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Urban Form and Microclimatic Conditions in Urban Open Spaces at the Densely Built Centre of a Greek City

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Abstract

The paper presents an experimental investigation of the microclimatic conditions in selected open spaces in the city centre of Volos, a medium-sized coastal city in Greece. It presents the results of systematic field measurements that took place in three urban sites; a public open space and two typical urban blocks. The measurements were carried out during the summer of 2013 and concerned air temperature and relative humidity recordings. Data collection was used to assess the formation and the eventual differentiation of microclimate on a restricted local scale in the urban environment, such as that of a typical urban block or/and a typical public square in the centre of Greek cities. Additionally, research has taken into account buildings construction materials, the predominant paving materials and the key parameters determined by urban geometry in the selected sites, i.e the Aspect Ratio (H/W) and the Sky View Factor (SVF). The measurements revealed microclimatic differences within the inside open space of two of the urban blocks, i.e the courtyard generated of the different building ownerships, the various street canyons and the recordings of the local meteorological station.

Keywords: field measurements, microclimate, open spaces, urban geometry, urban block, urban environment

1. Introduction

Similarly to most contemporary cities, the central areas in Greek cities are characterized by high building and population densities as well as by deteriorating environmental conditions. This situation gets worse also by the shortage of green open spaces, traffic congestion and the accumulation of numerous anthropogenic activities. As a consequence, environmental conditions are constantly worsening. Additionally, high temperatures are observed in the centre of Greek cities particularly in the summer, and affecting the quality of the city's environment, the thermal comfort conditions and the quality of life of inhabitants.

As cited by Gaitani et al (2007) "*Within a particular region, deviations in the climate are experienced from place to place within a few kilometres distance, forming a small-scale pattern of climate, called 'microclimate'* (Santamouris & Asimakopoulos, 1996)*.*" (Gaitani, Mihalakakou, & Santamouris, 2007, p. 317) The unique microclimate of an urban area is mainly defined by the complex built environment, human activities and the lack of cooling vegetated surfaces. Particularly on local scale of urban neighbourhoods, the microclimate is being mainly affected by parameters such as: topography, urban morphology, soil structure and the paving surfaces (Oke, 1987). All these contribute to a thermal contrast between urban and rural areas, characterized by high temperatures in the urban city centres unlike their surroundings, and is defined as the "Urban Heat Island (UHI) effect" (Oke, 1987).

Several studies have attempted to identify the intensity of UHI in the Greek cities; For the metropolitan area of Athens (e.g. Founda et al. 2015; Giannopoulou et al. 2011; Kassomenos & Katsoulis 2006; Livada, Santamouris, Niachou, Papanikolaou,& Mihalakakou, 2002; Mihalakakou, Santamouris, Papanikolaou, Cartalis, & Tsangrassoulis, 2004; Santamouris, Mihalakakou, Papanikolaou, & Asimakopoulos, 1999; Stathopoulou & Cartalis 2007); For the metropolitan area of Thessaloniki (e.g. Giannaros & Melas 2012; Kantzioura, Kosmopoulos, & Zoras 2012; Poupkou, Nastos, Melas, & Zerefos, 2011); For medium-sized cities, such as Patra, Iraklion, Volos (e.g. Papanastasiou & Kittas 2012; Stathopoulou & Cartalis 2007); For small cities such as Chania (e.g. Kolokotsa, Psomas, & Karapidakis 2009), Agrinio (e.g. Vardoulakis, Karamanis, Fotiadi, &

Mihalakakou, 2013) and Serres (e.g Dimoudi, Kantzioura, Zoras, Pallas, & Kosmopoulos, 2013).

In order to investigate the microclimatic conditions in urban outdoor spaces, such as the thermal comfort conditions, the urban heat island effect - and to assess the most important parameters that affect the urban microclimate in general, various methodological approaches have been introduced in the scientific literature of urban climatology. Among them, two are the most influential: a) the ‘observational approaches’, such as field measurements, thermal remote sensing or small scale models (models built for wind-tunnel tests or for measurements in the outdoor spaces) and b) the ‘simulation approaches’, i.e. where the microclimatic conditions are simulated using computational numerical models (Grimmond et al., 2010; Mirzaei & Haghighat, 2010; Souch & Grimmond, 2006). In the former approaches, field measurements constitute a key tool to estimate the main climatic parameters affecting the outdoor conditions in the cities. These parameters are air temperature, relative humidity, wind speed, solar radiation, surface temperature etc. There is a large number of studies using field measurements and monitoring climatic data for:

