

Monitoring the effect of urban green areas on the heat island in Athens

I. Zoulia · M. Santamouris · A. Dimoudi

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Abstract The role of urban green areas in the microclimatic conditions of cities, during summer, is investigated in this paper through monitoring campaigns carried out at the National garden, at the city centre of Athens. Two types of investigations were carried out: i) a microscopic one that investigated the thermal conditions inside the Garden and the immediate surrounding urban area and ii) a macroscopic one that compared the temperature profile of the Garden with that of the greater city centre area. It was concluded that in microscopic level, the temperature profile inside the National Garden and the immediate surrounding urban area did not showed a clear evidence of the influence of the Garden and it was dependent on the characteristics of each location. In a macroscopic scale, the Garden was found cooler than the other monitored urban locations and temperature differences were mainly greater during the night,

especially in streets with high building height to street width (H/W) ratio and low traffic, while in streets with high anthropogenic heat during the day, the biggest temperature differences were recorded during the day.

Keywords Urban green areas · Microclimate · Heat island · Monitoring

Introduction

Heat island is the more documented phenomenon of climate change. The phenomenon is associated with increased urban air temperatures compared to the air temperature of the surrounding rural or suburban areas. Many European cities present high heat island intensity mainly because of the positive thermal balance (Santamouris 2007). Heat island intensities vary between 1 to 10 degrees depending on the intensity of the heat sources in the area. Multiyear heat island measurements in Athens have permitted to have a very clear knowledge of the phenomenon in the area (Santamouris et al. 1998, 1999; Mihalakakou et al. 2004). It was found that maximum heat island intensity reaches values close to 10°C (Mihalakakou et al. 2002) while its impact on the energy consumption of buildings is extremely serious (Hassid et al. 2000; Santamouris et al. 2001). In addition, it was proved that heat island

I. Zoulia · M. Santamouris
Group Building Environmental Studies,
Physics Department, University of Athens,
University Campus, Build. PHYS-V,
Athens GR 15784, Greece

A. Dimoudi (✉)
Department of Environmental Engineering,
School of Engineering,
Democritus University of Thrace,
Vas. Sofias 12, 67 100 Xanthi, Greece
e-mail: adimoudi@env.duth.gr

increases considerably the ecological footprint of the city (Santamouris et al. 2007).

Various mitigation techniques have been proposed to fight heat island, like reflective natural materials (Doulos et al. 2004), highly reflective white paints, (Synnefa et al. 2006), and cool coloured coatings, (Synnefa et al. 2007a, b). In recent years, the role of green areas in moderating urban climate has been extensively studied all over the world. Trees and green areas have a large effect at moderating the microclimate and also contribute at cooling the cities (Dimoudi 1996; Santamouris 2001) as evapotranspiration from vegetation foliage reduces air temperature and increases humidity. Vegetated areas are known to be comparatively cooler during daytime than most other urban elements. The air temperature in the shade of trees was reported to be lower by 0.7–1.3°C (Souch and Souch 1993), 1.7–3.3°C (Taha et al. 1988) up to 3.6°C (Parker 1989) than areas with no trees. However, in other studies no significant reductions in air temperature in the shade of trees were detected (Herrington et al. 1972; Plumley 1975). Correlations between microclimatic parameters like air temperature, relative humidity and solar radiation in the sun and shade of trees in parks during summer were also investigated (Georgi and Zafiriadis 2006).

In the case of large green areas such as parks, vegetation affects the surrounding air temperature and thus, improves the thermal environment of the urban area. The cooling effect of parks was investigated by several researchers. The average air temperature in green areas was recorded to be lower by 0.47°C (Shobhakar and Hanaki 2002), 0.6°C (Watkins et al. 2002), 1.5–2.8°C (Nichol 1996) than surrounding areas. In another study, this temperature difference reached up to 3.3–5.6°C during summer with a 25% increase in the number of trees (Akbari et al. 1992). However, some studies suggested that vegetated areas can be warmer than the surrounding built-up environment, creating unpleasant microclimatic conditions (Grimmond et al. 1996; Jauregui 1990) especially during night-time in urban parks with dense, medium sized trees (Potchter et al. 2006). Also, an urban park covered with grass can be warmer and sometimes even more humid than the built-up area during the day (Potchter et al. 2006).

Although, most studies investigated the influence of vegetation on summer urban heat island, investigation during the winter period of the influence of land use on the heat island, showed that the local air temperature which is one of the many factors that define ‘urban climate’, cannot be directly correlated with land use factors (Kruger and Givoni 2007).

The influence distance of a park on the surrounding area was also investigated in several studies. It was shown that the influence of large parks (500 ha) reaches a radius of up to 2 km, about the same as the park dimensions (Jauregui 1990) while smaller parks (about 35 ha) may influence areas extended at a distance of 1 km when the wind is strong (Ca et al. 1998). In several cities, the uneven distribution of green areas in the urban fabric does not make the maximum exploitation of the moderating effect of green areas in the microclimate of the surrounding urban areas (Kosmopoulos and Papanastasiou 2005).

Urban trees also affect the solar radiation received at ground level. It is argued that the cooling effect in small green areas is mainly due to shading (Sharlin and Hoffman 1984; Shashua-Bar and Hoffman 2003). The solar radiation in the trees’ shade was measured to be 10% lower than in the open air (Givoni et al. 2003) and certain deciduous trees reduce solar radiation by 25% to 50%, with an average reduction of 35% (Thayer and Maeda 1985).

Assessment of the effect of green areas in the urban environment is carried out either by evaluation of monitored data or through modelling studies. Monitored data can cover the *macro scale* where climatic data in the green areas is compared with climatic data from other sites distributed around the city. In *micro scale*, data are monitored in different points inside the green area and the immediate surroundings in the urban area (Ca et al. 1998; Barradas et al. 1999; Narita et al. 2004; Chen and Wong 2006; Potchter et al. 2006). Studies on macro scale are based either on remote sensing data (Kawashima 1994; Nichol 1996) or on meteorological data taken from stationary stations around the city (Shashua-Bar and Hoffman 2000) or from mobile measurements by crossing parts of the city (Gomez et al. 1998; Wong and Chen 2005) or combination of them (Saito

1990/1991; Spronken-Smith and Oke 1998; Sonne and Viera 2000; Jonsson 2004).

Modelling studies were also employed to investigate the thermal benefits of green areas in cities. These resulted at the development of empirical models based on the statistical analysis of monitoring data (Shashua-Bar and Hoffman 2000) or based on mesoscale atmospheric models (Avisar 1996). Other studies employed simple models describing the basic physiology of the plant or CFD modelling (Dimoudi and Nikolopoulou 2003) and combined modelling with CFD, radiation and thermal conduction models (Robitu et al. 2006).

