THE THERMAL CHARACTERISTICS AND THE MITIGATION POTENTIAL OF A MEDIUM SIZE URBAN PARK IN ATHENS, GREECE

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ABSTRACT

An urban park located in a densely built area of Western Athens, Greece is monitored. Temperature data from 15 urban and suburban stations are also used to perform comparative analysis at the city level. The park presents an important temperature inhomogeneity during day and night due to the variable radiative cooling capacity and shading potential between its various zones. Average nocturnal Cool Island Intensities (CII) against the reference urban stations varied between – 0.7 K to – 2.8 K while during the daytime the maximum CII was between -0.2 to -2.6 K. A statistical significant correlation between the magnitude of the CII and the population density index is found for both day and night. The data analysis showed that the park was warmer than the urban stations for ambient temperatures lower than 34 °C, while for higher urban temperatures the park remained cooler. Moreover the absolute CII increased as a function of the ambient temperature. A strong correlation with the wind speed is observed for speeds higher than 6 m/sec. The mitigation potential of the park was assessed by using three traverses in and around the park. The analysis of the Park Cooling Index (PCI) showed a variation from 3.3 to 3.8 K. The traverses' temperature gradient was estimated to be between 0.16 to 1.4/100m.The climatic influence of the park was extended up to 300 m away from the borders of the park.

KEYWORDS

Urban Heat Island, Urban Park, Cool Park Intensity, Cool Island Intensity

1 INTRODUCTION

The urban heat island is one of the more studied phenomena of climate change. It deals with higher ambient temperatures in the central areas of the cities compared to their suburban or rural surroundings (Santamouris, 2001). Heat island is a very well documented phenomenon for the city of Athens, Greece (Livada et al, 2007, Santamouris et al, 1999, Kassomenos and Katsoulis 2006, Gobakis et al 2011) and is observed mainly in the Central and Western zones of the city. The increase of green spaces in the city under the form of green roofs, urban parks and other green zones is a known and efficient mitigation technique. Trees and green spaces contribute highly to the improvement of the urban climate as they provide solar protection, affect air movements and heat exchange, absorb solar radiation and cool the air through evapotranspiration processes. Consequently, decrease of the temperature is achieved. The present paper reports the analysis of the field measurements performed in and around a medium size park in Western Athens, Greece during the summer period. Data from 15 urban stations are used in a comparative way to understand and analyse the relative climatic conditions in the park and the reference urban areas as well as to evaluate its climatic distribution. The specific objectives of the present study are to analyse the thermal conditions and the temperature inhomogeneity in the park during the day and the night period, to investigate the climatic influence of the park in its immediate surroundings during the warm summer period and to compare the temperature status in the park against other city zones presenting different urban characteristics, thermal conditions and heat balances.

2 EXPERIMENTAL SITE DESCRIPTION

2.1 DESCRIPTION OF THE PARK AND THE AREA

The studied urban park is located in the Municipality of Peristeri, a suburb located in the western part of Athens, Greece, 37.58 ° N and 23.43 ° E. The total surface area of the park is 60.000 m^2 while it is surrounded by a densely built urban area involving medium size residential and commercial buildings with a heavy traffic. The park is covered by grass, various types of bushes, low trees dense medium and high size trees and it is watered during summer just after sunrise and sunset. The suburb of Peristeri is characterized by a strong heat island phenomenon ranging between 6 to 12 K (Mihalakakou et al, 2002, Gianopoulou et al, 2011) because of the very high density, the accelerated industrialization and the very significant anthropogenic heat.

2.2 Experimental Procedure

A series of measurements of the ambient temperature inside and in the surrounding of the park were performed during the period 29/7/2012-2/9/2012. The measurements were recorded by nine fixed meteorological sensors distributed inside the park, combined with measurements of the ambient temperature conducted inside the park and its immediate surroundings using a calibrated hand held thermometer. Three different traverses were designed and followed towards different directions around the park. Measurements were performed under hot stable climatic circumstances, clear skies and peak solar radiation conditions, and finally moderate to strong wind speeds from NE directions during the day period. Data from eighteen meteorological stations located around the Athens area have been also collected for the whole experimental period.

