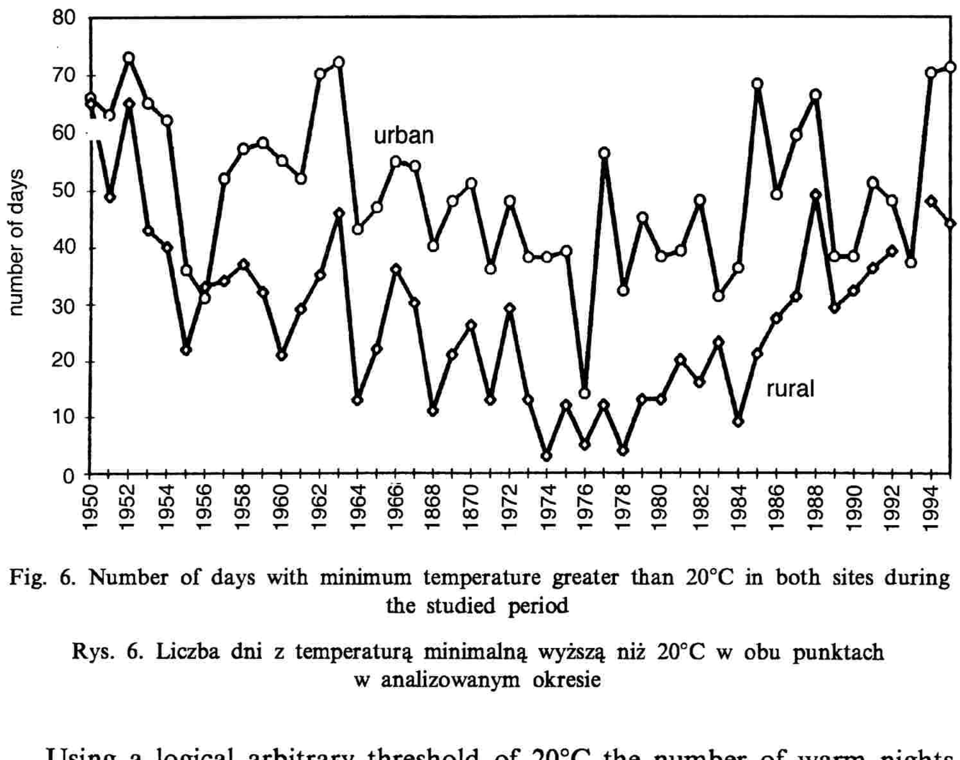


Fig. 6. Number of days with minimum temperature greater than 20°C in both sites during the studied period

Rys. 6. Liczba dni z temperaturą minimalną wyższą niż 20°C w obu punktach w analizowanym okresie

Using a logical arbitrary threshold of 20°C the number of warm nights in the both areas were calculated. The results of this estimation, showed in Fig. 6, indicate that the urban effect on the sensible temperature is important in summer as during all the studied period the number of the nights with minimum temperatures greater than 20°C were always higher in the urban area comparing with those at the rural site.

The wind-chill equivalent temperature is another indicator of the sensible climate around the year. Unfortunately was impossible to estimate the wind-chill temperature in the both sites, due to the lack of the wind data of the MAP station.

The investigation is limited only to the urban conditions, using the temperature and wind data from the AUTH station during the period 1946 to 1995 (50 years). The results of the wind chill temperature are indicated in the Fig. 7. The examination of this Figure shows that during the winter months the wind-chill temperature presents an increase from the beginning to the end of the studied period, resulting to more mild winters during the last half of the period. A decline of the values observed during the last years shows again the weakness of the urban effect.

In summer months there is not any pronounced fluctuation of the wind--chill temperature, as the range of the differences from year-to-year is less that to 2 or 3°C. The synoptic conditions prevailing in the greater area of Thessaloniki are characterized by a high frequency of calms and weak winds (Balafoutis 1985) especially during the warm period, and the very weak wind speeds play a secondary role in the formation of the wind-chill equivalent temperatures in the city during this period, giving these smooth top lines, especially during the three summer months.

CONCLUSIONS

From the above analysis the following conclusions were extracted:

1. In four of five nights (78.2%) exists a remarkable heat effect in the city, and for the remaining days the rural area is warmer or has the same minimum temperatures as the city. In average monthly values the city is warmer than the outskirts, but during the early afternoons, in the warm period, the city is cooler than the urban area.

