The Urban Heat Island Intensities in Greek cities as a function of the characteristics of the built environment

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dated : 10 June 2015

1. Introduction

Greece, with an overall land area of approx. 132,000 km2, is located in southeastern Europe (approximately between latitudes 34° and 42° N, and longitudes 19° and 30° E). It is both a maritime country, with numerous islands and a coastline of over 14,000 km in length, and a mountainous one, with four-fifths of the mainland consisting of mountainous terrain. The climate in Greece is predominantly of the Mediterranean type, with mild and rainy winters, relatively warm and dry summers and sunshine almost all year round.

According to the 2011 census, Greece's population is around 11 million, with 61.2% of this population (about 6.6 million people) living in cities. The country's two metropolitan areas of Athens and Thessaloniki account for over 1/3 (35.9%) of its total population. Around 80% of the urban population lives in the 18 largest cities, all of which have a population of over 50,000 inhabitants, while the remaining 20% live in another 66 cities, with populations ranging between 10,000 and 50,000 inhabitants [1]. Most urban centers, including the capital, Athens, and the second largest city, Thessaloniki, lie on the coast.

The Greek cities have common and recognizable characteristics of urban planning organization and architectural and constructional features of buildings and other integrated structures, and the uses and activities that they host. For instance, in their common feature they are included the non-functional organization of urban space, the dense construction with high thermal mass (building mass per unit area), the lack of green areas, the relative equal-height structure, the high roughness of the building surfaces, the increased albedo, the burning products and photochemical reactions as the main component of their atmospheric pollution (Fig.1). In many Greek cities there are studies that identify the presence of urban climate [2].

Fig*. 1*: Partial aerial view of Athens.

This work is based on a study regarding the main characteristics of the urban climate and the air quality in Greek cities [2. It focuses on the relation between Urban Heat Island intensities and the characteristics of the built environment as a step in the study of the impact of urban warming on the health of the inhabitants in the Greek cities.

2. Characteristics of the Urban Heat Island phenomenon in Greek cities

One of the factors that contribute to the formation of the air temperature in Greek cities is the urban heat island (UHI) phenomenon, the existence of which had already been confirmed by relevant climatological studies carried out in the early 1980s. Since then, the characteristics of the UHI in Athens have been the focus of numerous studies based both on ground measurements [3,4,5,6,7,8,9,10,11] and satellite observations [12,13,14,15]. These studies have shown that the phenomenon exists during both the summer and winter periods, with its spatial and temporal pattern strongly controlled by the unique characteristics of each area. The heat island phenomenon in Athens is characterized by much higher ambient temperatures in densely built and populated areas compared to the surrounding suburban and rural areas (Fig 2). In fact, it develops acuter in the central and western city zones and is mitigated by the presence of green areas in the form of urban parks, even by the medium size ones [16]. The UHI intensities vary from negative values of a few degrees up to more than 10 °C in major central areas (Table 1). Also, there is a convergence of opinion that the phenomenon is more pronounced during the summer period while, as far as its average daily fluctuation is concerned, its intensity is found to be more pronounced during the night, decreasing abruptly after sunrise and intensifying after sunset, according to the prevailing theory of UHI formation. As urban areas are characterized by compact and high buildings, they have a high thermal mass in contrast to non-urban areas that are characterized by a small thermal mass. Thus, during daytime, there is a lag in solar heating of urban areas due to the thermal properties of the building materials. Eventually, an UHI is developed around midday. At night non-urban surfaces cool more rapidly than urban surfaces as building materials are stores of heat; as a result an intense UHI is produced vegetation and surface emissivity appears to have a cooling effect on urban surface temperatures. Thus, during night-time, the more vegetated and of higher surface emissivity urban suburbs in the NE of Athens are cooler than the SW suburbs. From a recent study that examines the contribution of urbanization on the warming trends of air temperature in Athens it was found that, since 1975, the intensity of UHI has increased by approximately +0.2 °C/decade while, on a seasonal basis, the rate of UHI changes is more pronounced in summer than in winter, accounting for approx. 40% of the observed warming rates of summer air temperature in the city [17]. Apart from the built environment and the human activities that take place there, the appearance of the phenomenon has been found to be related to the sea and the local relief influence, as well as the prevailing synoptic-scale weather conditions [5,6,7,8,18,19] (Fig. 2).