Aim of paper

The aim of this paper is to investigate the effect of green areas on the thermal environment of the surrounding urban area during the summer period. The measurements, taken inside the National Garden of the Athens city and the immediate surrounding built area are analyzed in order to quantify the effect of parks on urban cities microclimate. Additionally, measurements in a greater scale covering the National Garden and other built areas in the city centre are analyzed in order to investigate the effect of the park in a macroscale.

Description of monitoring campaign

The measurements took place at the National Garden and its surrounding built area in Athens city (37°54' N, 23°43' E). The National Garden (15.5 ha), situated at the city centre next to the Sintagma Square and the House of Parliament, is the largest wooded area in the Athens centre (Picture 1). At the southern side of the Garden lies the crescent shaped ground of the Zappeion Exhibition Hall and its surrounding gardens. South-east of the National Garden and the Zappeion complex, the Panathinaic Stadium – the 1st Olympic Games open stadium – is located, surrounded by the woodland of the Arditos hill. At the southwest side of this complex, the Hadrian's Arch and the Ancient Temple of the Olympic Zeus are located. The Garden area is surrounded

by the Avenues of Vass. Sofias (North), Erodoú Attikou (East), Vass. Konstantinou and Vass. Olgas (South) and Amalias (West). The city centre is characterized by dense urban structure with multi-floor buildings (5–7 floors).

Five different routes were followed for the monitoring campaign. One route followed the perimeter of the Garden (Picture 2). The other four routes started from the Garden centre, they crossed it, following imaginary the four horizon directions (West: route A, South: route B, East: route C and North: route D), and they ended at the surrounding built area (Picture 3).

The characteristics of each route are as following:

Route A (10 measuring points): this route crosses a relatively disperse vegetated area of the Garden (4 measuring points inside the Garden and 1 at the perimeter) and continues at the adjacent high traffic, wide avenue (Amalias Av.). It passes through a typical 'urban canyon' street (Xenofontos str.) and ends at its corner with a high traffic, three lanes road surrounded by multi floor buildings (Filellinon str.).

Route B (14 measuring points): this route crosses the Garden (5 point in total, with 3 points at a non-dense vegetated area, 1 point at a denser vegetated area and 1 at its perimeter), passes through the grounds of the Zappeio Exhibition Hall (3 points), and its gardens (2 points) and continues at the adjacent Avenue that has relatively high traffic but no surrounding buildings.

Route C (12 measuring points): the route crosses a part of the Garden with moderate vegetation (7 measuring points in total, with the 3rd and 4th point next to a small lake, and the 7th point at the exit), continues at the adjacent avenue that has low traffic, moderate vegetation and buildings with gardens in front of them and continues through a typical 'urban canyon' street with low traffic.

Route D (14 measuring points): it crosses the Garden (8 points in total, with the 2nd



Figure 1 Overview of the National Garden and city centre – Location of meteorological stations

and 3rd point at a moderate vegetated area, the 4th and 5th points at a relatively dense vegetation, the 6th and 7th points located next to a small lake and a water reservoir and the 8th point at the perimeter), passes the adjacent wide Avenue with high traffic and light vegetation (2 points) and continues at the connecting Avenue (Akadimias Av.) that is also characterized by high traffic, light vegetation and characteristics of an ‘urban canyon’.

Perimeter: the external side of the Garden was monitored at 25 points.

The monitoring campaign was carried out during the summer, in the period of 11–31 July, 2005. Every route inside the Garden was monitored in 4 different periods during the sunshine hours of the day (11:00, 13:00, 15:00 and 17:00). At the Perimeter route, 3 monitoring campaigns per day were performed (12:00, 14:00, 16:00) (Table 1). The location of the measurements points was chosen in order to cover both the vegetated and the built environment area. Measurements were always taken in shade, at 10 to 14 predefined locations in each route, while at the perimeter 25 locations were selected. The points were located at a relatively equal distance, to be covered at about 1 min on foot and the measurement was taken 1 min later,