a) Estimating the microclimate conditions of urban outdoor spaces, such as: The urban canyons (e.g. Assimakopoulos, Georgakis, & Santamouris 2006; Bourbia & Awbi, 2004; Georgakis & Santamouris 2006; Niachou, Livada, & Santamouris 2008); The buildings’ courtyards and the enclosed courtyards inside the urban blocks (e.g. Berkovic, Yezioro, & Bitan 2012; Chatzidimitriou & Yannas 2004; Shashua-Bar, Pearlmutter, & Erell 2009; Taleghani et al. 2014); The urban open spaces (e.g. Cohen, Potchter, & Matzarakis 2013; Duarte & Gonçalves 2006; Eliasson et al. 2007; Elnabawi, Hamza, & Dudek 2013; Fintikakis et al. 2011; Lin 2009; Nikolopoulou, Baker, & Steemers 2001; Nikolopoulou & Lykoudis 2006; Soutullo, Olmedo, Sánchez,& Heras, 2011; Yang & Kang 2005); The urban parks and green spaces (e.g. Chen & Wong 2006; Cohen, Potchter, & Matzarakis 2012; Eliasson et al. 2007; Lahme & Bruse 2003; Mahmoud, 2011)
b) Identifying the intensity and the spatial distribution of UHI effect inside the cities (e.g. Bonacquisti, Casale, Palmieri, & Siani, 2006; Christen & Vogt 2004; Kolokotroni & Giridharan 2008; Mirzaei & Haghighat 2010; Papanastasiou & Kittas 2012; Santamouris, Cartalis, & Synnefa 2015; Svensson, 2004; Vardoulakis et al. 2013).
c) Estimating the impact of specific parameters on the microclimate of urban spaces, such as: urban geometry (e.g. Andreou & Axarli, 2012; Bourbia & Boucheriba, 2010; Elnabawi, Hamza, & Dudek 2013; Johansson 2006; Krüger, Minella, & Rasia 2011), paving materials of the urban surfaces (e.g. Chatzidimitriou, Chrissomallidou, & Yannas 2006; Georgakis, Zoras, & Santamouris 2014; Kolokotsa et al., 2012; Santamouris et al., 2012), vegetation (e.g. Georgi & Dimitriou, 2010; Ng, Chen, Wang, & Yuan, 2012; Oliveira, Andrade, & Vaz 2011; Shashua-Bar, Tsiros, & Hoffman 2010).
d) Investigating the thermal comfort in urban outdoor spaces through monitoring the basic meteorological parameters combined with the use of specific bio-meteorological indices such as the Physiological Equivalent Temperature – PET etc. (e.g. Chrysoulakis et al., 2013; Cohen et al. 2012, 2013; Elnabawi et al., 2013; Gulyás, Unger, & Matzarakis 2006; Johansson, 2006; Knez & Thorsson, 2008; Lin, 2009; Mahmoud, 2011; Nikolopoulou et al., 2001; Nikolopoulou & Lykoudis 2006; Oliveira et al., 2011; Pantavou et al., 2011; Scudo & Dessì, 2006; Tseliou et al., 2010; Tsitoura, Tsoutsos, & Daras 2014)
e) The measured data are often used either for validating the results of the microclimatic arithmetic models or as insert data in order to define the boundary and initial conditions of the simulation models. (e.g. Assimakopoulos et al., 2006; Berkovic et al., 2012; Chen & Wong, 2006; Elnabawi et al., 2013; Fintikakis et al., 2011; Georgakis et al. 2014; Karim & Nolan 2011; Krüger et al. 2011; Lahme & Bruse 2003; Ng et al. 2012; Santamouris et al. 2012; Shashua-Bar et al. 2010).

In the present research, the field measurements were carried out in two typical urban blocks and a public open space in the city centre of Volos. The measurements refer to air temperature and relative humidity recordings during the summer months in 2013. Regarding the two urban blocks the monitoring has been conducted both outside at the perimeter of the block and inside the enclosed open space of the block, i.e. the courtyard. The aim of this monitoring campaign was to identify the main microclimatic patterns and characteristics of the selected sites.

2. Methodology

2.1 Studied Area

The experimental investigation was held in the centre of the medium-sized coastal city of Volos, in Eastern Central Greece (latitude 39.29^o N, longitude 22.56^o E). Volos has the typical Mediterranean climate of coastal cities, i.e. mild and rainy winters, relatively hot and dry summers and extended periods of sunshine throughout most of the year. The cold and rainy period lasts from the mid of October until the end of March, and the warm and non-rainy season lasts from April until September (Hellenic National Meteorological Service [HNMS], 2011).

Figure 1. Location of the City of Volos (photo source: google earth)

The central area of Volos is densely built–up with few and small squares and green open spaces. The street pattern in the city centre represents a typical geometric grid (see Figures. 2-3). The majority of the city's building stock has been constructed during the rebuilding of the city after the devastating earthquakes 1955-1957. The type of 3-6 storey-buildings has become the dominant building typology in Greek cities in the post-war period (Gospodini, 1999; Hastaoglou, 2002). In the selected area, most of the buildings are of 4-6 floors and have been constructed mainly in the 60s, 70s and early 80s. The ground floor has usually a height of a 4.5-5m and it usually accommodates commercial shops. Upper floors accommodate offices or/and residences.

