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Detection of urban heat island in Ankara, Turkey(*)

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Summary. — Ankara is the second largest city in Turkey after Istanbul, and the rate of population increase and urbanization are quite high. In this study, the effects of urbanization on temperature variation due to urbanization in Ankara were investigated. The intensities of urban heat island (UHI) for long and short term were analyzed. Analysis of both long- and short-term data revealed that there is a significant increase in the intensity of UHI ($\Delta T_{(\text{u-r})}$) in winter during the period analyzed. Analysis of data collected for period of October 2001-September 2002 shows that intensity of maximum UHI is in February. In this month, positive UHI was observed in 26 nights and on all these days wind speed was less than $0.5\,\text{m}\,\text{s}^{-1}$. UHI is positive in all seasons and frequency and intensity of UHI in winter are higher than in the other seasons. This characteristic makes Ankara different from other temperate latitude cities.

PACS 92.60.Ry – Climatology, climate change and variability.

1. – Introduction

Temperature is the element of climate the most affected by urbanization. There is a significant increase in temperature as a result of urbanization. The difference in temperature between the urban and rural areas is dependent upon synoptic conditions. This temperature difference increases in clear and calm conditions and tends to disappear in cloudy and windy weather. Different topographical conditions, topoclimates, radiative fluxes and turbulent exchanges are very important conditions in the development of temperature differences. The difference between screen level temperatures of urban and rural areas is defined as UHI [1]. UHI is the result of: a) anthropogenic heat from building sides; b) greater short-wave absorption due to canyon geometry; c) decreased net long wave loss due to reduction of sky-wiev factor by canyon geometry (including reduced nocturnal radiative flux divergence); d) greater sensible heat flux due to decreased evaporation resulting from removal of vegetation and surface "water proofing";

(*) The authors of this paper have agreed to not receive the proofs for correction.

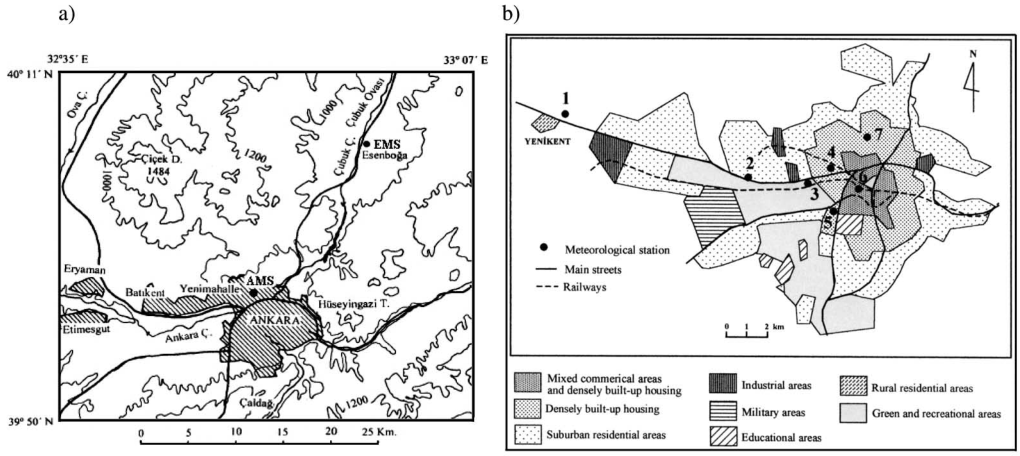

Fig. 1. – The simplified topographic map of Ankara and its surroundings (a) and the city of Ankara—the area of investigation (b).

e) convergence of sensible heat due to reduction of wind speed in the canopy [2]. These effects are generally positive. Although UHI occurs both day and night, it is much more intensive at nights. Surface cooling is associated with radiation exchange. While exposed rural sites cool rapidly after sunset, urban sites cool more slowly. The difference between urban and rural sites grows with time after sunset and reaches a maximum difference after about 4 hours.

The city of Ankara (40 °N, 32 °E) is settled on a plain formed by Ankara Stream and its branches. Ankara plain has an elevation of 850–900 m. The mountains surrounding it have an average height of 1250–1500 m (fig. 1).