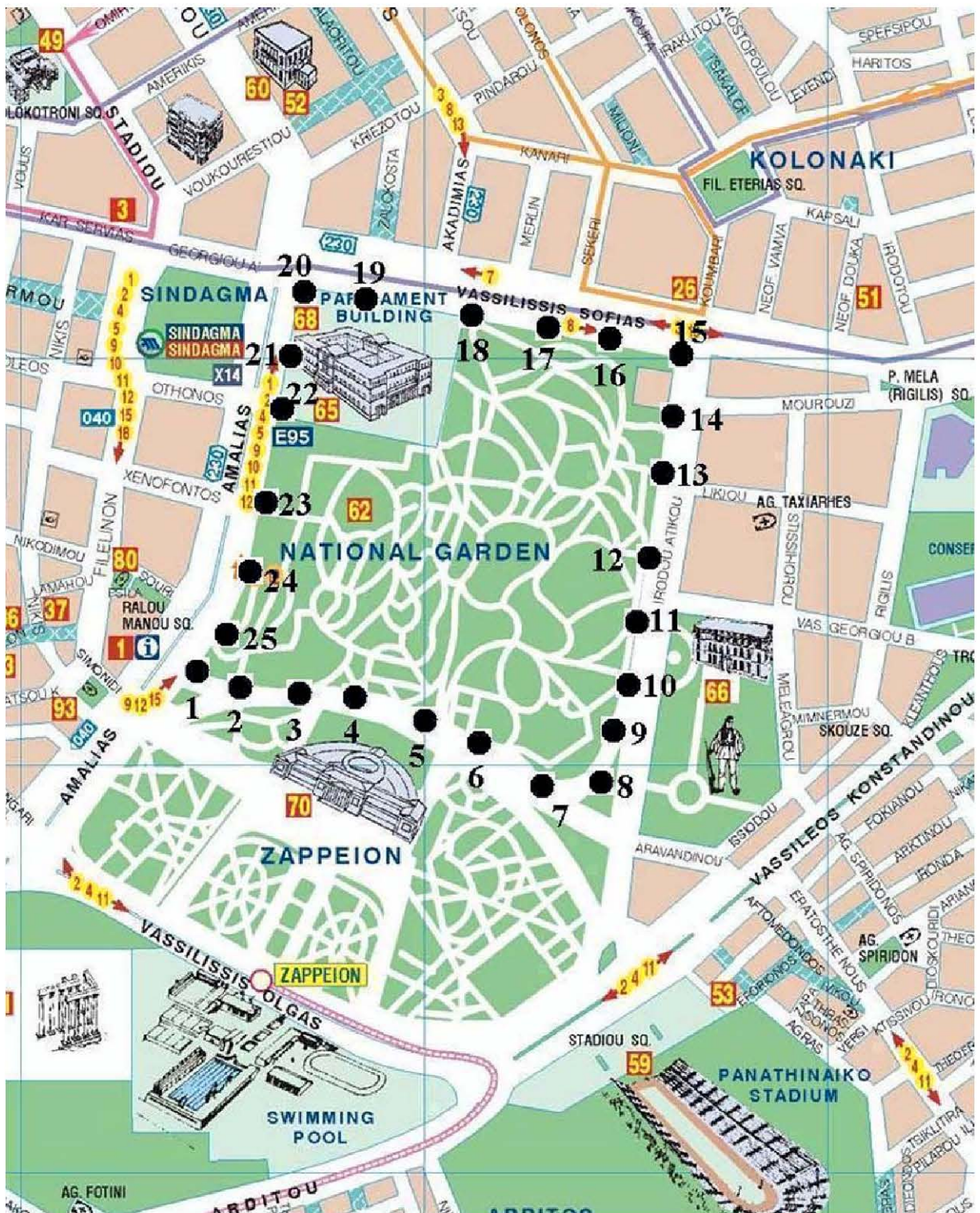
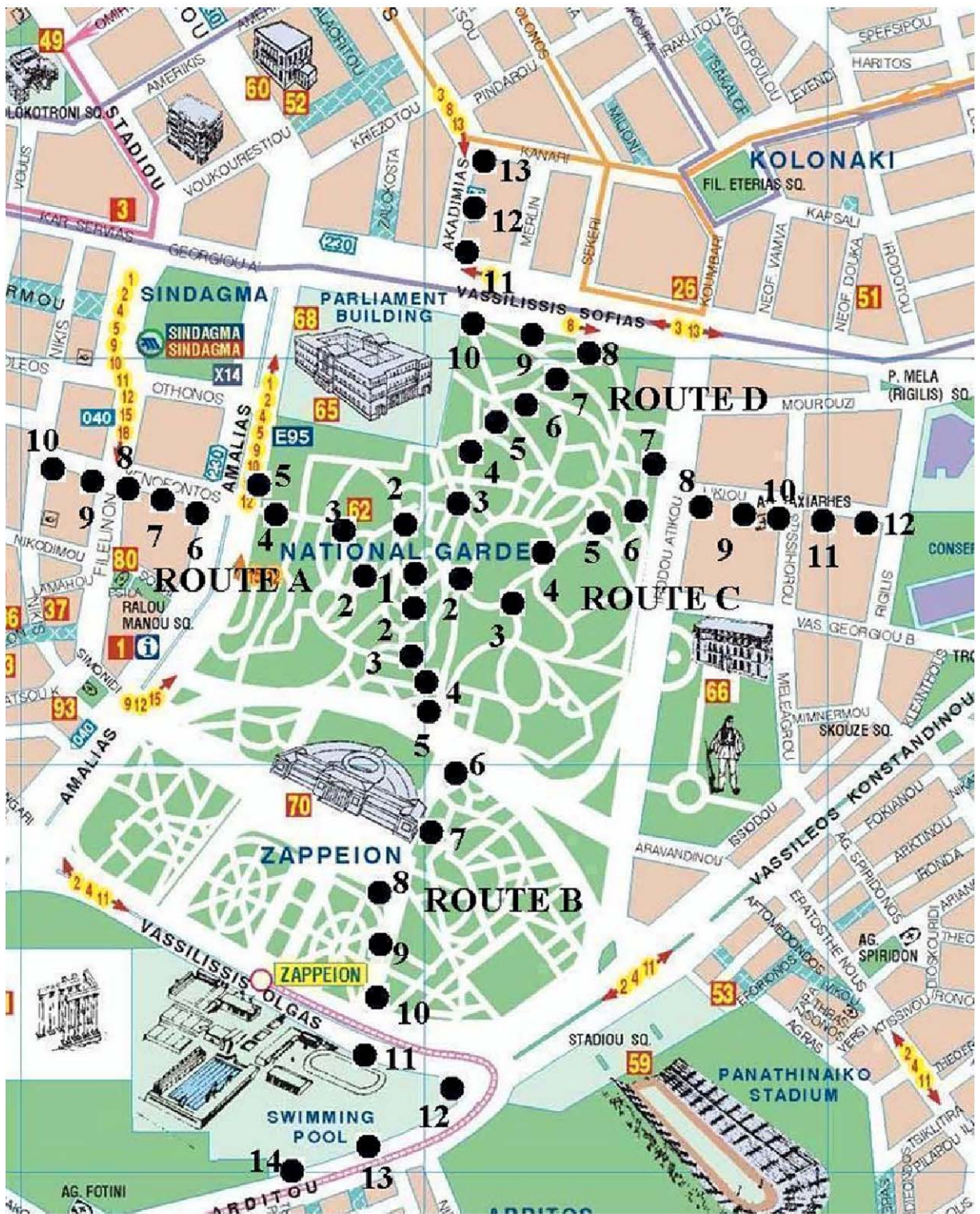


Figure 2 Overview of the perimeter route at the National Garden



Picture 3 Overview of the A, B, C, D routes across the National Garden

Table 1 Brief characteristics of the different monitoring routes

Route	No of observation points	No of observations	Days of measurements (2005)
Route A	10	4 times/day	July 11, 13, 29
Route B	14	4 times/day	July 13, 14, 22
Route C	12	4 times/day	July 23, 24, 30
Route D	14	4 times/day	July 25, 27, 31
Perimeter	25	3 times/day	July 12, 22, 29

allowing for the sensor to balance. Each route was covered on foot and measurements were taken in both directions, from the Garden centre to the last point of the route (forward route) and on the return back to the Garden centre (backward route). The duration of each monitoring session was about 45 min.

The air temperature at each measuring point was measured with a thermocouple temperature sensor, shielded with a small tube and covered with a reflective material on its external surface in order to protect the sensor from solar radiation. The sensor was positioned at a walkman earphone that was fitted at the head of the observer, eliminating in this way the thermal radiation effect from the human body. The air temperature sensor was connected with a small, portable data logger (Envirolog) powered by 9 V batteries.

A reference air temperature measurement was continuously recorded in a shaded location inside the Garden (Garden reference) (Picture 1). A Gemini Data Logger (Tinytag sensor) was positioned inside a wooden, ventilated box (with narrow lateral openings) that was fixed between the branches of a tree. All sensors were calibrated before the start of the measuring campaign.

The analysis of the recorded data aims at the investigation of the influence of the green area (National Garden) on the thermal environment of the surrounding urban area (microscopic scale).