2.2 Site Selection Criteria and Description

In the central area of Volos (see Figure 2a) three sites have been selected: a) two blocks typical of the city's morphology and fabric, but slightly different in terms of shape and size and b) Agios Nikolaos Sq, as typical public open space (see Figures 2b, 3).

a) **b)**

Figure 2. a) The selected urban area, and b) the selected sites: 1) Urban Block B-UB.B, 2) Urban Block A-UB.A, 3) Agios Nikolaos Square-AG.S (photo source: google earth and e-ktimatologio)

The Urban Block A (UB.A) has a typical northeast orientation and a rectangular shape with dimensions 84mx45m approximately. It has a total surface of 3.780m^2, whereas 2.445m^2 (64.7%) correspond to the buildings' covered surface and 846m^2 (24.4%) correspond to the total surface of the enclosed open space (courtyard). The rest 489m^2 represent the surface of the streets and the sidewalks along the perimeter of the urban block. The buildings are 3 to 6 storey-constructions, so their height varies from 8m to 20m and have been built primarily in late '60s/early '70s and secondly in the decade of 1980. The main construction material is concrete, while the basic paving materials are: black conventional asphalt, light coloured concrete tiles and concrete pavement. There is no vegetated ground surface, neither inside nor outside the block, but there are numerous trees planted along the sidewalks and just two (Citrus aurantium) at the southern part inside the enclosed courtyard. Most of the trees are planted along the North-western (16 trees) and North-eastern street canyon (8 trees) and vary between the species of ‘Citrus aurantium’ and ‘Ligustrum japonicum’. The streets around the urban block have narrow sidewalks and car parking is allowed, even at both sides in case the street is wide enough.

Figure 3. The selected urban sites and the location of the measurement points: Urban Block UB.A, Urban Block UB.B, Agios Nikolaos Square AG.S (photo source: google earth and e-ktimatologio, http://gis.ktimanet.gr/wms/apr1/)

Similarly, the Urban Block B (UB.B) has also a typical northeast orientation and rectangle shape with dimensions of approximately 34m x 34m. It covers a total surface of 1.537m^2, of which 61% (948m^2) is occupied by buildings, and almost 15% (225m^2) corresponds to the enclosed courtyard and 24% to the surrounding streets, pedestrian streets and sidewalks. So in this case, a smaller block is being examined with a respectively smaller enclosed courtyard, almost ¼ of the size of the courtyard of the first block. The existing buildings are also 3 to 6 storeys constructions dated from ‘70s and ‘80s. Same here, concrete is used as the main construction material and the basic paving materials are: black conventional asphalt, light coloured concrete tiles and concrete pavement. There is no vegetated ground surface, neither inside nor outside the block, but there are a very small number of trees planted along the pedestrian streets and the sidewalks (4-5) mainly of the species of ‘Aesculus hippocastaneum’ and ‘Prunus cerasifera’.

The public open space selected is the central square of Agios Nikolaos Cathedral (AG.S), which along with two surrounding pedestrian streets covers a total surface of 7.115 m^2. In this case only 11% of the total surface is covered by the building of the Cathedral; the rest remains open space. The buildings that define this square have a number of 4-6 floors and are mostly constructed in the ‘70s and early ‘80s. Regarding to the paving materials, these are soil and vegetated ground surface (about 12%), light coloured concrete tiles, ceramic tiles, white marble and black conventional asphalt. There are also various trees planted, but do not contribute effectively to shading or natural cooling of the open space.

As mentioned above, the various surfaces of both urban blocks consist mainly of impervious materials, with high thermal capacity and low reflectance to solar radiation, such as asphalt and cement. Consequently these surfaces contribute to the excessive heat storage at the urban sites during the day. Additionally, the lack of ground, water or vegetated surfaces contributes to the decreased evapotranspiration and therefore to reduced natural cooling from the urban areas. The low evapotranspiration rate in the contemporary cities contributes to the appearance of high temperature values (Christen & Vogt 2004; Grimmond & Oke 1999; Oke, 1987;1991; Santamouris, 2001; Taha, 1997)

2.3 Urban Geometry in the Selected Sites

Urban geometry represents a key factor influencing the microclimate, as it affects the wind flow and the solar access (Arnfield, 1990;2003; Oke, 1988). It is usually expressed either with the Aspect Ratio Height/Width (H/W) or with the Sky View Factor (SVF) (Bourbia & Boucheriba 2010; Johansson 2006; Smith & Levermore 2008). The Aspect Ratio Height/Width (H/W) refers to the ratio of the mean building height to the streets width (or generally to their mean in-between distance) (firstly introduced by Oke, 1987). Thus, the H/W ratio describes how densely buildings are spaced with respect to their heights (Unger, 2004). The SVF is a dimensionless measure between 0 and 1, representing totally obstructed (SVF~0, i.e. no sky visible) and free spaces (SVF~1, i.e. free hemisphere) respectively. It determines, though, the radiant heat exchange between the city and the sky (Chapman, Thornes, & Bradley, 2001; Oke, 1987). As mentioned by Unger (2004) "*the decreased SVF below roof level reduces radiative loss and also reduces turbulent heat transfer in the often calm canyon air. Therefore, theoretically it is considered to be a major component of the UHI phenomenon"* (Unger 2004, p.254).

