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On the characteristics of the summer urban heat island in Athens, Greece

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ABSTRACT

Data from 25 fixed temperature stations placed in the major Athens area have been used to analyse the characteristics of the heat island phenomenon during the summer season. The city has been divided in five geographic zones presenting different thermal balances and it is found that the differences between the mean and maximum daily air temperatures, among the five areas, were statistically significant, showing that the five areas of this analysis had definitely different temperature conditions. Higher air temperatures are found in the industrial western part of the city and also the center while the lower values were presented at the northern and the eastern parts. The intensity of the phenomenon is found to be close to 5 C. Statistical methods have been developed and the mean and maximum nocturnal air temperatures as well as the number of hours where air temperature exceeds 30 °C, can be estimated using the corresponding diurnal temperature values. The overall analysis is important to identify energy and comfort problems in the city and plan in a sustainable way the rehabilitation of the zones presenting important thermal problems.

1. Introduction

Heat island is the more documented phenomenon of climatic change (Santamouris, 2001). It is associated with much higher air temperatures in the central urban areas compared to the surrounding rural and suburban zones. Its magnitude is mainly related to the building density, the use of absorbing materials in the urban fabric, the urban canyon characteristics, the lack of green spaces and the production of increased anthropogenic heat (Oke, Johnson, Steyn, & Watson, 1991). Heat island has a very important impact on the energy consumption of buildings during the summer period, it increases the concentration of pollutants and causes human discomfort and health problems (Cartalis et al., 2001; Hassid et al., 2000; Santamouris et al., 2001; Santamouris, Paraponiaris, & Mihalakakou, 2007; Santamouris, Pavlou, Synnefa, Niachou, & Kolokotsa, 2007; Stathopoulou, Mihalakakou, Santamouris, & Bagiorgas, 2008).

Fighting temperature increase and heat island in the urban environment involves the use of many mitigation techniques like the application of reflective materials, additional green spaces, increased convective cooling, use of water, etc. (Akbari et al., 1992; Gaitani, Mihalakakou, & Santamouris, 2007). In particular, the use of cool materials presenting high reflectivity to solar radiation and high emissivity coefficient contribute highly to decrease the surface temperature of the cities (Akbari et al., 2009; Synnefa, Santamouris, & Livada, 2006; Santamouris, Synnefa, Kolokotsa, Dimitriou, & Apostolakis, 2008; Synnefa, Santamouris, & Apostolakis, 2007). Extensive green spaces and planted roofs have also a very important impact on the temperature regime of the cities (Julia, Santamouris, & Dimoudi, 2009; Santamouris, Pavlou, Doukas, et al., 2007; Shashua-Bar et al., 2010; Sfakianaki, Pagalou, Pavlou, Santamouris, & Assimakopoulos, 2009; Niachou, Papakonstantinou, Santamouris, Tsangrassoulis, & Mihalakakou, 2001; Yu & Hien, 2009).

Previous studies in Athens, Greece have confirmed the existence of a strong heat island phenomenon (Mihalakakou, Flocas, Santamouris, & Helmis, 2002; Mihalakakou, Santamouris, Papanikolaou, Cartalis, & Tsangrassoulis, 2004; Santamouris, Mihalakakou, Papanikolaou, & Assimakopoulos, 1999). The association of the heat island with synoptic climatic conditions have been identified (Livada, Santamouris, Niachou, Papanikolaou, & Mihalakakou, 2002), while the influence of the surface temperature and wind conditions have been analysed (Papanikolaou, Livada, Santamouris, & Niachou, 2008; Stathopoulou et al., 2009). In parallel, the impact of various mitigation techniques involving cool and reflective materials has been identified (Doulos, S, & Livada, 2001, Karlessi, Santamouris, Apostolakis, Synnefa, & Livada, 2009, Synnefa, D, Santamouris, Tombrou, & Soulakellis, 2008),

Given that all performed studies show clearly that heat island in Athens presents its upper limit during the summer period, when also the maximum energy and environmental impact is observed, the present paper focuses and presents a detailed analysis of the

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heat island characteristics during the hot season. Data from 25 meteorological stations installed at the greatest area of Athens have been collected and analysed using advanced statistical techniques.

2. Data collection and analysis

In general terms the characteristics of the urban heat island in a location are analysed by using advanced statistics of the air temperature distribution, wind speed, barometric pressure, solar radiation, cloud cover, etc. These data are obtained either from fixed urban and rural stations or mobile meteorological stations.

To study the heat island intensity and characteristics in Athens, 25 fixed temperature stations have been installed in the city and around it. The exact location and the characteristics of the stations are given in Table 1 and Fig. 1. To achieve a full description of the phenomenon, the greater area of Athens was divided in five parts (Fig. 1). These are: (a) the centre of Athens (station no. 1), which is the reference station of this analysis, (b) the northern part (station nos. 2–6), (c) the southern part (station nos. 12–16), (d) the eastern part (station nos. 7–11) and (e) the western part (station nos. 17–25). Fully calibrated high precision automatic miniature temperature sensors have been used for all stations. All sensors were placed in white wooden boxes with lateral slots approximating the Stevenson screen to be protected from solar radiation and rain. Temperatures were recorded at a frequency of 15 min. Data have been recorded for a complete year (December 2008–December 2009).