Analysis of monitored data – microscopic scale

The meteorological conditions of the city centre during the monitoring period were obtained from the meteorological station of the National Observatory of Athens, located at Thissio, at the borders of the city centre (Picture 1). The air temperature during this period varied between 30°C (at 11:00 on 14/7) to 39.7°C (at 13:00 on 11/7). Low to moderate wind velocities were prevailing

during most hours of the monitoring period (3.0–6.5 m s⁻¹). The wind velocity exceeded 7.0 m s⁻¹ in only 5 monitoring sessions and reached once 9.1 m s⁻¹. Calm conditions (0.9–1.1 m s⁻¹) were encountered in three monitoring sessions. Light cloudiness was observed for the one third of the monitored sessions and only in one session there was full cloudiness.

The recorded data for each route was analysed and the variation of the temperature profile along each route is discussed in “[Temperature variation across each route](#)”. For each route, two types of analysis and corresponding graphs are presented:

- i) The variation of air temperature at each monitoring point, during each one of the four monitoring sessions (11:00, 13:00, 15:00, 17:00). The air temperature illustrated in the graphs is the mean value of the air temperatures recorded at each point during the forward and backward route from the Garden. The hourly mean temperature recorded at the National Observatory of Athens (T_{obs}) is also illustrated at the same graph (City temperature).
- ii) In order to eliminate the effect of time variation of the ambient conditions during each monitoring session and directly compare the temperature of each point with Garden’s thermal conditions, the temperature difference between each monitoring point and the permanent measurement inside the Garden (Garden reference) is presented in graphs for each route.

One day is depicted from each route to illustrate in a graph the temperature variation along the different locations. The comments for each route are driven from the analysis of all data from the whole monitoring period for the specific route.

Additionally, a statistical analysis of the monitored data was performed and the statistical sig-

nificance of the measurements is discussed in “Statistical analysis of monitored data”.

Temperature variation across each route

Route A

The mean ambient temperature at each location of route A for one day is illustrated at Fig. 1. The temperature profile along this route follows the trend of the ambient temperature with time, as the highest temperature is recorded at 15:00 and the lowest at 17:00. Two groups of temperature are observed. The temperature at the early afternoon (13:00–17:00) is higher than the morning (11:00–13:00) and later afternoon (17:00–18:00) air temperatures.

The air temperature inside the Garden and the neighbouring built area is lower than the City temperature (T_{obs}) during the morning and early afternoon (11:00–15:00). The conditions are reversed later in the day (15:00–18:00) when higher temperatures are observed inside the Garden. It should be noted that during these hours, the air velocity was relatively high (S-SW 5.4 m s^{-1} at 15:00–16:00 and S 6.0 m s^{-1} at 17:00–18:00).

The recorded temperatures do not show a clear influence of the Garden. The lowest air temperatures were observed at the end of the route, inside the urban fabric, which is a street with the characteristics of an urban canyon (a narrow street with tall buildings at both sides and thus, shaded most of the day) and very low traffic. Moving from the main Avenue to the narrow street, the decrease of

the air temperature was more intense during the hottest days and hours. It should be noted that during these periods, the wind direction was S-SW, flowing from the hot urban fabric towards the Garden, influencing in this way the air temperatures inside the Garden. Inside the Garden, the lowest temperature during all tests was recorded at a location with dense vegetation.

The temperature differences between each location and the Garden reference measurement were examined (Fig. 2) and similar conclusions as previously mentioned are derived. Checking out the data from all monitored days at this route, it was observed that during some periods of the day, the air temperature outside the Garden was lower than inside but during these days there were time periods with light cloudiness. The biggest temperature differences between the monitoring points and the Garden reference station along this route were observed at midday (1.0 to -4.1°C at 11:00–12:00) and get lower late in the afternoon (-0.5 to 1.8°C at 17:00–18:00).

Route B

The air temperatures along the route B, as illustrated in Fig. 3, are also grouped at two sets, with the highest temperatures at the hot hours of the day (13:00–17:00). The locations along this route presented lower temperature than the City air temperature (T_{obs}), except for some locations that showed higher temperature than the City temperature during the afternoon period of 15:00–16:00.

Fig. 1 Temperature profile across Route A

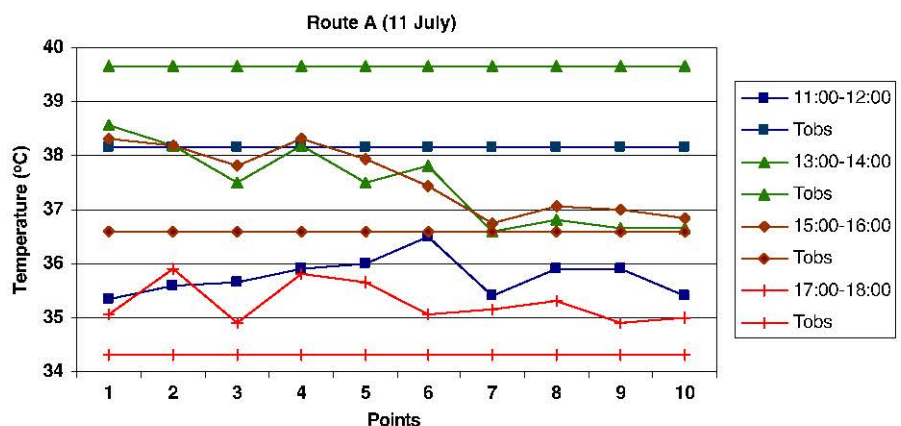
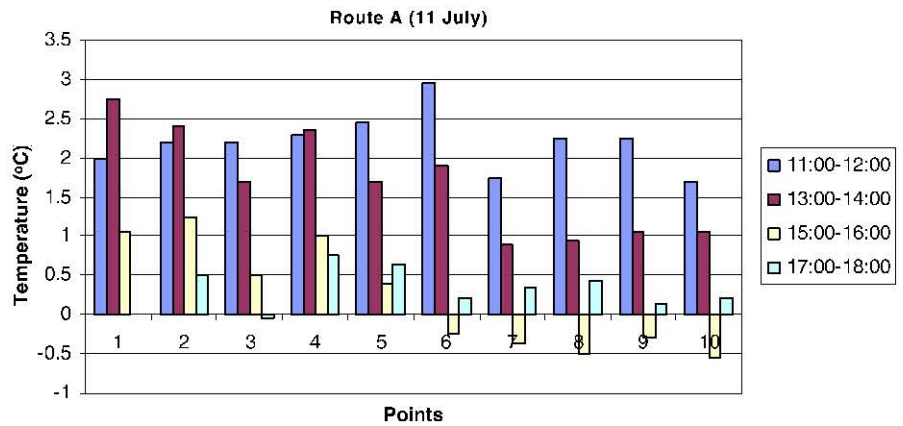


Fig. 2 Variation of temperature differences across route A



Inside the Garden, the lowest temperatures were observed at locations with dense vegetation and regular watering while the higher temperatures were observed at narrow paths with restricted air flow, not properly shaded and with vegetation in a relatively poor condition.