At the present study, the SVF values have been calculated by the ENVI-met software. Mapping of the sky view factors for the three case studies is illustrated by figure 4, where lighter shades of grey correspond to higher SVF values. At the Sky View Factor calculation was taken into consideration the existing trees in the various sites. Regarding the urban geometry of the selected sites, for each one resulted that:

- At the first urban block (UB.A), the H/W ratios in different points around the block are relatively high and their values vary between 1.3-1.5. Inside the courtyard, the H/W ratios are lower than outside the urban block since they have an average of 1.0. The SVF values at the street canyons around the UB.A are low and range between 0.3-0.4. At the street intersections SVF values are a bit higher, ranging from 0.5 to 0.6. Inside the UB.As' courtyard, the SVF range between 0.3-0.5 approximately (figure 4, table 1). At the surfaces below trees and canopies the SVF values are very low (0.1-0.3), as for instance at the south part of the courtyard where there are planted the two citrus trees.
- The urban block (UB.B), occupies a surface a bit less than 1/2 of the UB.As' surface, with a respectively smaller courtyard (almost ¼ of the UB.As' courtyard). The H/W ratios in different parts around the urban block are higher than those of UB.A and vary between 1.2-2.4, meaning an average of 1.8. In the courtyard, the H/W ratios are on the average of 1.2 approximately. The SVF values at the street canyons around the UB.B are low and range between 0.3-0.4. At the street intersections, SVF values range between 0.4-0.5. Inside the UB.Bs' courtyard, the SVF values are very low and range between 0.2-0.35 approximately. Same here, at the surfaces below trees the SVF values are very low (0.1-0.3).
- At the public open space (AG.S), the H/W ratios are respectively low, as their values average on 0.3.The SVF values are relatively high respected to the other two sites, since they range between 0.6-0.8, except the surfaces below trees (SVF values 0.1-0.4 approximately). Taking into account this two parameters, the various surfaces at the public square are freely exposed to solar radiation (figure 6), but in the meantime their view of the sky isn't seriously obstructed (due to high SVF values) permitting their radiative cooling to the cooler sky especially during the evening and night.

Thus, urban geometry, as expressed by the above mentioned parameters, the orientation and the geographical location appear to determine the incidence of the solar radiation on the selected sites. A simple shading analysis was carried out using the Autodesk Vasari software for the latitude of the city of Volos and for the exact location of the three sites, on the 21st June (figure 5).

Table 1. The SVF values at the measurement points of the selected sites

Site-Monitoring Point	SVF	Site-Monitoring Point	SVF	Site-Monitoring Point	SVF
Urban Block UB.A		**Urban Block UB.B**		**Public Square AG.S**	
Measurement point P1 (courtyard)	0.37	Measurement point P5 (courtyard)	0.34	Measurement Point P8	0.66
Measurement point P2 (courtyard)	0.46	Measurement point P6	0.35	Measurement Point P9	0.53
Measurement point P3	0.47	Measurement point P7	0.25		
Measurement point P4	0.46				

Table 2. The aspect ratio H/W at the selected sites

Site	H/W ratio	Site	H/W ratio	Site	H/W ratio
Urban Block UB.A		**Urban Block UB.B**		**Public Square AG.S**	
Northwestern Street canyon (NW)	1.35	Northwestern Street canyon (NW)	1.3	Average H/W ratio	0.3
Measurement Point P3	0.95				

Northeastern Street canyon (NE)	1.45	Northeastern Street canyon (NE)	2.4
Southeastern Street canyon(SE)	1.5	Southeastern Street canyon(SE)	1.2
Southwestern Street canyon (SW)	1.6	Southwestern Street canyon (SW)	2.1
Measurement Point P4	1.1		
(Courtyard)	1.0	Courtyard	1.2
Measurement Point P1		Central Point	
Measurement Point P2			