3 RESULTS

3.1 Temperature Distribution in the Park

The distribution of the minimum and maximum daily temperatures in the park as

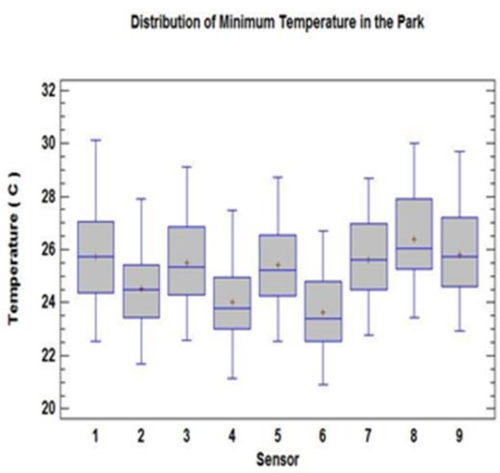

Figure 1: Distribution of the Daily Minimum Temperature in the Park during the experimental period.

recorded by the nine sensors is given in Figures 1 and 2 respectively. Minimum temperatures in the park recorded around sunrise. No important time lag is found between the different sensors. Minimum temperatures varied between 21 ° C to 30.5 ° C, with an average minimum temperature close to 25.2 ° C. The maximum temperature difference between the nine sensors was recorded around sunrise time and ranged from 1.0 to 3.0 K. Significant recorded temperature differences may be justified as a) the wind speed around sunrise was low during the whole experiment, (< 2 m/sec), advection phenomena were very weak and thus the transfer of air masses between the various zones of the park was insignificant; b) the sky view factor in the area around the sensors varied considerably and therefore the corresponding radiative cooling potential was very different. The maximum daily temperature in the park varied between 30 ° C and 41.4 ° C with an average value close to 34.8 ° C. Maximum daily temperatures are recorded around 14:30 - 15:30 local time, for all sensors. The average maximum temperature difference between nine sensors in the park was close to 2.5 K, however in specific days the daily maximum temperature difference in the park reached values close to 5 K. Daytime temperature differences inside the park are strongly related to the shading conditions in every zone.

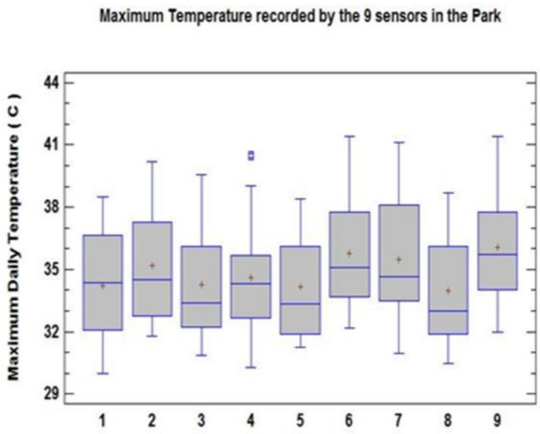

Figure 2: Distribution of the Daily Maximum Temperature in the Park during the experimental period.

3.2 Analysis of the Nocturnal Cool Island Intensity

In order to calculate the Cool Island Intensity of the Peristeri Park during the night and day period, the hourly, minimum and maximum daily temperatures measured inside the park have been compared against the corresponding data from 15 meteorological stations located in the major Athens area. In fact, seven of the stations are situated close to the park in the area of Western Athens, six of the stations are in and around the Athens Municipality and two of the stations are in the Northern part of the city. The distribution of the night time minimum temperatures recorded in the park as well in the 15 reference stations is given in Figure 3 for the whole period of measurements. Analysis of the night time temperature difference between the park and the urban stations revealed that the maximum ΔT occurs just after the sunset period and before midnight. During this period the average CII between the park and the urban stations varied between -0.7 K to -2.8 K. The