As a result of rapid urbanization occurred both in Ankara city and in the whole country surrounding it, the cities affected the climate, and hence UHI developed. The studies carried out upon this subject yielded some remarkable results as regards the formation of UHI as a result to rapid urbanization [3-6]. Karaca and Tayanç in their study [6] carried out on 54 different stations founded an urban bias of 0.24 °C/40 years for the mean temperatures, and of 0.48 °C/40 for the minimum temperatures both at the significance level of 99%.

Karaca *et al.* [3] investigated the effect of urbanization upon temperature in Ankara and Istanbul and annual trend of mean temperatures analyzing the data of five different stations in Ankara with urban, suburban and rural characteristics. The study showed a decreasing trend in both rural and urban stations. In this research, no significant trends between the temperature differences of the urban and rural areas were detected. The authors attributed these characteristics, which are also seen in many stations in Istanbul, to the significant decrease in temperature between Mediterranean and Middle East and relatively better planned urbanization of the city of Ankara. Nasrallah and Balling [7] have found that Turkey, with the highest sulphate ratios, had cooling trends in the west with −0.06 °C per decade and in the east with −0.08 °C per decade. However the factor such as the relatively long distance between the selected stations with topographical features must have also had an effect on decreasing trend in their research.

TABLE I. – *List and characteristics of meteorological stations used in the paper.*

Station no.	Station name	Station type	Elevation (m)	Sky view factor (Ψ_s)(*)
1	Yenikent	Rural	820	0.92
2	Şeker	Suburban	838	0.86
3	AOÇ	Suburban Park	862	0.81
4	Yenimahalle	Urban	870	0.46
5	Emek	Urban	903	0.35
6	Gar	Urban	884	0.29
7	Keçiören	Urban	885	0.39

(*) Sky view factor is a geometric ratio that expresses the fraction of the radiation output from one surface that is intercepted by another. It is a dimensionless number between zero and unity.

2. – The climate and stations

At Ankara Meteorology Station (AMS), the mean temperature is 11.7 °C and the annual average precipitation is 383.1 mm, which is concentrated in the cooler months of the year. Winds are relatively light, with monthly means between 1.6 and 2.3 m s^{-1}. The monthly mean temperatures of Ankara and its surroundings range above 20.0 °C in three months, between 10.0 °C–20.0 °C in four months and below 10.0 °C in five months of the year [8].

In this study, the effects of urbanization on temperature variation due to urbanization were investigated. The intensities of urban heat island (UHI) for long and short terms were analyzed. For the long-term analysis, daily average data registered by AMS and Esenboğa Meteorology Station (EMS) stations of State Meteorology Service (SMS) for period of 1956-2002 were used. AMS is located in the Regional Meteorological Directory of Ankara, which is supposed to reflect the urban effects in many ways due to taking place in the urban area for a long period; the other station EMS is located in a rural area (fig. 1a).

Seven stations were considered in order to determine the effect of urbanization in Ankara upon the climate (fig. 1b). These stations are located in the floodplain close to each other, in order to eliminate the effect of elevation upon the climate. The suburban slum areas surrounding the city are generally on the slopes of the hills and there is a significant difference of elevation in these areas. That was why there were no stations established in these areas. Table I gives important features of these stations. The difference in elevation between the stations was 83 m. The stations were mounted over a 2 m^2 concrete base, and measure the temperature at 1.5 m above the ground and wind velocity and direction at 2.5 m above the ground. The measurement range of thermometers is between $-40°$ and 60 °C with a 0.1 °C resolution. The anemometers range at 0–79 m s^{-1} with a 0.5 m s^{-1} resolution. The starting date of the observations in these stations was October 2001, and the measurements were taken at every half hour automatically.

3. – Results and discussion

3·1. *Trend analysis of temperature.* – The temperature differences across seasons at 21:00 local time were taken and a linear trend analysis was applied to observe the long-term annual changes of UHI at AMS and EMS stations. According to the analysis,

TABLE II. – *Observed trends for seasonal time series of differences between AMS-EMS (1956-2002).*

Seasons	Linear trend
Winter	0.43 °C/50 years
Spring	0.80 °C/50 years
Summer	0.18 °C/50 years
Autumn	0.27 °C/50 years

positive linear trends were found in all seasons. At the end of the analysis, the spring was found to have the most salient UHI (table II). Spring is the most rainy season in Ankara. The reduction in energy used in evapotranspiration at the urban surface must then be distributed between the observed increased heating of urban atmosphere and an increased heat storage by the urban surface.