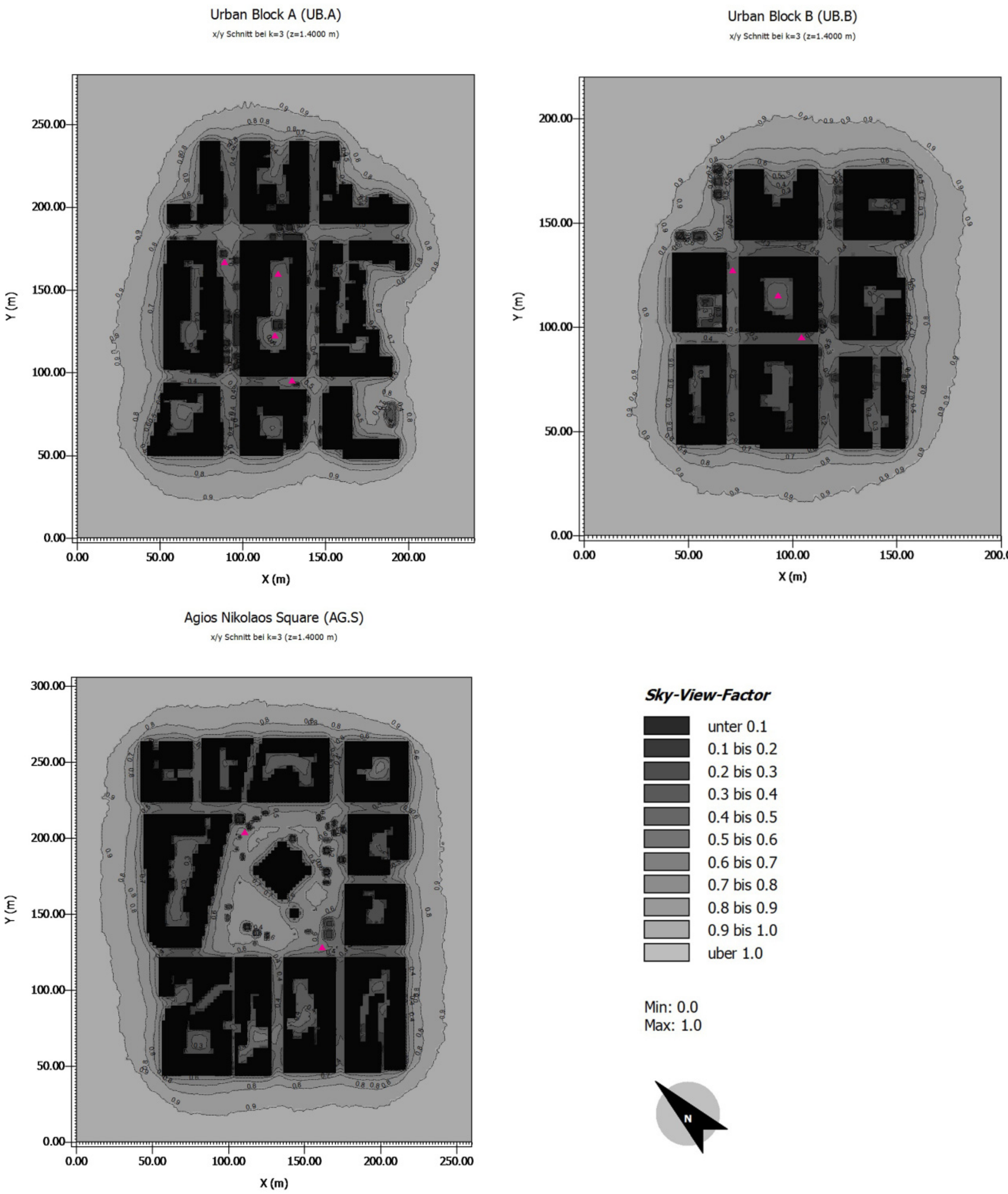


Figure 4. The Sky View Factor distribution at 1.40m above ground level, by ENVI-met v3.1, and indication of the location of the measurement points at the three selected sites

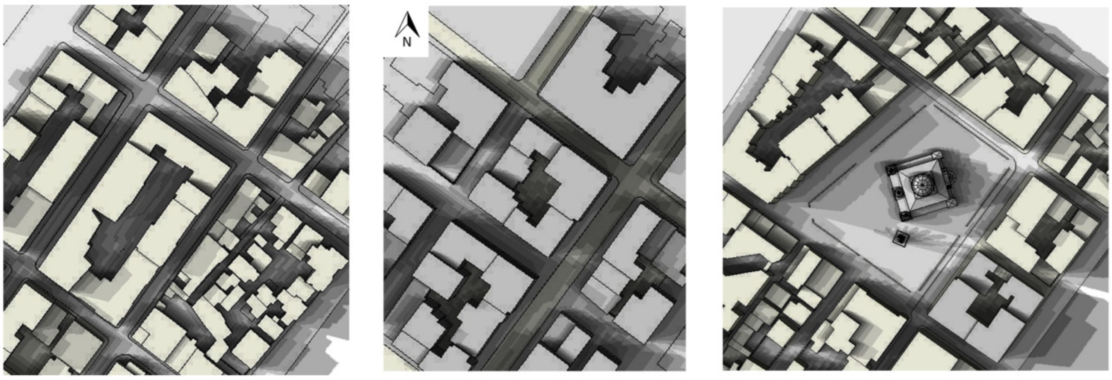


Figure 5. Shadow ranges of the three sites on June 21st, from 10:00 to 18:00, i.e. the warmest period of the Greek summer day

2.4 Monitoring Campaign

The present study carried out experimental measurements in order to investigate the microclimatic conditions in the outdoor space of the public square of Agios Nikolaos, the enclosed open space inside UB.A and UB.B and at the external perimeter of the blocks, i.e. the urban canyons (formed by the surrounding streets and buildings), in terms of temperature and relative humidity.

The experimental measurements took place during summer 2013, in July and August. These months are the warmest period of the Greek summer, hence the period when it can be identified as the greatest thermal discomfort in the Greek urban environment. The field surveys involved a detailed monitoring in two ways using the same equipment:

a) The equipment was fixed in the field at 1.40m height, monitoring constantly for several days, i.e. the case of the enclosed courtyards of the two urban blocks. In this case, the data was being monitored consecutively in a 15min time lapse and for several days.

b) The equipment was portable (mounted on a bicycle at 1,20m height), monitoring for 5 certain periods during the day (09^{00}-10^{00}, 12^{00}-13^{00},15^{00}-16^{00}, 18^{00}-19^{00}, 21^{00}-22^{00}) i.e. the case of the public square and the external part of the urban blocks. The recording had consecutively been held every 10 seconds. This approach has been adopted due to the exposure of the equipment at various human activities (car circulation, bicycle and pedestrian crossing, narrow sidewalks, kids playing etc.) and the necessity of more observers to be simultaneously present at the field.

The measurement of climatic parameters and specifically of air temperature (T_{air} in ^oC) and relative humidity (RH, %) has been implemented by Onset HOBO U23 Pro v2 Data Loggers. The loggers' temperature internal sensor, operates between -40^{o}C to 70^{o}C with an accuracy of ±0.21^{o}C (from 0^{o}C - 50^{o}C). Respectively the relative humidity sensor operates between 0 to 100% with an accuracy of ±2.5% (from 10%-90%). Both sensors have a response time of about 40min in air moving 1m/sec with protective cap.