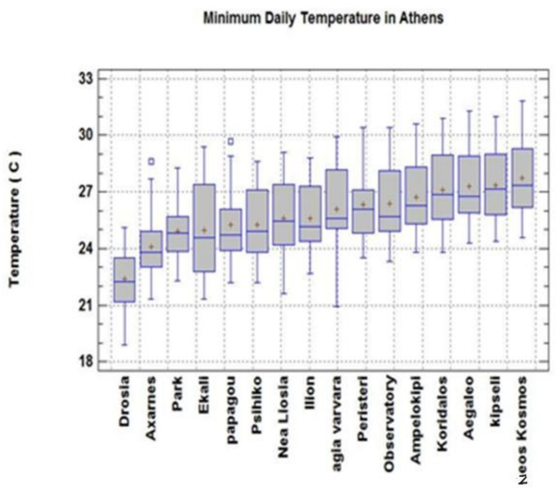

Figure 3: Distribution of the Minimum Daily Temperature in the Park and the other 15 stations in Athens.

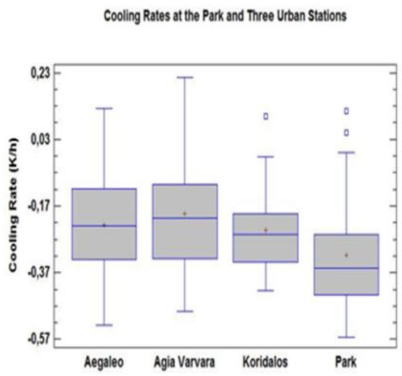

Figure 4: Cooling Rates, (K/h) for the park and three urban stations.

cooling rate of the park as well as of three surrounding urban stations was calculated for the period between sunset to sunrise, and for all days of the experiment (Figure 4). The average cooling rate in the park was calculated close to 0.32 K/h, a much lower value than the ones reported for Gothenburg, Sacramento and Vancouver. This may attributed to the much higher urban density in the considered area compared to the previously mentioned cities. In parallel, the cooling rate of the urban stations varied between 0.19 K/h to 0.24 K/h, values to about 60-70 % lower than in the park. As shown (Figure 3), the average minimum temperature in the park was lower than the corresponding value of all the urban reference stations (-0.7 to -2.4 K), while it was slightly higher than that of the three stations located in green areas in the borders of the city (+2.5 K and +0.8 K). Lower minimum nocturnal temperatures in the park and higher cooling rates should be attributed: a) to the higher radiative cooling capacity in the park because of the much higher sky view factor, and b) to the high convective thermal gains released in the reference urban areas by buildings and urban structures heated during the day time. Both of the parameters are related to the density and the characteristics of the buildings and in a way to the population density in a region .There is a statistically significant strong correlation between the observed nocturnal CII and the corresponding population density for every considered urban area that confirms the importance of the urban density on the development of lower nocturnal temperatures in the park (Figure 6). The night time temperature difference, CII, calculated for each reference station presents a high daily variability. Figure 5 gives the daily variation of the calculated CII around the sunrise period, for four reference urban stations presenting high temperature differences against the park. As shown, the daily fluctuation of the temperature difference in all stations is very significant and may reach values between -4.7 to 0.6 K. However, it is important to note that the pattern of the four curves is very similar although the magnitude of the corresponding CII differs between the stations. This signifies that the daily evolution of the temperature difference is mainly affected by global changes at the city level, like synoptic scale phenomena, than changes of local scale. To better understand the daily fluctuation of the nocturnal temperature differences, the relation between the daily minimum temperature and the corresponding CII in five urban stations were calculated (Figure 7). As shown the higher the minimum ambient temperature in the urban station, the higher the nocturnal temperature difference value. A similar pattern is also found between the maximum temperature of the previous day and the corresponding nocturnal Cooling Island Intensity. Higher daytime ambient temperatures result to an important increase of the minimum night-time temperatures