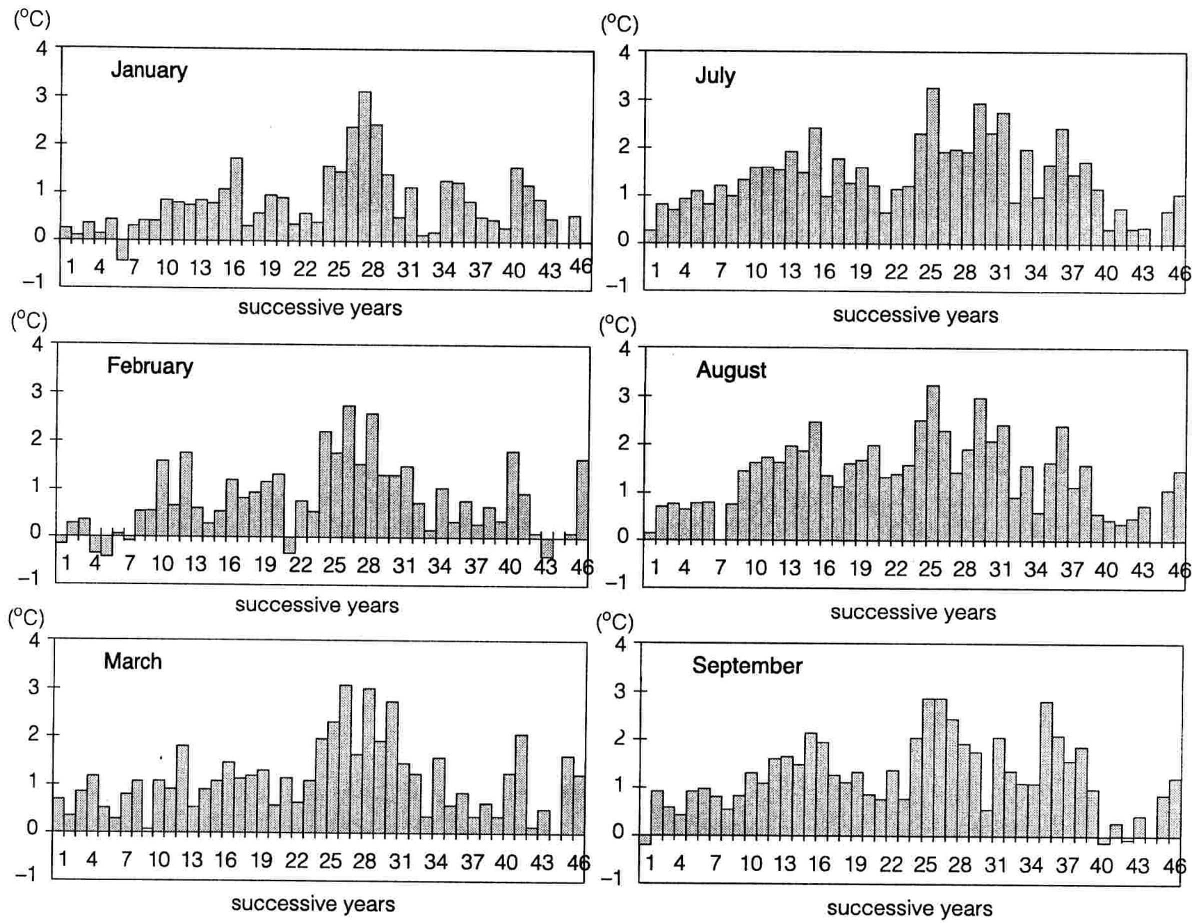
2. The intensity of the heat effect is more pronounced during the anticyclonic conditions or during the weak pressure fields.

3. The year-to-year monthly course of the minimum air temperature differences not exceed the 4°C and present a fluctuation. Which is more intense during the 70s.

4. The heat island presents a weakness during the 90s, maybe due to some small changes in the close environment of the stations.

5. The urban area shows a much greater disaffection as the nights with minimum temperatures greater than 20°C are always higher in the city.

6. The wind-chill equivalent temperature makes more mild the winters in the urban area, but it has not any sufficient influence during the summer.


(°C)
January
successive years
(°C)
July
successive years
(°C)
February
successive years
(°C)
August
successive years
(°C)
March
successive years
(°C)
September
successive years