Furthermore, since the data loggers would have been exposed to outdoor conditions, and thus to sunlight, it was necessary to protect the loggers' sensor from solar radiation (as recommended by the manufacturer's own) and rain. Meanwhile, the logger had to be protected not only against solar radiation but also had to be properly ventilated thus to achieve the actual measurement of the temperature in shade. For this purpose the data loggers where placed inside wooden protective boxes with elongated slots in their vertical sides, constructed according to the standards of Stevenson's meteorological Screen (see Figure 6).


Figure 6. Views of the protective screens with the data loggers, inside both courtyards

The Measurement Points of the selected sites are shown in Figure 3. In all sites the measurement points were set to north and south respectively, either at the public square and at the enclosed courtyard inside the urban blocks or outside at the perimeter of the blocks. Particularly, for the three selected sites the monitoring campaign was conducted as descripted in Table 3.

Table 3. The monitoring campaign

Site-Monitoring Point	Number of Observations	Days of Measurements 2013
Urban Block UB.A		
Measurement point P1 & P2 (courtyard)	Every 15mins for 24 hours	July 27,28,29,30,31, August 1, 5 ,6,7
Measurement point P3	5 times/day (10^{00}, 13^{00},16^{00}, 19^{00}, 22^{00})	August 5,6
Measurement point P4	5 times/day Every 15mins for 12 hours	August 5,6
Urban Block UB.B		
Measurement point P5 (courtyard)	Every 15mins for 24 hours	July 31 August 1, 2
Measurement point P6	5 times/day	August 1, 2
Measurement point P7	5 times/day	August 1, 2
Public Square AG.S		
Measurement point P6	5 times/day	August 7, 8
Measurement point P7	5 times/day	August 7, 8

Table 4. Climate data recorded at the Meteorological Station in the City of Volos (WSV).

Monitoring Period	Air temperature (°C)			Relative Humidity (%)			Wind Speed (m/s)		
	max	min	avg	max	min	avg	max	min	avg
27-31 July 2013	34.1	24.8	29.1	73.4	47.4	59.6	15.5	0.0	3.7
01-07 August 2013	33.1	24.6	28.5	70.0	43.0	58.9	15.2	0.0	4.2

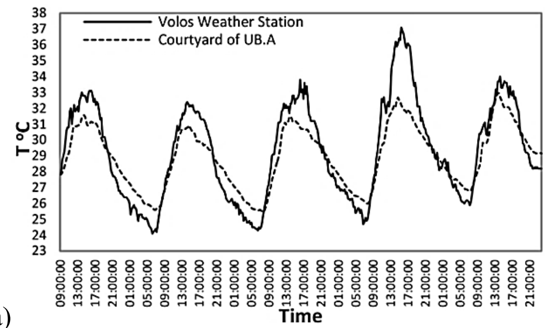
3. Results and Discussion

The results of the three case studies showed for each of them:

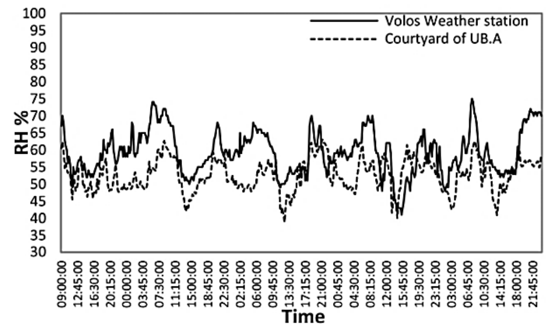
Urban block A (UB.A)

Regarding the period from 27 July 2013 to 1 August 2013, the recorded air temperature of UB.As' courtyard is quite lower (-1.5°C on average) during the day than the one given from the corresponding Weather Station for the city of Volos (WSV). There have been recorded lower temperatures up to 4.5°C. More specifically the maximum difference in temperature was recorded in a heatwave day on July 30th 2013, where inside the courtyard the temperature didn't exceed 32.7°C while the city's weather station recorded 37.2°C.

On the contrary, the temperature inside the courtyard after the sunset is higher than that of the city, except the heatwave day, where the courtyard remained cooler. The relative humidity inside the courtyard was recorded to be lower than that of the city on 8-13 percentage units. There was noted a differentiation in temperature recordings between the two measurement points at the enclosed courtyard. At the north-eastern point (P1) higher temperatures up to 2.3 °C have been recorded, due to different orientation, geometric characteristics and lack of vegetation (contrary to P2 located at the south part where are planted also the two trees) that affect the incidence and the absorbance of solar radiation.



a)



b)

Figure 7. a) Temperature, and b) Relative Humidity fluctuation at UB.As' Courtyard, 27/07-31/07/2013

Regarding the monitoring period from 5 to 7 August 2013, same here, during the day the recorded air temperature of UB.As' courtyard was much lower than the one given from the corresponding WSV for the city. There have been recorded lower temperatures up to 2.7°C. Between the two measurement points (P1, P2) at the enclosed courtyard, there were also recorded higher temperature values at the north-eastern point (P1) up to 1.5°C.