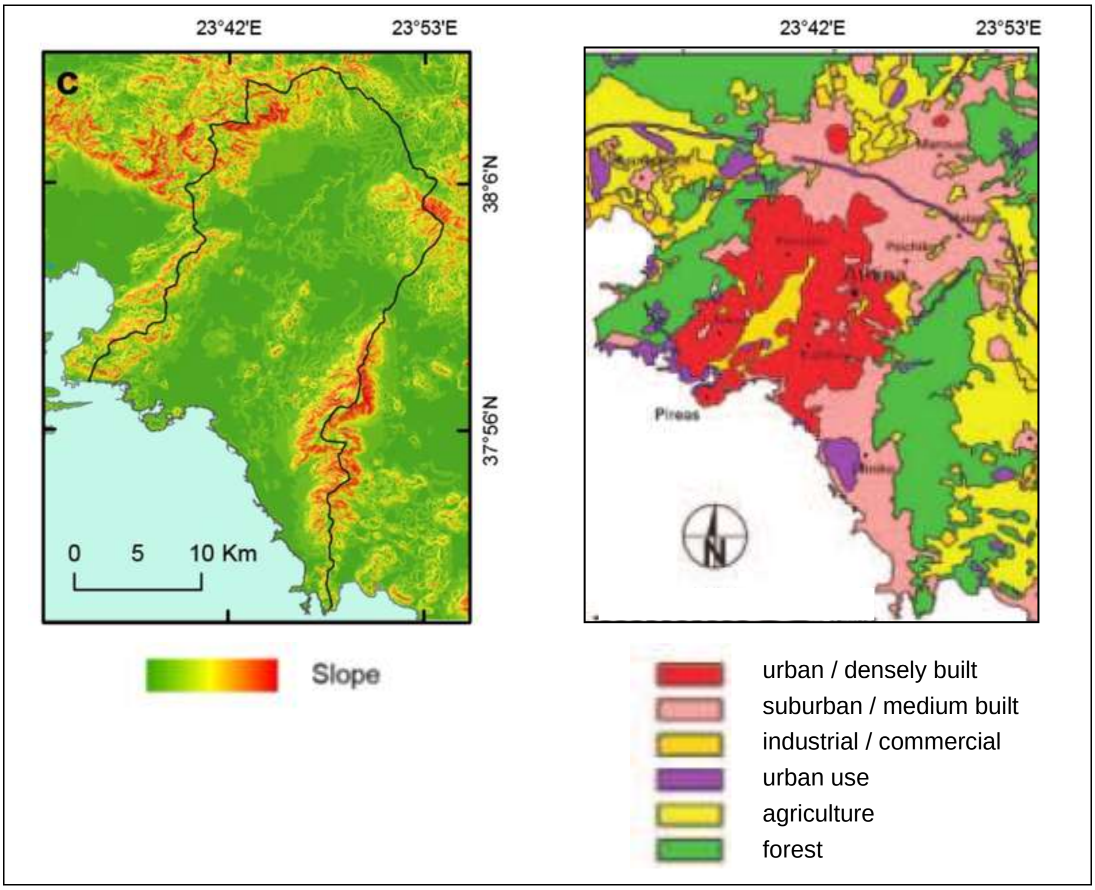

Fig.2 Maps of Athens basin showing the slope gradient of the basin and the land cover/use areas

Table 1: Summary results of the estimations of the UHI intensity in Athens.

Period of study	Source of data	Estimated UHI intensities	Ref.
1925-1996	Ground-based stations	After World War II, and especially after 1970, the urbanization effect, expressed as the difference of the maximum temperatures between one urban and one rural station, amounts to about 2 °C in spring and summer and less in fall, while no urbanization effect is evident in winter.	[20]
1975-2010	Ground-based stations	In summer, the UHI intensities, expressed as the difference in the average temperatures between urban and suburban/rural or rural stations, have been found to have reached up to 2 °C. Negative values have also been marked, which in one case reached -2 °C.	[17]
1990-2001 (at 06:00 LT)	Ground-based stations	In almost 20% of the days per year, the UHI intensity is higher than 4 °C while during almost the 1/3 of the days annually, the UHI intensity is higher than 3°C. During almost the 1/3 of the days annually, the UHI intensity is negative while in almost 15 % of the days per year, the UHI intensity is lower than -1 °C.	[8]
1996-1997	Ground-based stations	The night-time UHI intensity is higher (reaching 5.4 °C) at a central densely populated and built station, while at 3 other urban stations it fluctuates between 0.5 and 3.5 °C. The mean seasonal daytime UHI intensity values for 7 central stations have been reported as follows: 7.5 °C for summer, 5.1 °C for autumn, 3.7 °C for winter, and 4.6 °C for spring. Accordingly, the mean seasonal values for 15 urban stations around Athens are: 5.4 °C for summer, 3.2 °C for autumn, 2.1 °C for winter, and 3.1 °C for spring.	[7]
1996-1998	Ground-based stations	- In summer, during daytime, the UHI intensity for most of the central urban stations is close to 10°C. The UHI intensity is much lower in suburban areas and ranges between 6 and 2°C. During the night-time, the UHI intensity varies between 2 and 5°C. Urban green areas present 2-3°C lower than the reference. - In winter, the UHI intensity in the central area is not significantly reduced compared to the summer period. During daytime, the mean UHI intensity in the central Athens area is close to 10°C, while it is reduced to 3-6 °C in the surrounding suburban areas. During the night-time, the UHI intensity is up to 10°C.	[4]
June 1996 - March 1998	Ground-based stations	- During the WP (December to February) and WTP (November and March) periods, the absolute minimum air temperature values in urban stations are 2-3 °C greater during the WP and 2 °C in WTP, in comparison with the values from suburban stations. - During the SP (July and August) and STP (June and September) periods, the minimum absolute air maximum values in urban stations are 5 - 6 °C greater that the corresponding values of suburban stations, while the maximum of the absolute maximum values exceed by 2 - 5 °C the respective maximum values of the suburban stations.	[6]
1997-1998	Ground-based stations	UHI intensities have been recorded, which in several cases exceeded 10 °C and approached 15 °C at individual stations, regarded as the most representative of strong urban conditions as they are characterized by heavy traffic, increased air pollution and high building density.	[5]
June, July and August 2009	Ground-based stations	The mean air temperature differences between an urban and a suburban station have been estimated to range between 3.0 and 5.3 °C during daytime and between 1.3 and 2.3 °C during night-time, while absolute hourly differences are lower than 4.8 °C during night-time and 1.8 °C during daytime.	[10]
24 and 25 July 2009 (at 08:00, 14:00 and 23:00 LT)	Numerical models and ground-based stations	The UHI intensity has been found to be rather strong (>4 °C) during the night, whereas in early morning and solar peak hours the thermal contrast is less pronounced, reaching even negative values.	[11]
2000-2009	Satellite images	Hot-spots' thermal intensities in summer, compared to a suburban area, are of 9-10 °C and have been found to be highly correlated to their areal extent.	[15]
20 May 2000 (at 08:57 UTC)	Satellite images	Central urban areas are 3.3 °C warmer than rural areas, whereas suburban areas are about 2.3 °C warmer than rural areas. Mixed urban areas (Industrial/commercial and transport units, mine, dump and construction sites as well as sport and leisure facilities) are ''hot spots'' of the city as they appear to be 1.9 °C warmer than the central urban areas and 5.2 °C warmer than the surrounding rural areas.	[12]
11 October 2003 (at 23:32 LT) and 12 October 2003 (at 11:53 LT)	Satellite images	- In daytime, urban/densely built and suburban/medium built surfaces have been found to be about 1°C cooler than rural surfaces, leading to a negative UHI intensity with a mean value of 1.0 °C and a maximum value of 5.85 °C. Industrial/commercial surface areas, as well as urban use surface areas, have been found to be about 2.7 °C warmer than the residential surface areas. - At night-time, the urban densely built surfaces have been presented to be warmer than the surrounding rural surfaces leading to a strong UHI intensity with an observed mean value of 4.3 °C and a maximum value of 7.4 °C.	[14]