In addition to a linear trend, the Mann-Kendall test (sequential version) was applied to the seasonal temperature differences. This test was used by many researchers to discover a trend in series [3,4,9,10]. The method was also suggested by WMO [11](1). As a result of the Mann-Kendall test, significant increasing trends were observed especially in winter and spring. In these seasons, the increase was significant especially after the second half of 1980s (fig. 2).

One of the pairs of stations analyzed by Karaca *et al.* [3] was the AMS-EMS pair. The researchers report that UHI has been influential in this pair in recent years. While they found an increasing trend in the minimum temperature differences, they found a weak positive trend in the maximum and mean temperature differences of the AMS and EMS. There were significant trends in the seasonal values of 21:00 temperature differences. UHI development was found out, especially in the spring seasons after 1986 at 99% significance level. The fact that there was an effective increasing trend in the UHI intensity in winter and spring, while it was not salient in summer and autumn, could be related to moisture of soil. A great amount of solar energy absorbed by soil is transferred into the atmosphere through evaporation in the seasons when the soil is damp (winter and spring) in the rural area. This causes an increase in the intensity of UHI. However, the rural and urban areas have similar heating behavior as the latent heat transfer is small due to a decreasing evaporation from the rural areas in the dry seasons (summer and autumn). Hence, the impact of urban canyons on the long-wave radiation consists in an effective development of UHI in summer and autumn.

Data collected by seven stations for period of October 2001-September 2002 (described above) were also analyzed to investigate the effect of urbanization on UHI. Results of analysis of this data are plotted in fig. 3. Figure 3 shows the average seasonal temperatures and difference between these temperatures ($\Delta T_{(\text{u-r})}$). As seen in this figure, in

(1) In a time series, for each element y_i, the number n_i of elements y_j preceding it ($i > j$) is calculated such that $y_i > y_j$. The test static t is then calculated by $t = \sum_{i=1}^{n} n_i$, t is distributed very nearly as a Gaussian normal distribution with an expected value of $E(t) = \frac{n(n-1)}{4}$ and a variance, $\text{var}(t) = \frac{n(n-1)(2n+5)}{72}$. A trend can be seen for high values of $|u(t)|$ with $u(t) = [t - E(t)]/\sqrt{\text{var}(t)}$. This principle can be usefully extended to the backward series and $u'_i = -u(t'_i)$ can be obtained. The intersection of $u(t)$ and $u'(t)$ curves denoted approximately the beginning of the trend. This is called the sequential version of the Mann-Kendall test.

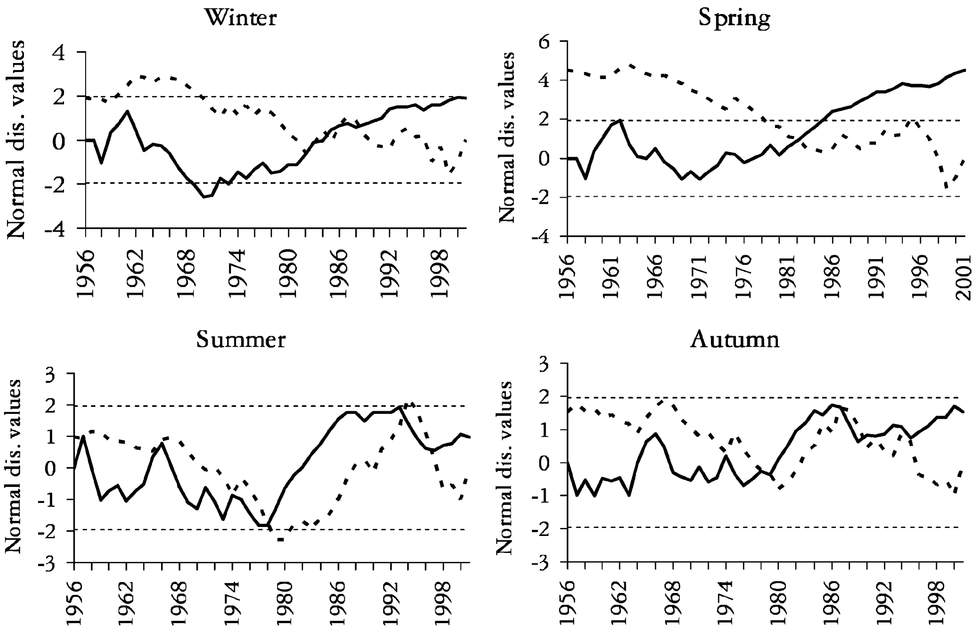

Fig. 2. – Time series of seasonal mean temperature differences between AMS-EMS as derived from the sequential version of the Mann-Kendall test. (Straight line $u(t)$ and dashed line $u'(t)$ test sample values are shown.)