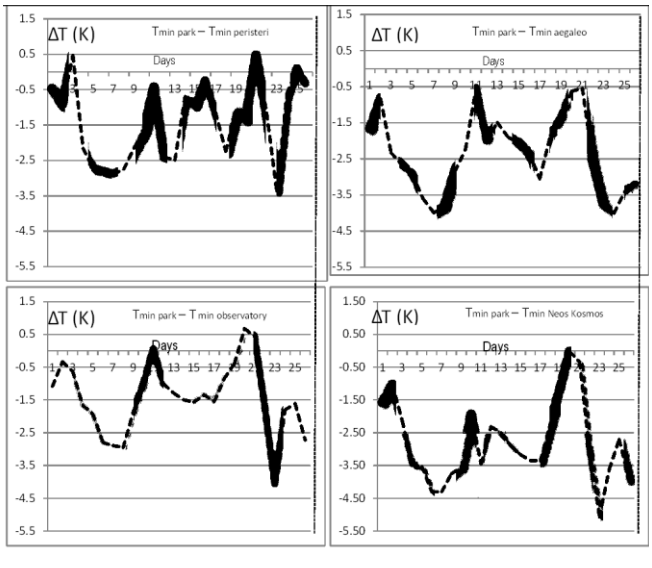

Figure 5: Daily Nocturnal Difference of Minimum Temperatures between the park and four Urban Stations.

and a significant decrease of the daily temperature amplitude in the urban stations. On the contrary, higher urban temperatures affect much less the magnitude of the daily temperature amplitude in the park than in urban areas as their thermal capacity is much lower and the anthropogenic heat is almost negligible. The daily amplitude for the urban stations and the park is quite similar for ambient temperatures close to 30 ° C however, for temperatures around 40 ° C the amplitude in the urban stations may be 4-5 K lower than that in the park.

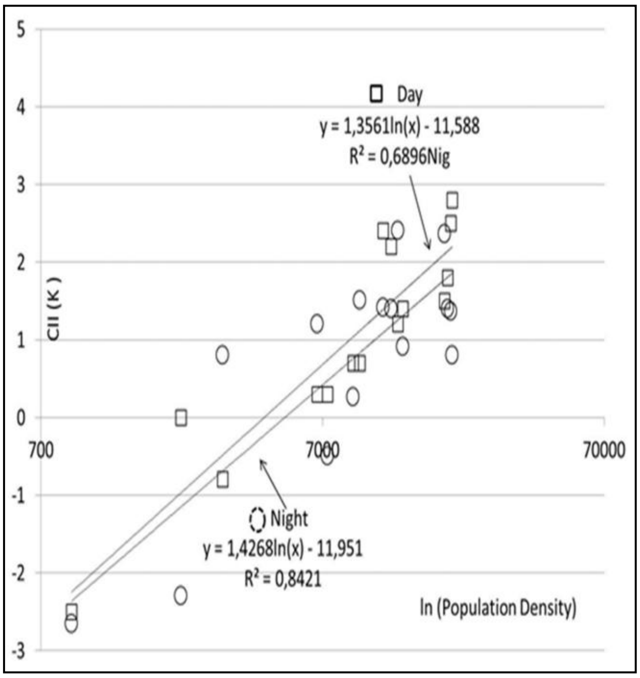

Figure 6: Relation of the daytime and nocturnal Cool Island Intensity with the Population Density.