Moving outside the National Garden to the Zappeion Exhibition building surrounding area, a temperature drop was observed, as the pedestrian area was shaded from the building and there was dense and well catered vegetation. The temperature profile was affected by the wind direction and magnitude. Low temperatures were also observed at the first locations at the surrounding Avenue (points 10, 11) which is a wide road with restricted traffic and tall, with thick foliage trees. Also, this Avenue is next to an open swimming

pool and playing fields with grass (points 12, 13) and thus, the temperature at the Avenue was affected, especially in days with wind coming from this direction. A temperature peak was observed, depending on the wind direction, towards the end of the route (point 12, 13) as these locations were at a street with high traffic and thus, high anthropogenic heat.

The temperature differences between each location and the Garden reference station (Fig. 4) follow the same trend as discussed above for this route. It can be mentioned that some cooler locations were also observed outside the Garden but this also happened in days and time periods with high wind velocity from N-NA and in another case with low S wind but light cloudiness. The highest temperature differences were observed at midday

Fig. 3 Temperature profile across Route B

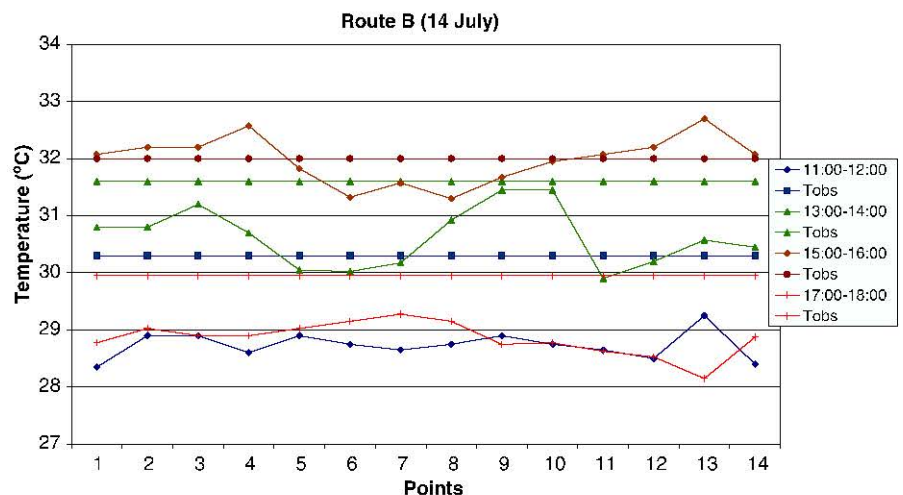
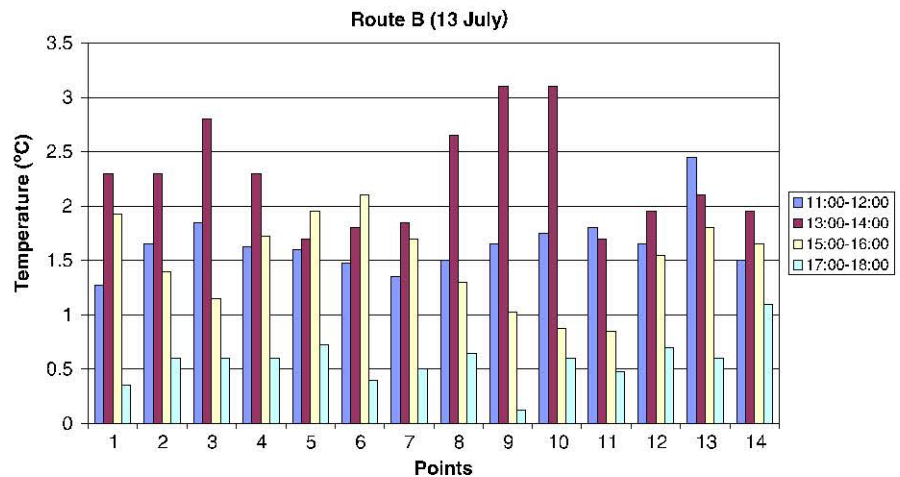


Fig. 4 Variation of temperature differences across route B



and early afternoon (−0.4 to 3.7°C at 11:00–12:00, 0.5 to 4.0°C at 13:00–14:00) and the lowest temperature between 17:00–18:00 (−0.6 to 1.2°C).

Route C

Figure 5 presents the temperature variation across this route. The monitored air temperatures were lower than the city air temperature (T_{obs}). During most hours of the day, the air temperatures were quite close to each other, except the first monitoring session at 11:00–12:00. The characteristic of the day presented at Fig. 5 is the relatively high wind velocity during most hours of the day (6.6–7.5 $m s^{-1}$).

Analysing all measurements taken in this route, the highest temperature inside the Garden was

not systematically observed at the same location but was changing according to the wind direction and time of the day. In general, the temperature profile inside the Garden was dependant on the prevailing weather conditions (wind and clouds) and the characteristics of the specific location (dense vegetation, pool with water or without, etc.).

The temperature at the last part of the route, a street with characteristics of an urban canyon but with gardens in front of the buildings and a green area at the end of the route, was about the same magnitude or slightly lower than the temperature at locations inside the Garden. It is worth mentioning that the temperature was influenced by the topography and characteristics of the area, as in a specific location (point 11) at a corner

Fig. 5 Temperature profile across Route C

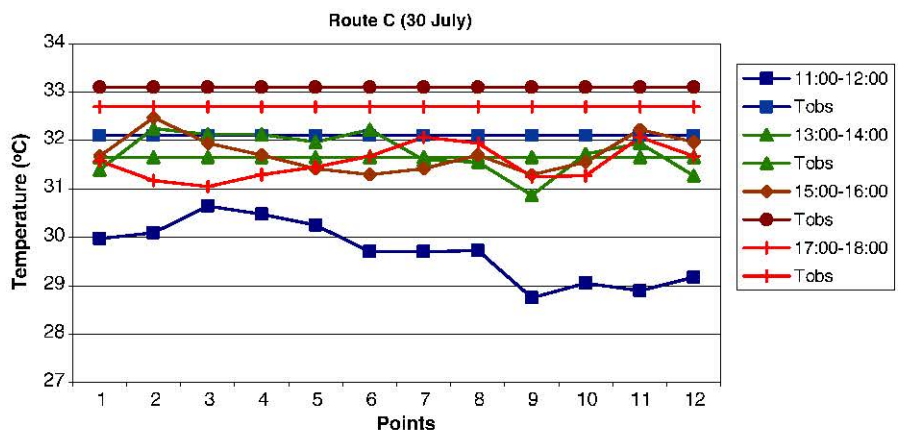
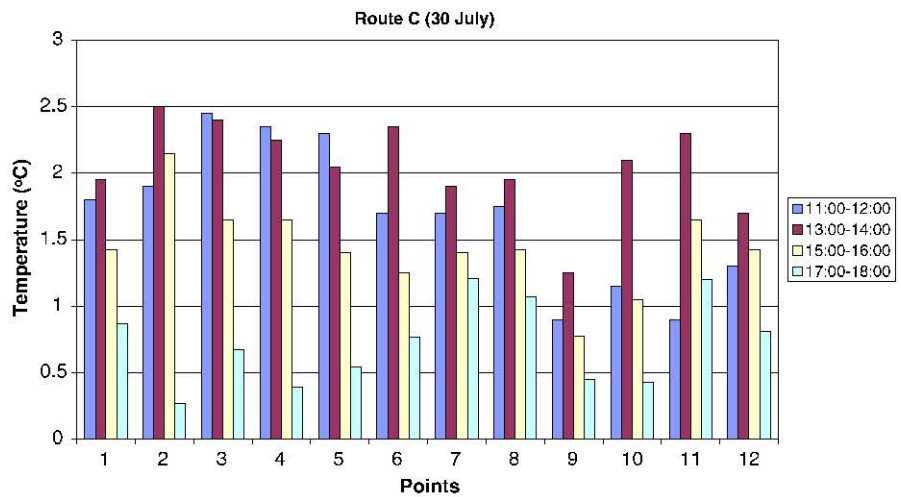