The recorded air temperature at the two external measurement points (P3 & P4) in the perimeter of the UB.A is higher both than that recorded in the courtyard and at the WSV for the greater area of Volos, up to 2.2°C. More specifically, higher temperature values were measured at point P3 up to 2.8°C and at the point P4 up to 3.3°C than those recorded at the WSV. The maximum difference in temperature (3.3°C) was recorded at the south-western point P4 on August 6th 2013, in which was implemented a continuous recording with a 15min lapse for the period of half a day (10^{00}-22^{00}). That was the case where the protective shell with the equipment was mounted on a semi-floor's balcony at 1.40m height above the street level approximately.

Consequently, between the two external measurements points (P3, P4) the temperature recordings vary up to 1.8°C. The different exposure to solar radiation due to different orientation and geometry (H/W ratios, SVF), contributed to lower temperature values at P3 contrary to P4 located to south, except during morning to midday where there were recorded higher temperatures to P3. It's well known that site orientation to mainly W-E axis, combined with low H/W ratios, contributes to more stressful thermal conditions in outdoor spaces, due to excessive exposure to solar radiation for mid and high latitude climates (Ali-Toudert & Mayer 2006, 2007; Oke, 1988). Additionally, the predominant construction and surface materials with high thermal capacity (such as cement and asphalt), when exposed extensively to sunlight they favour the increased heat storage and thus the increased air temperature values.

Regarding the relative humidity, the values recorded at the external points are lower than those inside the courtyard (up to 5 percentage units) and those recorded for the city from the WSV (up to 14 percentage units). Therefore higher values of temperature are accompanied by lower percentages of relative humidity.

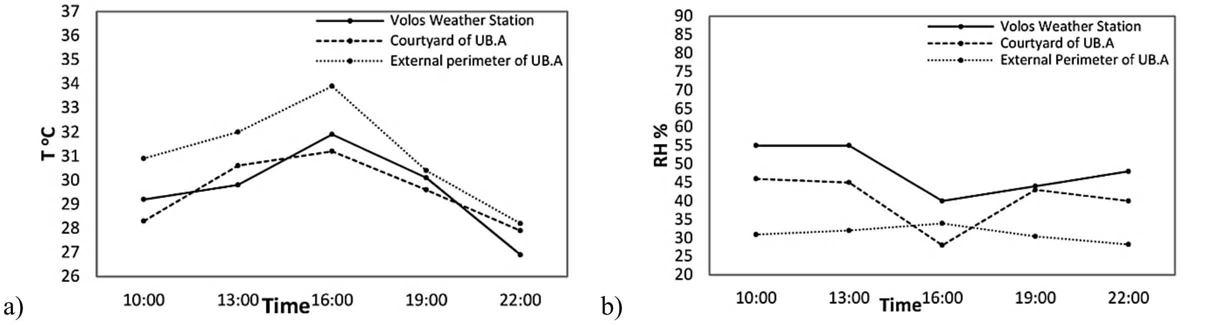


Figure 8. a) Temperature, and b) Relative Humidity fluctuations at UB.As' Courtyard and External Measurement Points, 05/08/13 (at the 5 predefined time periods)

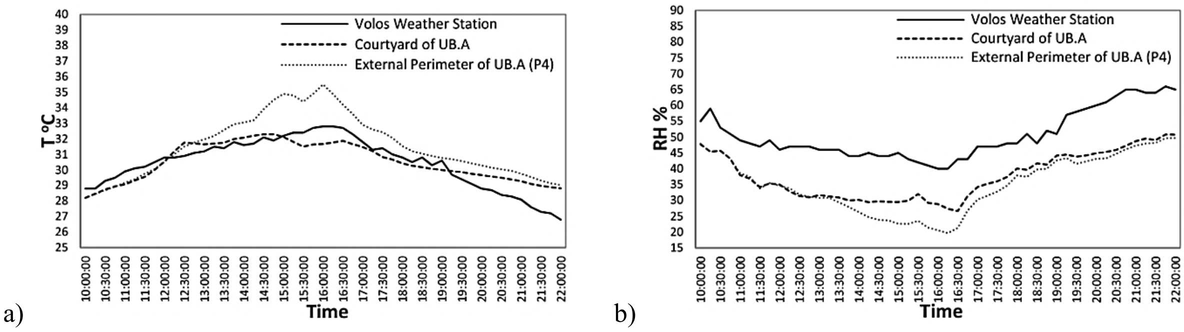


Figure 9. a) Temperature, and b) Relative Humidity fluctuations at UB.As' Courtyard and External Measurement Points, 06/08/13 (10:00-22:00)