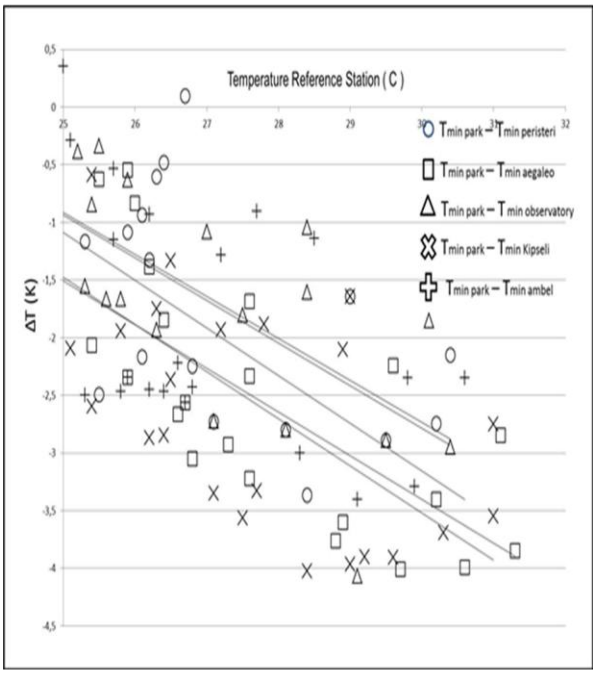

Figure 7: Relation between the daily minimum temperature and the corresponding ΔT for five urban stations.

3.3 Analysis of the Day Time Cool Island Intensity

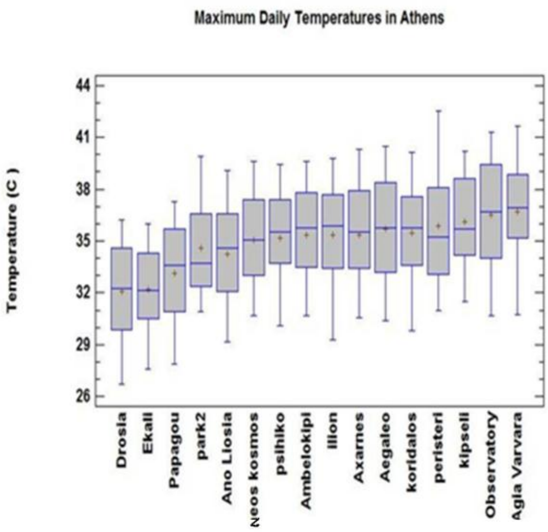

Figure 8: Distribution of the Daytime Maximum Temperature in the Park as well as in 15 urban stations.

The distribution of the daytime maximum temperatures recorded in the park during the whole period of the measurements as well as in the 15 previously presented reference stations indicate that the average maximum temperature of the park was lower than all the urban stations (Figure 8). However, it was warmer than the two stations located in suburban areas around the city, Ekali and Drosia, and an urban station located in a quite green zone of Athens. The Cool Island Index against the 12 urban stations was varied between -0.2 K and -2.6 K with an average value close to -1.4 K. The park presented almost 2.5 K higher maximum temperature than the suburban stations of Ekali and Drosia. Lower daytime maximum temperatures in the park compared to the urban stations are mainly attributed to the increased shading in the park provided by the plants that decreases the soil surface temperatures and the corresponding convective gains to the ambient air, the lack of antropogenic heat, the evaporation losses, and the absence of convective gains from high temperature urban structures and buildings. It is characteristic that the reported Cool Island Intensity values increase by -1.2 K when the temperature of the more shaded part of the park is used as reference while it decreases by the same absolute value when the more exposed to solar radiation part of the park is used as a reference instead of the average park temperature. In parallel, an important correlation between the daytime Cool Island Intensity and the population density is found (Figure 6). The relation is statistically significant although is less strong than the one found for the nighttime period. Like during the night period, the daily variability of the daytime Cool Island Intensity in the park is high. Particularly, varies between + 2.5 K to - 7.0 K, while the pattern of the daily evolution is similar for all stations. A very important correlation between the maximum ambient temperature and the corresponding Cool Island Index in the park, is obtained, (Circle points). It is found that that the higher the maximum daytime temperature in the urban station, the higher the CII in the park (Figure 9). However, it is very interesting to note that when the temperature in the city is higher than 38 to 39 ° C the Cool Island Intensity of the park is decreasing seriously and does not