Fig. 6 Variation of temperature differences across route C



of a narrow street, with tall buildings and without vegetation, the temperature was occasionally becoming higher than the surrounding points.

The temperature differences between each location and the Garden reference station along this route (Fig. 6) show that the greater temperature differences were observed between 13:00 and 14:00 (0.3 to 3.6°C) and the lowest ones at the first and last monitoring sessions (−0.8 to 1.8°C at 11:00–12:00 and −1.0 to 1.2°C at 17:00–18:00). Negative temperature differences were also observed during the days with clouds and higher wind velocity.

Route D

The temperature profile along this route is illustrated at Fig. 7. The temperature inside the Garden was also influenced by the characteristics of each location: lower temperatures were recorded at areas with dense vegetation or next to a pool and higher temperatures at locations with insufficient shading (e.g. point 5 at a cross-pathway).

Moving outside the Garden and entering the urban canyon in the adjacent Avenue (Akadimias Av.), an increase of the air temperature was

Fig. 7 Temperature profile across route D

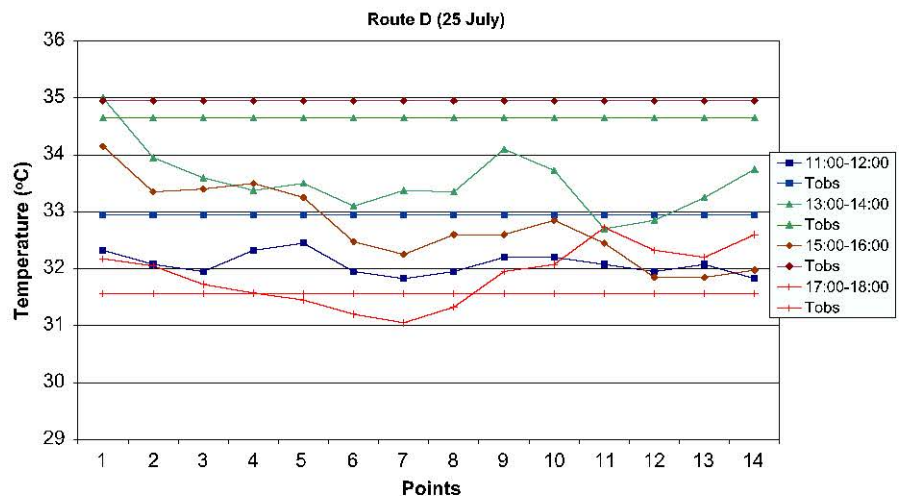
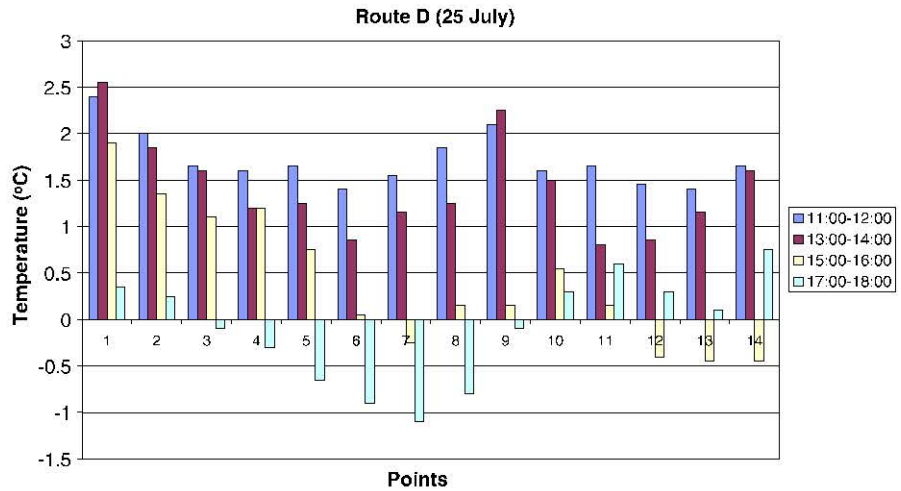


Fig. 8 Variation of temperature differences across route D



observed. This Avenue is a wide street with tall buildings that shade most part at the pedestrian level and lined with trees at its starting section, along the length that was monitored during this route. Traffic was high but less heavy than the Avenue next to the Garden (V. Sofias Av.). Higher temperatures were observed at the part of the Avenue that is less shaded.

Analyzing the temperature differences of all data for this route (Fig. 8) it can be observed that the highest temperature differences were observed between 13:00–14:00 (0 to 3.6°C) and the lowest ones at 17:00–18:00 (–2.6 to 1.8°C). In periods with cloudiness and low wind velocity, negative temperature differences were observed.

Perimeter

Figure 9 illustrates the temperature variation at the perimeter of the Garden. It can be observed that the south side of the Garden presents high temperatures and the north one the lowest temperatures.