Given that heat island has a major impact on energy and comfort conditions during the summer period (Livada, Santamouris, & Assimakopoulos, 2007), the specific temperature data recorded in June, July and August of 2009 have been analysed.

In a first step and in order to study the characteristics of the mean and max daily air temperature values for each summer month and for all the meteorological stations, a statistical analysis has been performed to test the difference of means using the pair *t*-statistic of means (Tables 2 and 3). Setting the null hypothesis H_0 the difference of means (or maximums), between daily pairs of air temperature values for all combination of five parts, to be equal to zero, the *t*-test of pairs was fitted and the t values was tested at the significance level of 0.05 ($\alpha = 0.05$). As concluded, the differences referring to mean and max daily air temperatures, among the five areas, were statistically significant, showing that the five areas of this analysis had definitely different temperature conditions.

As shown in Table 2, the differences between the mean daily values are smaller between the center of Athens and the western part and higher between the Northern and the western part of the greater Athens area, but in both cases the differences are statistically significant. Also the differences are greater during July and August between the northern and southern, the northern and west-

Table 1
Location characteristics of the 25 stations network.

Parts	Stations	Latitude	Longtitude
Center of the city			
1	Athens University	37°58′50.78″S	23°44′2.42″E
Northern part			
2	N. Erythrea	38°5′23.69″S	23°49′9.11″E
3	Ano Liosia	38°4′44.00″S	23°42′8.00″E
4	Kamatero	38°3′34.80″S	23°42′50.66″E
5	Filadelfia	38°2′6.78″S	23°44′17.99″E
6	Marousi	38°3′8.77″S	23°48′30.50″E
Eastern part			
7	Zografou	37°58′10.29″S	23°47′11.50″E
8	Kessariani	37°58′8.95″S	23°45′42.44″E
9	Ilioupoli	37°55′57.37″S	23°45′30.88″E
10	Byronas	37°57′24.21″S	23°45′44.23″E
11	Agia Paraskevi	38°0′50.34″S	23°49′27.79″E
Southern part			
12	Glyfada	37°51′52.72″S	23°44′39.97″E
13	Renti	37°57′45.94″S	23°40′27.88″E
14	Elliniko	37°54′27.35″S	23°44′32.43″E
15	Kallithea	37°57′25.18″S	23°42′9.91″E
16	Moschato	37°57′12.44″S	23°40′55.58″E
Western part			
17	Korydallos	37°58′44.84″S	23°38′32.82″E
18	Agia Varvara	37°59′22.58″S	23°39′36.70″E
19	Haidari	38°0′44.42″S	23°39′34.40″E
20	Egaleo	37°59′50.40″S	23°40′4.29″E
21	Petroupoli	38°2′26.72″S	23°41′16.59″E
22	Peristeri	38°0′45.58″S	23°41′42.08″E
23	Ilion	38°1′54.33″S	23°42′27.25″E
24	Agii Anargyri	38°1′34.14″S	23°43′3.37″E
25	Zefyri	38°3′3.33″S	23°42′40.90″E

Table 2
t-statistic of the difference of means between the five parts of greater Athens area for June, July and August (mean daily values).

June	Center of the city	Northern	Eastern	Southern	Western
Center of the city	0	12.31	7.06	5.41	2.81
Northern		0	15.17	16.13	34.46
Eastern			0	2.23	15.68
Southern				0	11.93
Western					0
July	Center of the city	Northern	Eastern	Southern	Western
Center of the city	0	11.49	5.77	4.03	5.34
Northern		0	17.90	47.77	63.88
Eastern			0	29.49	41.06
Southern				0	5.28
Western					0
August	Center of the city	Northern	Eastern	Southern	Western
Center of the city	0	14.68	5.35	19.14	11.63
Northern		0	24.94	100.13	96.89
Eastern			0	68.96	61.03
Southern				0	27.10
Western					0

Table 3
t-statistic of the difference of means between the five parts of greater Athens area for June, July and August (max daily values).

June	Center of the city	Northern	Eastern	Southern	Western
Center of the city	0	23.52	22.80	18.77	15.59
Northern		0	1.19	3.39	32.0
Eastern			0	2.29	30.32
Southern				0	25.30
Western					0
July	Center of the city	Northern	Eastern	Southern	Western
Center of the city	0	16.18	16.29	2.51	1.89
Northern		0	0.56	44.5	64.21
Eastern			0	44.46	63.97
Southern				0	15.45
Western					0
August	Center of the city	Northern	Eastern	Southern	Western
Center of the city	0	7.18	4.62	33.17	19.35
Northern		0	7.35	118.9	94.49
Eastern			0	110.54	87.92
Southern				0	6.18
Western					0