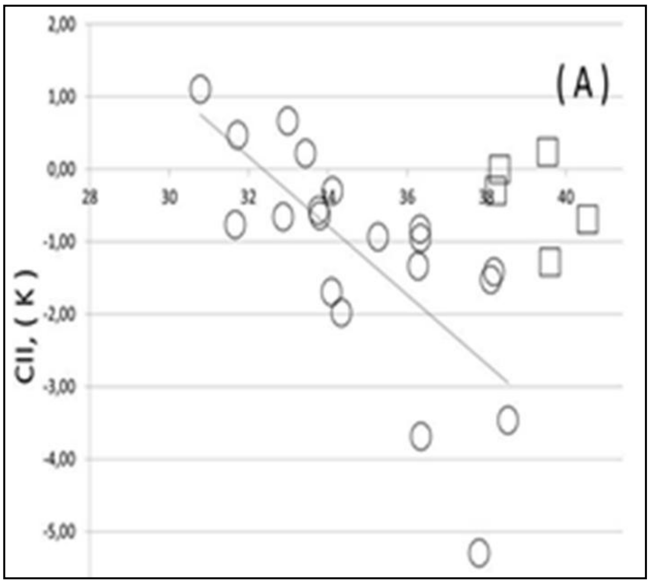

Figure 9: Relation between the daily average maximum ambient temperature of eight urban stations with the corresponding average Cool Island Intensity in the park.

follow the previous found trend between the CII and the ambient temperature (Figure 9, square points).

3.4 Mitigation Potential and Analysis of the Traverses around the Park

As already mentioned, three types of traverses were designed and carried out to estimate the climatic influence of the park in the surrounding area during and around the noon period. The first and the second traverses were performed on a daily basis since the 23rd of August to the 2nd of September 2012. For the first traverse, monitoring of the temperature was extended up to 420 m from the park towards NE directions and on a principal street with quite heavy traffic. The traverse included eight dense residential blocks with buildings of 2 or 3 stores. The street has a width close to 7 m, is covered by asphalt and has very few trees around it, while its H/W ratio varies from 1.0 to 1.Eight measurements are taken along the road as shown in Figure 10. The second traverse was carried out along the same road but towards NW direction. The street continues to have the same characteristics as described previously, however the first 120 meters immediately after the park exit, are surrounded from both sides by a non-built open space (Figure 10). Measurements are taken at seven specific points.

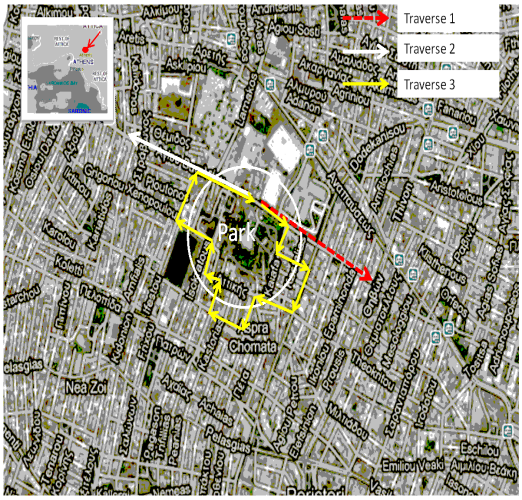

Figure 10: Traverses around the park area.

The distribution of the average temperature along the first and the second traverses are given in Figure 11. As shown, the distribution of the temperature along the traverse follows a second order polynomial relation with R^2= 0.95-0.97 for both cases. The calculated average Park Cooling Index PCI, was close to 3.3 K. During the first traverse, while the average temperature in the park was 32.6 ° C, the temperature increased by 1.1 K just out of the main entrance of the park and reached values close to 35.9 at the end of the traverse. This last point of the traverse corresponds to an intersection with a major traffic artery of the city where the generated anthropogenic heat is high. Temperatures tend to stabilize at about 300 m beyond the park, while the high value measured at the end of the traverse was influenced by the traffic. Interpretation of the complete set of measurement permits to consider that the climatic influence of the park should not exceeded 300-350 meters. During the second traverse, the PCI was 3.8 K, while a very rapid increase of the temperature was observed for the initial 150 meters because of the vicinity with the non shaded open space.

