An assessment of microclimatic conditions inside vegetated and non-vegetated small-scale open spaces in the Athens urban environment

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Abstract: A vast amount of studies on typical urban green and open spaces such as parks and urban squares does exist. Studies on small-scale clusters such as open spaces between buildings and similar design features that may provide passive cooling potential are, however, in general, limited. This study examines the microclimatic conditions of small-scale open spaces such as courtyards and small backyards in Athens. Courtyards are common architectural solutions that can be positive or negative urban climatic elements. Backyards, the result of regulations due to the high building density, are irregularly shaped space, usually without plants and trees. A vegetated courtyard and two different backyards were appropriately monitored along with two reference sites during the summer of 2019. A detailed statistical analysis was performed. The maximum values of the cool island effect were found to be on the order of 8 K inside the more vegetated locations (i.e. Vegetated Backyard, Garden Sunlit and Garden Shade). The maximum values of the heat island effect were found to be on the order of 6K (Garden Sunlit, 5.9 K; Backyard, 5.7 K).

1 Introduction

The phenomenon of Urban Heat Island (UHI) in Athens is particularly intense with the difference in average air temperature among urban and suburban locations reaching up to 4.5 K (Giannopoulou et al. 2011, Livada et al. 2002). Large urban green spaces have been examined extensively for their cooling effect (Bowler et al. 2010). In the case of Athens, large urban green spaces (i.e. parks) have been found to play a critical role in the pattern of UHI but their cooling effect holds only for a few meters off their perimeter due to anthropogenic heat from traffic and worse thermal conditions as a result of vegetation absence (Zoulia et al. 2009). In contrast, the thermal behavior of small spaces (green or not) whose existence may not even be the result of intentional design, such as irregular open spaces between buildings, has not been investigated in relation with their potential contribution to urban microclimate. One of the first quantitative studies in Greece showed that under heat wave conditions, air temperature values in small vegetated areas appear to be lower by 7 K compared to the surrounding area (Tsiros and Hoffman 2014). Also, densely vegetated courtyards may be used as passive cooling tools for buildings, contributing to the reduction of energy consumption during the summer months (Tsiros 2010). This study is aimed at quantifying the contribution of small urban green spaces to mitigate adverse bioclimatic conditions within the urban environment of Athens during summer, where the UHI phenomenon is aggravated.

2 Data and Methodology

2.1 Location and Data

Measurement sites were established in a typical neighborhood of Athens, Patisia, and included three courtyards located in the interior of urban blocks and one at the roof level open to the sky, all located within an 80 m radius (Fig 1). In the first courtyard two monitoring locations were arranged, one in the center of a rear-wooded garden characterized by sunlit conditions (Garden Sunlit) and one in the same garden but under tree canopy (Garden Shade). The second courtyard is a typical non-vegetated small backyard (Backyard) shaded mainly from the surrounding walls and the third courtyard is a backyard shaded from dense tree canopies along with surrounding walls (Vegetated Backyard). Such backyards are mainly the result of regulations due to high building density construction in the 1950–1970 period in Athens. During that period, the old family houses were replaced by small apartment blocks resulting to the backyard areas, irregularly shaped spaces, usually without plants and trees, mainly designed for daylight and ventilation to the backside rooms (Tsianaka 2006).The roof level location (Roof) is on the top of the two-story building next to the first courtyard. Nea Filadelfeia station (Hellenic National Meteorological Service - HNMS) located approximately 3.8 km from the neighborhood inside a 120-acre green area with xerophytic vegetation ("Park"), was chosen as a reference site.

Small air temperature (and air humidity) loggers (three Onset Hobo MX2302A and two Onset Hobo Pro) were installed in all five locations for simultaneous measurements of air temperature (Tair, °C). All instruments were fixed inside white aluminum louvered solar radiation shields, placed in approximate 1,1 m of the ground and programmed in five-minute interval logging. Meteorological data from the Nea Filadelfeia station were obtained from the Hellenic National Meteorological Service in the form of three-hour averages. Measurements were conducted in a twenty-six-day period August 18 - September 12, 2019.

Fig. 1. Measurement positions. 1, Garden Sunlit; 2, Garden Shade; 3. Roof; 4, Backyard and 5, Vegetated Backyard.