all seasons temperature of urban areas is higher than that of rural areas. Maximum temperature difference is in winter, when its value is 1.7 °C. This temperature difference decreases in spring and summer. The fact that urbanization is more effective in winter may be due to anthropogenic heat release. On the other hand, the similarity in soil moisture level in urban and rural areas causes the decrease in magnitude of UHI, in these seasons. Analysis of both long-term data of AMS-EMS station pair and annual data of Gar-Yenikent station pair clearly indicates the presence of UHI in winter.

Figure 4 shows the frequencies of UHI intensities with respect to the seasons. As it is possible to see in this figure, high-intensity UHIs are observed in winter. Frequen-

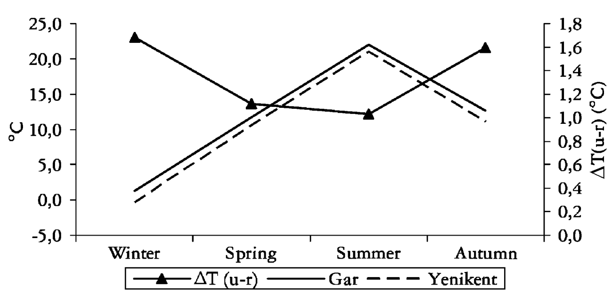

Fig. 3. – Variation of seasonal average temperatures in Gar (urban) and Yenikent (rural) areas, and difference of these temperatures.

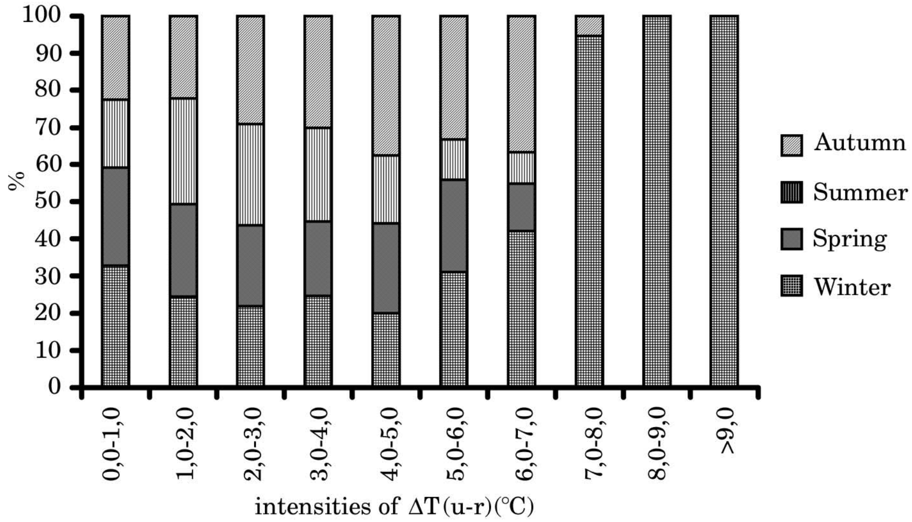

Fig. 4. – Frequency of intensity of UHI in the different seasons.

cies of UHIs with intensities 1.0–2.0 °C are higher in summer than in the other seasons. On the other hand, it is known that, in temperate latitude cities, there is often a seasonal variation of the heat island, with the greatest frequency of occurrence and greatest intensities being registered in the warmer half of the year, especially summer and autumn [2, 12-14]. The fact that high-intensity UHIs are registered in summer indicates that anthropogenic heat release does not have the primary effect on the development of UHI [14]. Higher-intensity UHI registered in winter in Ankara shows that Ankara has a different characteristic from the temperate latitude cities. This could be the result of climate conditions and geomorphologic features of Ankara. In Ankara, the climate is very dry in summer and in part of the autumn. As a result, in these seasons urban and rural areas show similar heating behaviors, hence intensity of UHIs is small in summer. Since Ankara is settled at the bottom of a basin surrounded by mountains, the depth of urban boundary layer decreases, due to temperature inversion, and hence anthropogenic heat plays an important role on the intensity of UHI in winter. As a result of these factors, different from other temperate latitude cities, the intensity of UHI in winter is higher than in other seasons in Ankara.