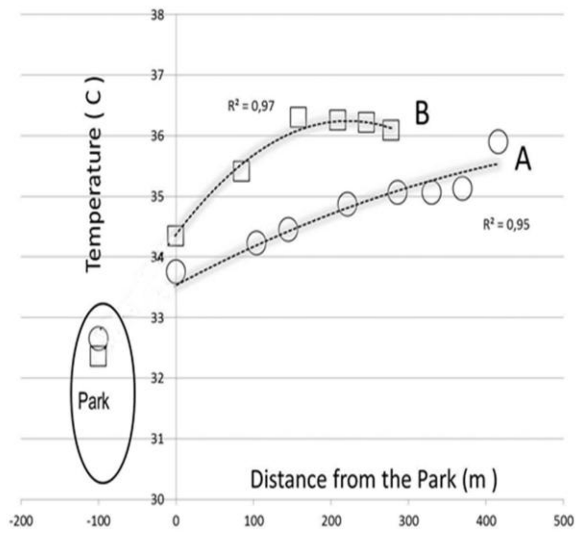

Figure 11: Distribution of the average ambient temperatures along the first, (A) and the second, (B), traverse. Also, the average temperatures of the park are given.

Temperatures increased along the initial 220 meters end then were stabilized or even slightly decreased. The temperature gradient along the first traverse varied between 0.16 K/100 meters and 0.84 K/100 meters with the average value of 0.52 K/100 meters. Calculations are based using as initial reference temperatures that out of the park and as final the one at the end of the traverse. For the second traverse, the temperature gradient was higher because of the proximity with open field and varied between 0.75 K/100 meters and 1.4 K/100 meters. When as reference the average temperature in the park is used than the temperature at the exit of the park, the temperature gradient varied between 0.45 K/100 meters to 1.1 K/100 meters with an average value of 0.78 K/100 meters for the first traverse, and values between 1.0-1.8 K/100 meters for the second traverse with an average close to 1.2 K/100 meters. These values are much higher than the temperature gradients reported by Lindqvist S. (1992), for a low density area in Gothenburg and considerably lower than those reported by Lee et al, (2009) for a very dense commercial area in Seoul. It is found that the temperature gradient along both the traverses is strongly influenced by the wind speed, especially for values higher than 5 m/sec (Figure 12). Increase of the wind speed tends to rise in a statistical significant way the temperature gradient beyond the park limit. Higher wind speed towards the windward side of the park, create a high pressure that seriously limits the flow of cool air from the park to the surrounding area. The third traverse around the park perimeter had as objective to investigate the temperature differences between the windward and the leeward sides of the park. Traverses have been carried out 24 times during the experimental period between 13:00-14:00. The main conclusion of the analysis is that the park is in average 0.8-1.2 K cooler than its immediate surroundings. In parallel, it is found that temperature around the park is very similar and there no significant temperature differences between the leeward and windward sides. This happens because of the density, the layout and the generated anthropogenic heat around the park vary considerably involving non shaded open spaces, partly or fully shaded urban canyons and some green spaces. Thus, the possible thermal benefits from the park are counterbalanced by various thermal gains.

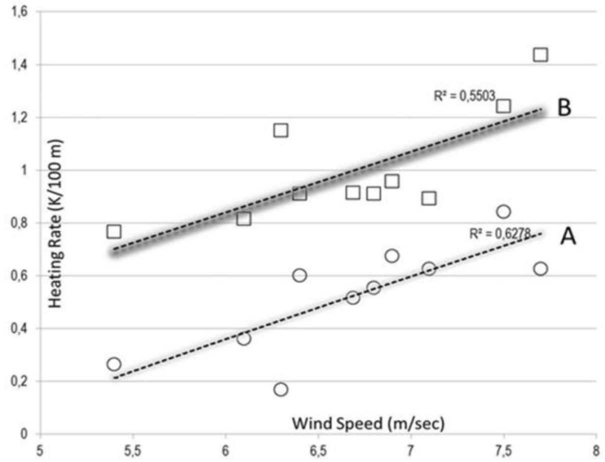

Figure 12: Relation between the wind speed and the heating rate for wind speeds higher than 5 m/sec for the first, (A) and the second traverse, (B).