Analyzing the data of the air temperature differences for all monitored days (Fig. 10) it can be observed that the maximum temperature differences from all routes were observed at the perimeter of the Garden. The temperature differences were decreasing during the hot afternoon hours (1.7 to 6.8°C at 12:00–13:00, 0.6 to 3.1°C at 13:00–14:00 and 0.2 to 5.2°C at 16:00–17:00). This

Fig. 9 Temperature profile at the perimeter of the Garden

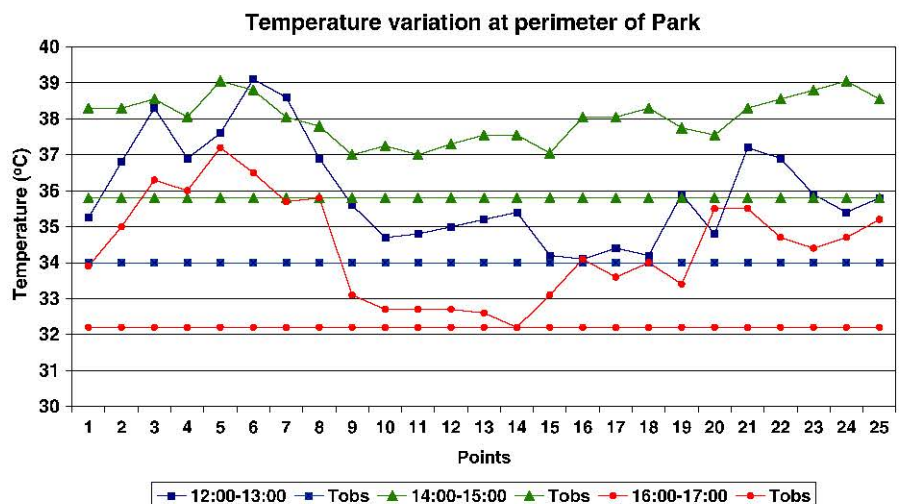
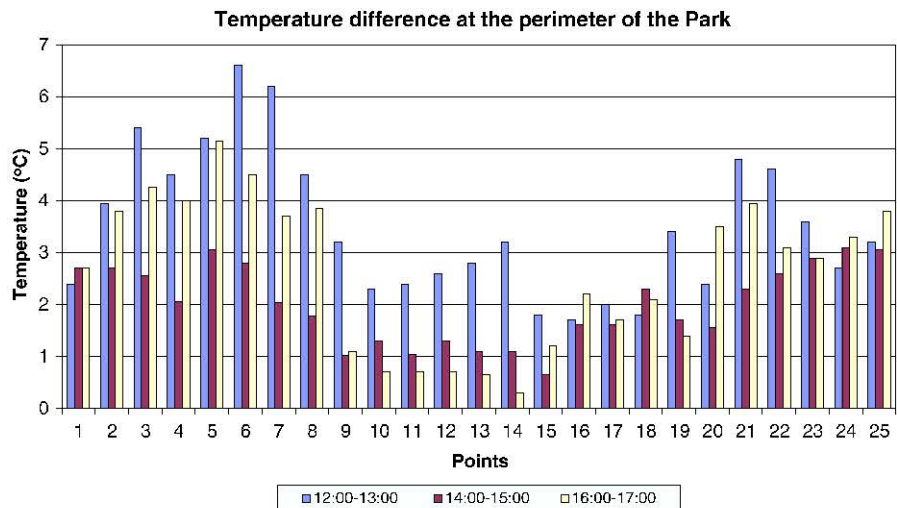


Fig. 10 Temperature difference at the perimeter of the Garden



indicates that the cooling effect of the Garden diminishes during the hot afternoon hours.

Statistical analysis of monitored data

In order to test the statistical significance of the collected data, the data from all monitoring campaigns were statistically analysed in two ways (Zoulia 2005).

- i) all data for each monitoring point were statistically processed in order to define the mean, minimum and maximum air temperature value for each measuring point. The extreme values were rejected and thus, the range of the acceptable values was defined (the 25% of the minimum and 25% of the maximum values were rejected). Additionally, the data for each route were grouped into two sets: data from points inside the Garden and points outside it, and the mean, minimum and maximum air temperature of the Garden and the surrounding built area were estimated. In the same way, the extreme values were also rejected from the analysis. The statistical package SPSS was used to analyse the data and draw box plots for each case.
- ii) the statistical significance of the monitored data was examined by applying the *t*-test methodology. Two sets of analysis were performed: i) for each one of the four daily

monitoring sessions – three for the perimeter – all the monitored data for every point were statistically analysed and ii) all data for each point were analysed irrespective of time period.

The statistical analysis of the monitored data showed that:

- i) Mean, maximum and minimum values

Route A The national Garden was slightly cooler than the surrounding urban area in the period of 11:00–12:00, in the order of up to 1.0°C, both in the mean and the maximum temperature values. Insignificant differences at the minimum values were observed. Later in the day, the temperatures inside the Garden were slightly higher than the surrounding area (the mean and minimum temperature was up to 1.0°C higher at the period 13:00–14:00 and for the period 15:00–16:00 up to 0.8°C for the maximum temperature and up to 0.4°C for the minimum values). In days with light clouds, the situation was reversed. During the last monitoring period (17:00–18:00), insignificant variations at the temperature were observed. In all cases, significant increase was observed at the border of the Garden with the Avenue and the results

of the statistical analysis was in line with the conclusions driven at the previous analysis on the variation of the temperature with the characteristics and topography of the location.

Route B Insignificant temperature variation was observed across this route during the morning (11:00–12:00). During a day with low wind velocity, the maximum temperature inside the Garden and the surrounding Zappeion Exhibition gardens was lower by up to 0.8°C, while during the day with high wind velocity, reaching up to 9.1 m s⁻¹, the maximum temperature inside the Garden was higher by 1.3°C than the locations outside the Garden. Later in the day (13:00–14:00), the Garden was presenting slightly higher temperatures than the surrounding built area, which for the day with high wind velocity reached the difference of 1.5°C, 2.0°C and 1.7°C for the minimum, maximum and mean values. There was no temperature increase at the exit of the Garden. Similar conclusions can be driven from

the analysis of the data for other time periods. The influence of the weather conditions (light clouds, wind) was evident in all tests.

Route C The statistical analysis of the data showed that in all time periods of the day, the Garden presented higher temperature than the built area, with the maximum, mean and minimum values being higher in the range of 0.5 to 1.6°C.

Route D There was insignificant temperature variation between the interior and exterior of the Garden, with the mean value being higher or lower during the different time periods by about 0.3°C (at 11:00–12:00), 0.4°C (at 15:00–16:00) and up to 0.8°C (at 17:00–18:00). At 17:00, the minimum temperature inside the Garden was by up to 1.3°C lower than the outside area. It should be noted that along this route there were always some locations cooler than the other areas of the Garden and thus, influencing the overall temperature profile of the Garden.