The UHI has also been found to be pronounced in the Thessaloniki area [21]. A recent study shows that it is stronger during night-time and decreases with increasing wind speed. There are also indications that it is more intense during the summer period. Measurements of the maximum UHI intensity in Thessaloniki range from 2 °C - 4 °C and 1 °C - 3 °C during the summer and winter periods, respectively, and show a smaller variability during the summer months than in the winter [22]. A study of the UHI using thermal remote sensing data with medium spatial resolution has shown that its intensity at night can reach up to 8 °C for the cities of Thessaloniki and Heraklio and up to 7 °C for the cities of Patra and Volos [23]. Finally, other studies on the UHI have also proved its existence, with lower intensity, in Patra, Heraklio and Volos [12,13,24] and even in smaller cities, such as Seres in northern Greece [25], Chania in Crete [26] and Agrinio in western Greece [27].

High urban temperatures affect the human health in many ways. Studies on the impacts of the urban climate on humans that have been conducted in the wider area of Athens have scrutinized and confirmed the negative impact of the urban warming on its inhabitants by applying human-biometeorological indices [28,29,30,31,32]. More particular studies which examined thermal discomfort during the summer period by applying a range of thermal comfort indices both in Athens [33,34,20,35,36,37,38,39] and in Thessaloniki [40,21,41,42,22] areas, noted that, at times, levels of discomfort were severe and occasionally lasted for several days. Also, studies have shown the contribution of the urban climate in the deterioration of morbidity and mortality rates of the inhabitants of Greek cities [43,44,29,45,46,47]. A common conclusion of these studies is that the impacts of the urban climate on humans are directly connected with urbanization and the associated UHI phenomenon. Indeed, in a recent study in the area of Athens it has been realized that the frequency of thermal discomfort days has increased since 1980 and the period during which they are marked has prolonged, following the urbanization rate [48].

3. Conclusions

The Greek cities, regardless of their difference in size, have similar town-planning organization. In addition, the buildings in them have similar and specific architectural and constructional features and operating patterns. These facts produce similarities in the basic qualitative characteristics of the urban climate in them. On the other side, the inhabitants of cities in Greece – in effect, the majority of the Greek people – cannot be very content with the environment in which they live. This environment is characterized by increased levels of atmospheric pollution and the prevalence of the urban climate, with aggravating impacts on the human-biometeorological conditions, particularly during the summer period. This study identifies and describes the basic characteristics of the UHI phenomenon in Greek cities. Based on measurements from relevant studies, it explores the relation between the intensity of the phenomenon and the characteristics of the built environment in which it is measured. A number of conclusions emerging from the study can be utilized in the planning and implementation of measures to improve the overall living conditions in Greek cities.

Acknowledgment

The authors wish to thank the Natural Hazards, Tsunami and Coastal Engineering Laboratory of the Technical University of Crete for their support.

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