4 CONCLUSIONS

It is demonstrated that even medium size urban parks can create local cool islands during the day and the night period. During the night time the average cooling rate in the studied park was 0.32 K/h, much higher than in the reference urban stations where values ranged between 0.19 to 0.24 K/h. This has resulted to important night time Cool Island Intensities in the park (-0.7 K/h to -2.8 K/h) against 13 urban stations. Temperature differences varied as a function of the urban characteristics and found to correlate in a statistical significant level with the population density index of the considered urban areas. Higher maximum daytime temperatures correspond to lower day-night temperature amplitudes in the urban stations while a strong correlation has been found between the daily maximum temperatures and the nocturnal Cool Island Intensities in the park. During the day period, the average maximum temperature in the park was lower than in 12 reference urban stations and the magnitude of the corresponding daily Cool Island Intensity varied between -0.2 K and -2.6 K with an average value close to -1.4 K. The CII found to have a strong correlation with the population density in the corresponding urban areas. The park is found to be warmer than the urban areas for ambient temperatures lower than 34 C, however the CII increased as a function of the ambient temperature for values higher than 34 C. The calculated PCI was between 3.3 K and 3.8 K, while the temperature gradient along the traverses from the park to the urban areas varied between 0.16 to 1.4 K/100 meters connected strongly with wind speeds higher than 5 m/sec. Parks may contribute highly to mitigate urban heat islands, however their climatic influence is subject to the characteristics of the park and the thermal properties of neighbouring urban areas.

5 ACKNOWLEDGEMENTS

This work would not have been possible without the considerable help of the Professor Mathheos Santamouris.

6 REFERENCES

Giannopoulou K., I. Livada, M. Santamouris, M. Saliari and M. Assimakopoulos, Y.G. Caouris, (2011) : On the Characteristics of the Summer Urban Heat Island in Athens, Greece. Journal Sustainable Cities and Society, Volume 1, Issue 1, Pages 104-115

Gobakis, D. Kolokotsa, A. Synnefa, M. Saliari, K. Giannopoulou, M. Santamouris, (2011) : Development of a model for urban heat island prediction using neural network techniques, Sustainable Cities and Society, Volume 1, Issue 2, Pages 104-115

Kassomenos, P.A. and Katsoulis, B.D, (2006) : Mesoscale and macroscale aspects of the morning Urban Heat Island around Athens, Greece, Meteorology and Atmospheric Physics, Volume 94, Issue 1-4, Pages 209-218

Lee Sang-Hwa, Kyoo-Seock Lee and Wen-Cheng Jin, (2009) : Effect of an urban park on air temperature differences in a central business district area, Landscape Ecol. Eng, 5:183–191

Lindqvist S. (1992) : Local climatological modelling for road stretches and urban areas. Geograjska Annaler 14A,265-274.

Livada – M.Santamouris, M.N.Assimakopoulos, (2007) : On the variability of summer air temperature during the last 28 years in Athens, JGR, 2007, Journal of Geophysical Research, Vol. 112, D12103.

Mihalakakou P., H.A. Flocas, M. Santamouris and C.G. Helmis, (2002) : 'Application of Neural Networks to the Simulation of the Heat Island over Athens, Greece, Using Synoptic Types as a Predictor, J. Applied Meteorology, 41,5,519-527.

Santamouris, G. Mihalakakou, N. Papanikolaou and D. N. Assimakopoulos, (1999) : ' A Neural Network Approach for Modeling the Heat Island Phenomenon in Urban Areas During the Summer Period' Geophysical Research Letters, 26, 3, p.p. 337-340.

Santamouris, M. (Ed.), (2001). Energy and Climate in the Urban Built Environment. James and James Science Publishers, London.