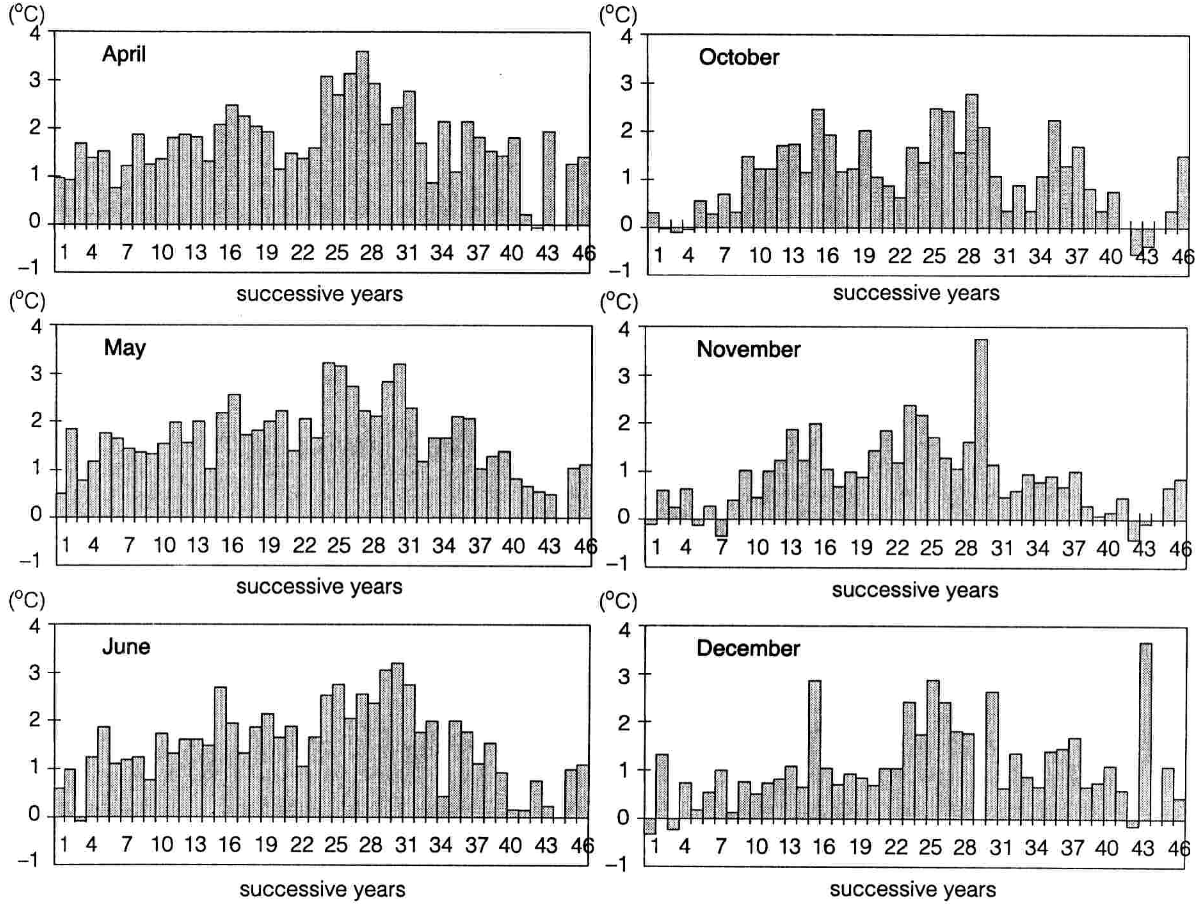


Fig. 7. The monthly year-to-year course of the wind-chill temperature

Rys. 7. Zmiany z roku na rok miesięcznych wartości wskaźnika ochładzania wiatrem

REFERENCES

B a l a f o u t i s Ch., 1985, *The Climatology of the Urban Heat Island in the City of Thessaloniki,* [in:] *Fourth Seminar for the Environmental Protection and Air pollution. Thessaloniki 4–7 November,* p. 49–53

B a l a f o u t i s Ch., 1985, *On the Frequency of the Weak Winds in Thessaloniki,* [in:] *On the Environment and Life Quality in the city of Thessaloniki. Thessaloniki – Greece, 5–8 October,* p. 359–362

C h a n g n o n S. A., 1979, *What to do About Urban-Generated Weather and Climate Changes,* Amer. Plan. Assoc. J., Vol. 45, p. 695–718

L a n d s b e r g H. E., 1981, *The Urban Climate,* Academic press, New York, 275 pp.

L i v a d a s G., 1962, *The Frost Weather in Greece,* Senior Lecture Dissertation, Thessaloniki, p. 88

O k e T. R., M a x w e l l G. B., 1975, *Urban Heat Island Dynamics in Montreal and Vancover,* Atmos. Environ., Vol. 9, p. 191–200

Thessaloniki through 23 centuries, 1985, *Special Congress on Environment and Life Quality in Thessaloniki, 3–5 October,* Thessaloniki, Greece

Department of Meteorology and Climatology
Aristotle University of Thessaloniki, Greece

STRESZCZENIE

Badano intensywność miejskiej wyspy ciepła w Salonikach w okresie 1950–1995. Dobowe dane o minimalnej temperaturze powietrza ze stacji miejskiej i zamiejskiej wykorzystano w celu oceny miesięcznego przebiegu efektu wyspy ciepła w ciągu ostatnich 46 lat. Uzyskane wykresy wskazują na istnienie intensywnej wyspy ciepła w Salonikach w niektórych przypadkach przekraczającej natężenie 6°C (różnice temperatury Tu–Tr), a wartości miesięczne dochodzą do ±4°C. Analizowano również miesięczne przebiegi wskaźnika ochładzania wiatrem w Salonikach dla okresu 50 lat (1946–1995). W chłodnych miesiącach roku w świetle tego wskaźnika stwierdzono efekt złagodzenia klimatu miasta.