2.2 Methodology

All air temperature data recorded in-site were averaged in one-hour timesteps and hourly minimum and maximum values were also calculated. Data obtained from the HNMS Station where downscaled from three-hour values to one-hour values using linear interpolation. To examine warming and cooling patterns in the study area, hourly air temperature values (Tair) recorded at the monitoring sites were compared with the corresponding values of the reference site. In order to quantify further the patterns, hourly air temperature differences(ΔTair) were calculated by subtracting the hourly air temperature in the reference site from the corresponding air temperature on each location. Thus, ΔTair negative values indicate cooling patterns (cool island effect) and positive values indicate warming patterns (heat island effect).

2.3 Statistical analysis

Descriptive statistical data were calculated and evaluated for air temperature values, air temperature differences and meteorological conditions, measured at the reference site. Kruskal-Wallis H test was used to identify the potential statistically significant differences between the position profiles in Tair and ΔTair. Distributions of Tair and ΔTair values were similar for all groups, as assessed by visual inspection of a boxplot. Pairwise comparisons were performed using Dunn's procedure with a Bonferroni correction for multiple comparisons. Tair data showed a non-normal distribution and thus Spearman correlation coefficients (r_s) were used to examine the association between them. Linear regression used to model air temperature differences based on air temperature measured in the reference station. Assumptions for homoscedasticity and normality of residuals were met.

3 Results

For each location (five in urban cluster and one in reference site) the same number (n=607) of hourly Tair measurements was obtained and thus five ΔTair sets (each urban positions' Tair minus reference site's Tair) of the same number were calculated. Minimum average Tair (27.3°C) recorded in the reference site outside of the examined urban cluster and maximum (29.3°C) was recorded in the Roof. Among the three courtyards the lowest average Tair values were recorded in the Garden Shade (27.6°C) and the Vegetated Backyard (27.7°C) locations (Table 1a). The highest Tair value was recorder in the Roof (40.2 °C, 26/8/19 16:00) and the lowest logged in the reference station (19.8 °C, 8/9/19 03:00). The highest mean daily range of Tair was found in the Roof (9.5 K) and the lowest in the Vegetated Backyard (4.8 K) which is the least exposed to the sky. The daily pattern of minimum and maximum Tair values (Fig. 2) portray a significantly warmer Roof considering the maximum values in contrast with the Vegetated Backyard which shows the lowest between all positions.

Mean air temperature differences between the reference site and the examined locations (Table 1b) range from 0.3 K (for the Garden Shade) to 2 K (for the Roof).Hourly average air temperature differences (Fig. 3) show strong cool island patterns in the morning until noon with peak hour approximately 9:00 and an extended peak period of four hours (09:00-13:00) for Vegetated Backyard. Heat island patterns peak in the afternoon and all night with peak hours approximately from 18:00 to 20:00.

Table 1. (a) Air temperature (Tair) in examined locations and the reference site during measurement period and (b) Air temperature differences (ΔTair) between examined locations and the reference site. Positive values indicate warming patterns (heat island effect).

a	Mean	Median	SD	Min (Abs)	Max (Abs)	Min (DM)	Max (DM)	Range (DM)
Tair (°C) Garden Sunlit	28.1	28.0	3.24	21.9	37.3	24.6	32.9	8.3
Tair (°C) Garden Shade	27.6	27.7	2.97	21.8	35.1	24.5	31.0	6.5
Tair (°C) Backyard	28.4	28.3	2.65	23.1	35.8	25.3	31.9	6.6
Tair (°C) Vegetated Backyard	27.7	27.7	2.30	22.8	34.6	25.6	30.4	4.8
Tair (°C) Roof	29.3	29.2	3.85	21.8	40.2	25.0	34.5	9.5
Tair (°C) HNMS Station	27.3	27.4	3.72	19.8	37.6	23.3	32.2	8.9
b								
ΔTair (°C) GSu-F	0.7	1.8	3.01	-7.7	5.9	-5.0	4.4	
ΔTair (°C) GSh-F	0.3	0.9	2.80	-7.8	5.4	-5.3	4.0	
ΔTair (°C) B-F	1.0	1.7	2.83	-6.8	5.7	-4.4	4.5	
ΔTair (°C) VB-F	0.4	1.2	3.13	-8.0	5.3	-4.9	4.1	
ΔTair (°C) R-F	2.0	2.4	2.87	-5.7	8.2	-3.7	6.5	

Abbreviations: SD, Standard Deviation; Abs, Absolut; DM, Daily Mean; GSu-F, Garden Sunlit - HNMS Station; GSh-F, Garden Shade - HNMS Station; B-F, Backyard - HNMS Station; VB-F, Vegetated Backyard - HNMS Station; R-F, Roof - HNMS Station.