3˙2. *The change of UHI in February 2002*. – The magnitude and variation of UHI in February 2002 were determined using the measurements made at the Gar (urban) and Yenikent (rural) stations. Firstly, the distribution of $\Delta T_{(\text{u-r})}$ differences in this month was considered. The investigation of daily variation of UHI showed that UHI nearly disappeared between 10-11 and 24-27 February (fig. 5). These days were dominated by cyclonic conditions. There were precipitations in these periods, and the wind speed was above $8.0\,\text{m}\,\text{s}^{-1}$ in urban and $10.0\,\text{m}\,\text{s}^{-1}$ in rural stations. This is largely due to difference in cooling rates of urban and rural areas and urban canyon geometry. Oke *et al.* [15] recognized that urban/rural cooling rates and thermal radiant emittance are causes of the dynamic nature of the UHI. The rates of cooling of different surfaces differ thereby causing different heat island intensities. Largest nocturnal winter UHI follows long periods without precipitation. Dry spells in wet seasons could result in lower than

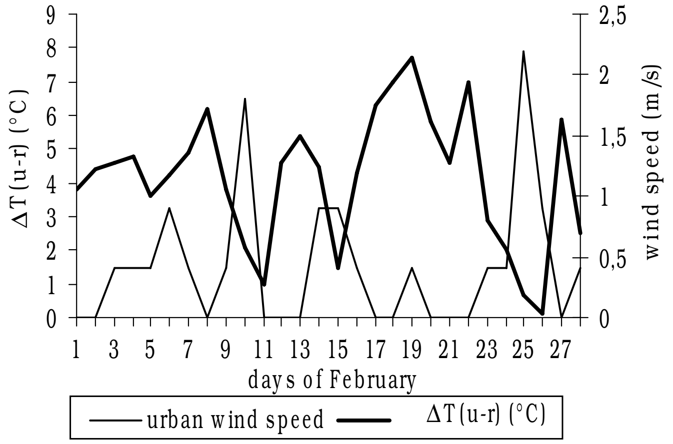

Fig. 5. – The change of the amplitude of UHI and wind speed at 21:00.

seasonal rural thermal admittance, and larger UHI magnitudes [16].

In February there was positive $\Delta T_{(\mathrm{u\text{-}r})}$ at 21:00 every night. In this study $\Delta T_{(\mathrm{u\text{-}r})} \geq 0.5\,^{\circ}\mathrm{C}$ was taken as a threshold to identify a well-developed UHI. Therefore, there were well-developed UHIs on 26 nights. The distribution of UHI in February was as follows: 4.1–5.0 °C 32.1%, 5.1–6.0 °C 10.7%, 6.1–7.0 °C 14.3% and above 7.1 °C it was 3.6%. In other words, more than half of UHI were above 4.0 °C in this month. When we look at the relation between the wind speed and formation of UHI, we see that UHI gets weaker when the wind speed in the city was above $1.0\,\mathrm{m\,s^{-1}}$. The wind speed was below $0.5\,\mathrm{m\,s^{-1}}$ when the magnitude of UHI increased.

3˙3. *Diurnal variation of UHI*. – On 19-20 February 2002, there were anticylconic conditions dominating over the whole Turkey, with sea surface pressure above 1020 hPa on Ankara. Due to these anticylconic conditions, the frontal systems were not effective on the western, central and northern parts of the country. These conditions resulted in clear skies and calm weather in the country. The maximum visibility was above 1600 m and the wind speed was lower than $0.4\,\mathrm{m\,s^{-1}}$. The terresial radiation which occurred in the morning caused the formation of dew and fog.