Table 2 Statistical results of the temperature differences between the Garden reference station and the measuring points, at the different routes

	Minimum	Maximum	Mean minimum	Value maximum	Std. deviation
Route A					
11:00–12:00	0.99	3.84	1.37	2.53	0.32÷0.71
13:00–14:00	-0.14	3.33	0.77	2.97	0.31÷0.63
15:00–16:00	0.24	2.47	-0.24	1.87	0.24÷0.64
17:00–18:00	-0.05	1.69	0.25	1.03	0.25÷0.53
Route B					
11:00–12:00	-0.07	2.37	0.55	1.80	0.27÷0.93
13:00–14:00	0.54	3.81	1.02	2.72	0.37÷0.88
15:00–16:00	0.33	2.52	1.34	2.09	0.39÷.68
17:00–18:00	0	1.13	0.16	0.55	0.28÷0.51
Route C					
11:00–12:00	0.17	2.75	0.13	2.03	0.34÷0.55
13:00–14:00	0.01	3.52	-0.14	2.19	0.36÷0.65
15:00–16:00	0.01	2.54	-0.38	1.43	0.50÷1.23
17:00–18:00	±0.13	1.46	-0.07	0.77	0.18÷0.58
Route D					
11:00–12:00	-0.02	2.85	1.00	1.73	0.33÷0.58
13:00–14:00	-0.11	3.63	1.60	1.96	0.65÷1.04
15:00–16:00	-0.25	3.17	-0.02	1.11	0.49÷1.10
17:00–18:00	-0.34	1.70	0.35	-1.14	0.44÷1.11

The minimum, maximum and mean values of the temperature differences between the different locations and the Garden reference station during the different time periods are summarized at Table 2.

It can be concluded that insignificant differences were observed in all tests and the weather conditions were influencing the temperature profile of the area. The temperature variation in the different locations was dependent on the characteristics of the location (urban canyon, existence of trees inside the urban fabric, dense or light vegetation inside the park, existence of water surfaces, watering conditions of the vegetated area in the Garden).

ii) *t*-test results

A two-sided check was applied, for a significance level $\alpha = 0.05$, and the critical values, t_α , were defined from the t -distribution curves. These values (t_α) were checked against the t -values in order to validate the statistical significance of the data (if $|t| < t_\alpha$, the zero hypothesis is valid, that means that the mean values of the two sample data coincide).

The t -test analysis of both analysis sets, as described earlier, showed that the mean values of the data populations were the same. This draws up the conclusion that during the monitoring period, although temperature differences were recorded, these were statistically insignificant and thus, there is no confidence in drawing a conclusion about the Garden being cooler or hotter than the surrounding area. Despite this conclusion, the trend of increase or decrease of the temperature that was observed in some locations – as described at “[Temperature variation across each route](#)” – was systematic in all tests.

Macroscopic scale

The effect of the National Garden during summer at a greater scale was investigated by comparing its hourly temperature profile with hourly air temperatures recorded at three other locations of the greater built city centre area of Athens: Ermou str., Ippokratous str., Solonos str. (Picture 1). The Ermou str. is a narrow pedestrian street with

a high ratio of buildings’ height to street width (H/W) while the other two ones are two-lane streets with continuous traffic during the day. All streets are surrounded by tall buildings and have the characteristics of an urban canyon.

Miniature temperature data loggers equipped with a thermistor as a sensing element were used for measuring the hourly values of ambient air temperature throughout the day at the different locations inside the city. These monitoring stations are part of a network of meteorological stations recording data for the urban heat island within the greater area of Athens, documented in other papers (Livada et al. 2002). The instruments were installed at a height of approximately 3.0–5.0 m, in white screened wooden boxes with lateral slots, similar to the Stevenson screens, in order to protect instruments from solar radiation and rain. Data for the summer period (July–Sept. 1996, May–Sept 1998) were derived from the yearly database and were analysed for the needs of the current investigation. The main conclusions drawn are the followings:

- In all cases the National Garden was cooler than the other areas.
- The greatest temperature differences between the pedestrian street (Ermou str.), and the Garden station were recorded during the night, reaching a value up to 6.3°C. Due to lack of traffic in the pedestrian street, the anthropogenic heat is negligible and the strongest effect is during the night due to the heat absorbed at buildings and the street floor and trapped inside the urban canyon.
- Regarding the Ippokratous str., a street with high traffic and thus, anthropogenic heat during the day, the greatest temperature differences from the Garden were observed during the day and reached up to 13.0°C. During the night, the temperature differences decreased and for several days temperatures were almost identical.
- The National Garden was cooler than the Solonos str., mainly during the night. For several days, the air temperature during the day was almost the same in both stations while some days, even higher temperatures were recorded at the Garden. During the night, the

Solonos str. was hotter than the Garden due to the urban canyon effect and the temperature differences between the two stations reached up to 7.2°C.

- During days with heavy clouds or/and rain there were no significant differences in the air temperature between the different stations.

Statistical analysis of the recorded data (Zoulia 2005) in terms of mean daily temperatures and temperature differences showed that the temperature differences between the four monitoring stations were statistically significant and thus, according to the previous comments, the Garden was statistically cooler than the other areas.

Concluding remarks

Monitoring campaigns carried out at the National Garden of Athens during the summer day-period, between 11:00 to 18:00, showed that in microscopic level, the temperature profile inside the National Garden and the immediate surrounding urban area did not show a clear evidence of the influence of the Garden. The temperature conditions were dependent on the characteristics of each location. Like in narrow streets (e.g. Likiou str. Xenofontos str.) with tall buildings (high ratio H/W), where the solar incidence to the buildings and the street floor was limited, lower air temperatures than the National Garden were systematically recorded. Additional characteristics, like existence of trees and green areas, orientation of streets relatively to the wind direction, were influencing the local thermal conditions. These parameters, among others, may explain the low temperatures recorded at wider streets with lower H/W ratio (e.g. Akadimias Aven.).

At the exit of the Garden, next to the main adjacent Avenues (e.g. Vass. Sofias Aven., Amalias Aven.), higher temperatures were recorded. The temperature increase may be attributed at the greater exposure of this area at the solar radiation, which results at greater radiated heat from the street floor, but also at the anthropogenic heat from the traffic in the Avenue.

Some of the parameters influencing the air temperature at the different locations inside the

Garden were the density and condition of vegetation, vegetation watering pattern, existence of water surfaces.

When the air temperature of the Garden was compared to locations of the urban fabric in the wider city centre area (macroscopic scale), the Garden was found cooler than the urban locations. Temperature differences were mainly greater during the night, especially in streets with high H/W ratio and low traffic, while in streets with high anthropogenic heat during the day, the biggest temperature differences were recorded during the day.

It should be mentioned that during the macroscopic analysis recordings were made at only one location in each area and in the case of the Garden, the weather station was located in a well shaded area. Thus, there was no evidence of the thermal conditions in other areas around the Garden. While, the recordings during the microscopic scale tests were made at different locations inside and outside the Garden, mapping in this way in a detailed way the thermal conditions around the Garden and the surrounding built area. These measurements were recording the thermal conditions inside the Garden, which varied according to the characteristics of each location.

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