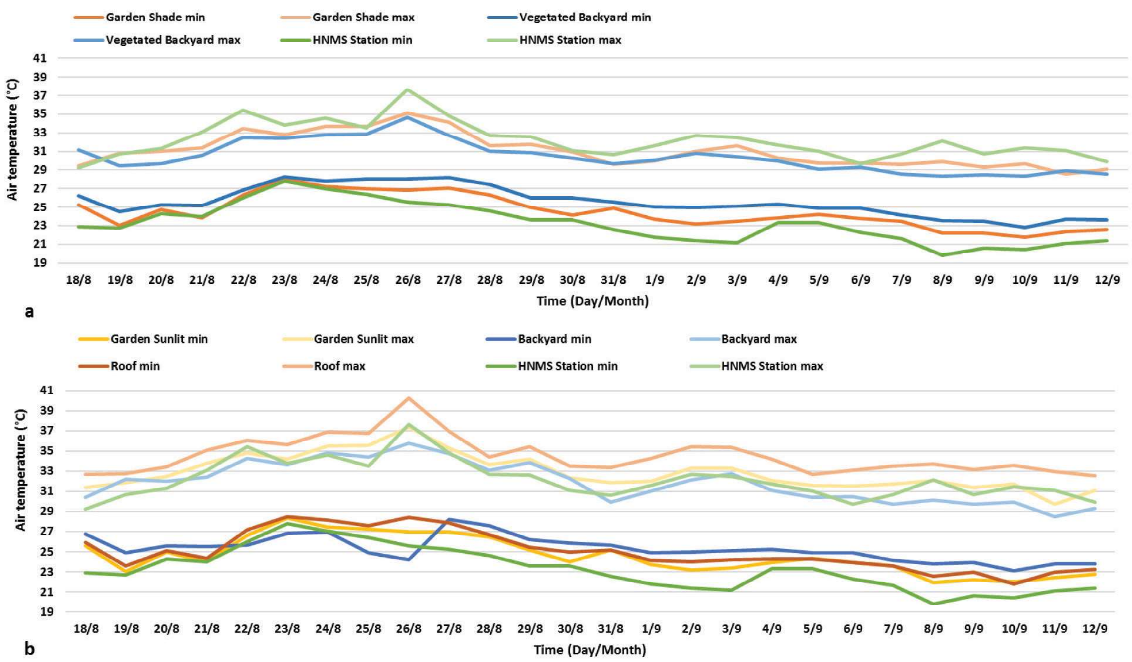

Fig. 2. Daily minimum and maximum air temperature patterns in examined locations and reference site during the monitoring period. (a) Garden Shade, Vegetated Backyard and HNMS Station, (b) Garden Sunlit, Backyard, Roof and HNMS Station.

Hour (24h)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
ΔTair (°C) GSu-F	2.58	2.33	2.08	1.98	0.66	-0.55	-1.62	-3.14	-4.43	-5.22	-4.33	-2.95	-1.55	0.53	2.02	2.78	2.74	3.30	4.20	4.12	3.73	2.92	2.48	2.39
ΔTair (°C) GSh-F	2.21	2.03	1.81	1.72	0.42	-0.76	-1.87	-3.37	-4.64	-5.50	-4.22	-1.93	-1.59	-0.71	0.15	0.81	1.79	2.82	3.77	3.73	3.27	2.34	1.94	1.93
ΔTair (°C) B-F	3.00	2.87	2.94	2.87	1.61	0.43	-0.77	-2.27	-3.64	-4.55	-3.34	-2.44	-1.54	0.31	0.68	1.23	2.30	3.27	4.16	4.07	3.82	3.36	2.91	2.85
ΔTair (°C) VB-F	2.99	2.94	2.84	2.75	1.52	0.35	-0.81	-2.28	-3.73	-4.80	-4.63	-4.23	-4.05	-2.59	-1.18	0.07	1.41	2.67	3.68	3.70	3.52	3.21	2.95	2.90
ΔTair (°C) R-F	2.92	2.70	2.45	2.26	0.91	-0.30	-1.48	-3.05	-3.93	-2.32	0.08	0.57	0.68	2.24	3.14	4.12	5.40	6.17	6.30	5.20	3.84	3.22	2.92	2.87