In order to examine the formation of UHI on 19-20 February 2002, there were temperatures taken at 12.00, 15.00, 18:00 and 21:00 on 19th February and temperatures taken at 00:00, 03:00, 06:00 and 09:00 on 20th February were considered into account. The investigation of the temperature map of 12:00 local time of 19 February 2002 showed that there was a weak positive UHI (fig. 6a). The temperature in the city was 10 °C while the temperature of the rural region was 9 °C. The amplitude of UHI was 1.4 °C. Western wind was dominant in this period with a wind speed of less than $1\,\mathrm{m\,s^{-1}}$. A similar weak UHI continued until 15:00 (fig. 6b). This is due to the fact that dry soil absorbs more radiation during day time as explained before. The UHI becomes more distinctive starting from 16:00, where it reached 3.9 °C (fig. 6c). The increase of this difference to 3.4 °C at 18:00 from 1.2 °C at 17:26 when the sun set shows the fact that rural areas cooled down faster since the heat capacity of rural areas are much lower than that of urban areas.

The heat capacity of rural areas is lower than the heat capacity of urban areas.

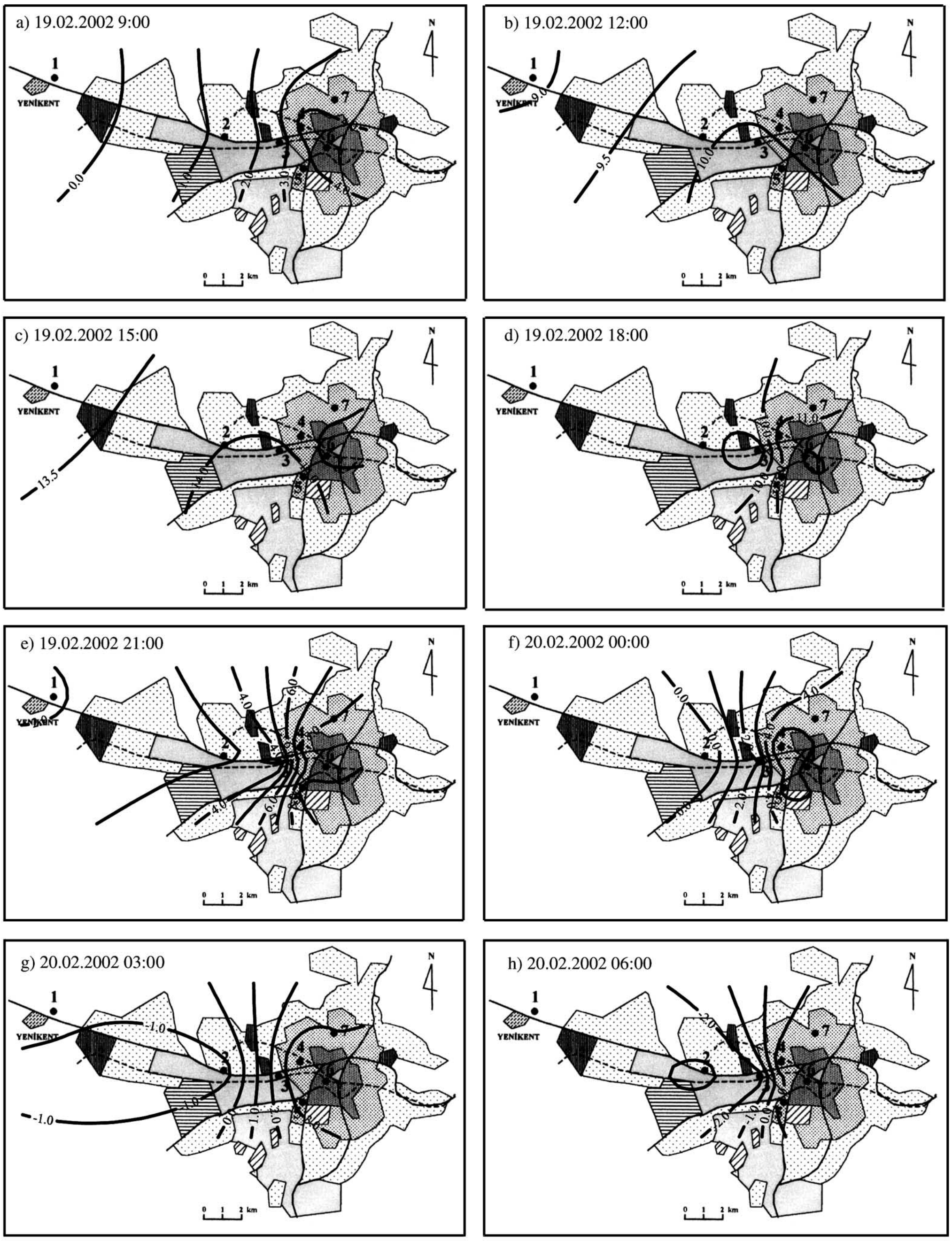

Fig. 6. – The change of UHI in Ankara (°C).

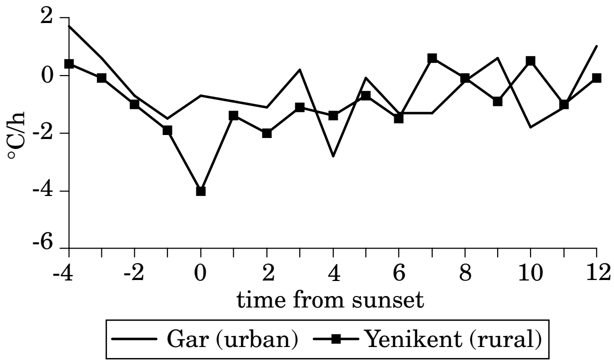

Fig. 7. – Hourly cooling rates at Yenikent and Gar stations (19-20 February 2002).

The fact that the temperature at suburban AOÇ station showed a decrease of 2.9 °C in thirty minutes, while this decrease was merely 0.1 °C in Gar station, clearly indicates the difference between the rate of cooling of urban and rural areas (figs. 7, 8). The wind speed at this time was $0.9\,\mathrm{m\,s^{-1}}$ in Yenikent and $1.3\,\mathrm{m\,s^{-1}}$ in Şeker stations. The wind speed at the other stations was $0.0\,\mathrm{m\,s^{-1}}$. The fact that wind conditions were calm in urban and suburban areas has a positive effect upon the development of UHI.

The UHI reached its maximum value at 21:00 local time with a temperature difference of 7.7 °C. When the temperature was 8.0 °C in city station while it merely reached 3.0 °C in suburban areas, causing a very sharp cliff of UHI. The green area formed by Şeker and AOÇ stations caused the formation of a cold bay of UHI [17]. A number of studies have shown that large spatial gradients of temperature are possible in the vicinity of urban parks [18, 19].

The $\Delta T_{(\text{u-r})}$ value at 00:00 on 20th February was 7.3 °C. The period between 21:00 and 00:00 was the time in which the UHI was the strongest (fig. 6d-e). $\Delta T_{(\text{u-r})}$ started to become weaker after midnight. The most striking feature here is the rate of cooling, very fast in urban stations and relatively slow in rural and suburban ones. The rural characterized areas cooled down by 1.5 °C within a period of 3 hours while there was no (for example Yenikent) or very little change in urban or suburban areas (for instance

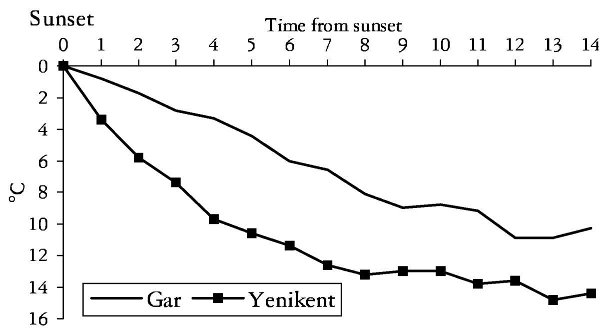

Fig. 8. – Cumulative nocturnal cooling curves for urban/rural sites in Ankara (19-20 February 2002).

Şeker with 0.4 °C^{-3h}). Dew-point was reached after midnight (6-7 hours after the sun set) in rural areas, and this fact caused the release of latent heat of condensation, with a consequent increase of temperature (fig. 7).