Fig. 3. Hourly average air temperature differences (ΔTair) during the monitoring period. Negative values (green cells) indicate cool island effect and positive values (red cells), heat island effect. Values are color-scaled independently for every measuring position. Abbreviations: GSu-F, Garden Sunlit - HNMS Station; GSh-F, Garden Shade - HNMS Station; B-F, Backyard - HNMS Station; VB-F, Vegetated Backyard - HNMS Station; R-F, Roof - HNMS Station.

Median Tair ($p<0.001$) and median ΔTair ($p<0.001$) were significantly different among all locations. Adjusted p-values are presented. Between all Tair profiles Roof shows statistically significant differences with all other locations ($p<0.001$ in all cases except with Backyard, $p=0.07$).Backyard's profile is significantly different with Vegetated Backyard ($p=0.012$), Garden Shade and HNMS Station ($p<0.001$) while Garden Sunlit's differs significantly from HNMS Station ($p=0.009$). Between ΔTair profiles Roof showed significant difference with all other locations ($p<0.001$), Backyard appeared significant different from Vegetated Backyard ($p=0.16$) and Garden Sunlit ($p<0.001$) while Garden Sunlit differs significantly from Garden Shade ($p=0.005$).

A strong positive correlation was found between all Tair profiles of the urban cluster ($p<0.001$, $r_s>0.8$) and a weaker between HNMS Station profile and the cluster's profiles, with stronger the one between Roof and HNMS Station ($p<0.001$, $r_s=0.68$) and weaker the one between Vegetated Backyard and HNMS Station ($p<0.001$, $r_s=0.45$). Strong positive correlations were observed also between all ΔTair profiles with stronger the one between Garden Shade's and Small Backyards' profiles ($p<0.001$, $r_s=0.96$) and weaker the one between Vegetated Backyard's and Roof's profiles ($p<0.001$, $r_s=0.73$).

Linear regression produced significant results between Tair in the reference site and the ΔTair of all five locations in the urban cluster (Table 2). The best model of ΔTair was found for the Vegetated Backyard location accounting for 58.5 % of the variations in ΔTair and predicting -0.68 K of air temperature difference for every degree of ambient air temperature (Tair in reference site).

Table 2. Linear regression results for all five ΔTair profiles in relation with air temperature in the reference site (HNMS Station). Maximum Tair 38.8 °C was recorded at the reference site for the year 2019.

ΔTair profile	Sig.	Adj. R^2	Intercept	Slope coefficient	If HNMS Station = 38.8 °C
GSu-F	$p < 0.001$	26.3 %	12.82	-0.44	-4.3 K
GSh-F	$p < 0.001$	33 %	12.86	-0.46	-5.0 K
B-F	$p < 0.001$	44.6 %	15.80	-0.54	-5.2 K
VB-F	$p < 0.001$	58.5 %	19.10	-0.68	-7.4 K
R-F	$p < 0.001$	7.7 %	8.26	-0.23	-0.7 K

Abbreviations: GSu-F, Garden Sunlit - HNMS Station; GSh-F, Garden Shade - HNMS Station; B-F, Backyard - HNMS Station; VB-F, Vegetated Backyard - HNMS Station; R-F, Roof - HNMS Station.

Abbreviations: GSu-F, Garden Sunlit - HNMS Station; GSh-F, Garden Shade - HNMS Station; B-F, Backyard - HNMS Station; VB-F, Vegetated Backyard - HNMS Station; R-F, Roof - HNMS Station.

4 Conclusions

This study analyzed data from in-situ measurements concerning air temperature patterns in typical small urban open spaces (vegetated and non-vegetated) for a limited period during the summer of 2019 in the city of Athens. Vegetated backyards show a stronger cool island pattern compared to non-vegetated open spaces. The shade effect from the surrounding buildings in typical urban blocks should, however, be studied further as a separate cooling factor. Further studies should also focus on the correlation of meteorological parameters between a standard meteorological station outside the examined urban cluster and a reference location inside the cluster (i.e. a roof or a nearby square) to have a versatile way of modeling the thermal conditions in various urban environments.

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