The temperature difference between the rural and urban areas started to decrease half an hour before sunrise and went to 4.3 °C at 06:00 (fig. 6f, g). Lower heat capacity of rural area caused a rapid loss of energy after the sunset. There was a very rapid rate of cooling at Yenikent station within the first hour following the sunset (figs. 7, 8). A rapid cooling rate in urban areas was observed four hours after the sunset due to heat emitted by anthropogenic surfaces. The decrease in temperature was fast in rural areas and slow in urban areas, due to the loss of energy stored in the urban areas throughout the day. The positive UHI was still active at 09:00. The urban areas were bounded with 3.0 °C isotherm which decreases towards the rural area and suburban and rural areas are approximately bounded with 0.0 °C isotherm. The rural station Yenikent was the only subzero station with −0.8 °C.

4. – Conclusions

This study investigated the UHI values in February 2002 and the development of a UHI between 19-20 February 2002 in Ankara, which is the second most populated city in the country. In addition to this short-term analysis, data registered by two State Meteorology Stations (AMS and EMS) and seven stations installed by the authors were analyzed to detect long-term temperature variation in Ankara. The main results obtained are the following:

– There was UHI at 21.00 at each night in February 2002. In 26 days of them $\Delta T_{(\text{u-r})}$ is greater than ≥ 0.5 °C. The nocturnal UHI amplitude was 7.7 °C. The wind speed has an important effect upon the magnitude of UHI. Most of the UHI occurred at 21:00, with temperature difference of 4.0 °C.

– UHI intensity gets higher following the sunset and reaches the maximum between 21:00 and 00:00. This can be attributed to the lower heat capacity of rural areas and urban canyon geometry.

– The urban areas cool down faster than the rural areas after midnight.

– With a significance level of 95% and 99% respectively in winter and spring, an increasing trend in the UHI intensities was observed since the second half of 1980s in Ankara.

– Ankara is settled at the bottom of a basin, which is surrounded by mountains. The depth of urban boundary layer decreases, due to temperature inversion [20], and hence anthropogenic heat plays an important role on the intensity of UHI in winter. As a result of these, different from other temperate latitude cities, the intensity of UHI in winter is higher than other seasons in Ankara.

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REFERENCES

[1] Landsberg H. E., *The Urban Climate* (Academic Press, New York) 1981.
[2] Oke T. R., *Review of Urban Climatology*, 1973-1976 (WMO No: 539) 1979.
[3] Karaca M., Tayanç M. and Toros M., *Atmos. Environ.*, **29** (1995) 3411.
[4] Karaca M., Anteplioğlu Ü. and Karsan H., *Nuovo Cimento C*, **18** (1995) 49.
[5] Tayanç M. and Toros H., *Climatic Change*, **35** (1997) 501.
[6] Karaca M. and Tayanç M., *Urbanization effects on the regional climate in Turkey*, in *Proceedings of Second European Climate Conference, Vienna 1998*.
[7] Nasrallah A. and Balling R. C., *Climatic Change*, **25** (1993) 153.
[8] Çiçek İ., *Ank. Üniv. DTC Fak., Fakülte Der.*, **40**, 1-2 (2000) 189.
[9] Yague C., Zurita E. and Martínez A., *Atmos. Environ. B*, **25** (1991) 327.
[10] Montávez J. P., Rodríguez A. and Jiménez J. I., *Int. J. Climatol.*, **20** (2000) 899.
[11] Sneyers R., WMO Technical Note 143 (Geneva) 1990.
[12] Lee D. D., *Weather*, **30** (1975) 102.
[13] Unwin D. J., *Weather*, **35** (1980) 43.
[14] Oke T. R., *Q. J. R. Meteorol. Soc.*, **108** (1982) 1.
[15] Oke T. R., Yap D. and Maxwell G. B., *Comparison of urban/rural cooling rates at night*, in *Proceedings International Symposium on Environment and Second Conference On Biometeor.* (American Meteorological Society, Boston) 1972.
[16] Runnals K. E. and Oke T. R., *Phys. Geogr.*, **21** (2000) 283.
[17] Klysik K. and Fortuniak K., *Atmos. Environ.*, **33** (1999) 3885.
[18] Spronken-Smith R. A. and Oke T. R., *Boundary-Layer*, **93** (1999) 287.
[19] Saito I., Ishihara O. and Katayama T., *Proceedings of the Fourth International Conference on Urban Climate, Planning and Building, Kyoto, 1989*.
[20] Sipahioğlu Ş., *Meteoroloji Dergisi* (1985) 23.