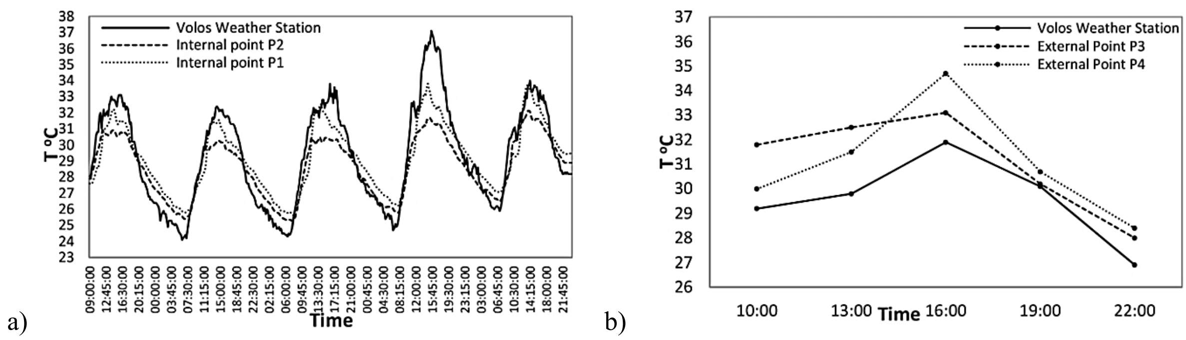


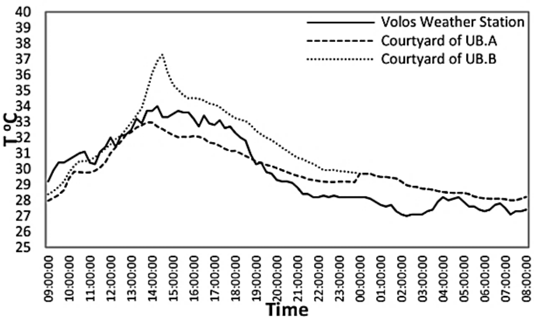
Figure 10. a) Temperature fluctuation at UB.As' Internal Measurement Points, 27-31/07/13, and b) Temperature fluctuation at UB.As' External Measurement Points, 05/08/13

Urban block B (UB.B)

Contrary to UB.A, the fluctuation of the air temperature at the enclosed courtyard of UB.B is higher during the day than both the UB.A's courtyard and the city's weather station (up to 4°C). More specifically, on July 31st 2013, inside the UB.Bs' courtyard the maximum temperature recorded was 37.3°C, while the city's temperature was recorded 34°C by WSV and the temperature recorded at the UB.As' courtyard didn't exceed 33°C on average. In late evening and during the night, the temperature of the greater area of Volos was lower than both UB.As' and UB.Bs' courtyard, up to 1.4°C and 2.1°C respectively (Figure 11a).

The enclosed courtyards of UB.A and UB.B have the same orientation and are characterized of similar paving and construction materials. They differ mainly in terms of morphology, geometry, size and vegetation, since at the central-south area of UB.A's courtyard there are two medium-sized citrus trees. The UB.B has a courtyard with a total surface about ¼ of UB.As, a bit higher H/W ratio and lower SVF than those of the UB.As' courtyard (table 1, 2). Therefore, primarily the space morphology combined to the vegetation affects their microclimate.

Respectively, low percentages of relative humidity were recorded inside the UB.Bs courtyard compared to those given for the UB.A's courtyard and the city's weather station (up to 5 and 19 percentage units respectively). Furthermore, the lack of vegetated surface in the courtyard contributes to low percentages of relative humidity.

a)


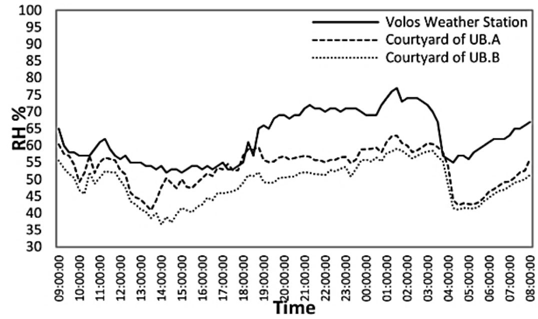
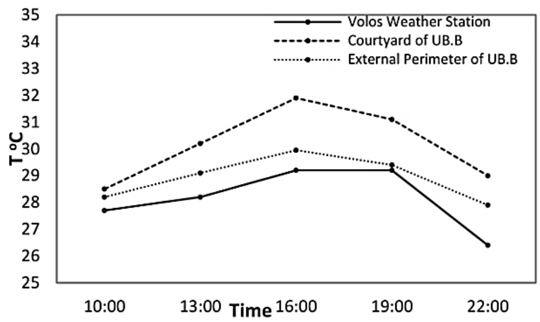
b)


Figure 11. a) Temperature, and b) Relative Humidity fluctuation inside the Courtyards of UB.A and UB.B (from 09:00 31/07/13 to 08:00 01/08/13)

Regarding the values of air temperature recorded at the two external measurement points in the perimeter of the UB.B, those were lower than the values recorded in the inner courtyard during both days (up to 1.1 °C at August 1st and 0.7 °C at August 2nd). On average of both measurement points, the air temperature was higher than the city's greater area, up to 1.6 °C. The values of relative humidity recorded at the external points are respectively higher than those recorded inside the courtyard, i.e. up to 4 percentage units approximately for the monitoring period, but lower than those recorded at the WSV for the entire city.

Between the two external measurement points (P6, P7) there is a differentiation in temperature recordings due to different orientation, geometric parameters (H/W ratios, SVF) and paving surfaces that affect the microclimatic conditions. The southern point P7 has a higher H/W ratio (almost 2.1) and a relatively low SVF (0.25) compared to the northern point P6, which has H/W ratio equal to 1.3 and a SVF equal to 0.35. This fact implies that the southern point P7 is exposed less to the solar radiation than the measurement point P6 and thus lower temperatures were measured at the point P**7**, up to 2 °C.

a)


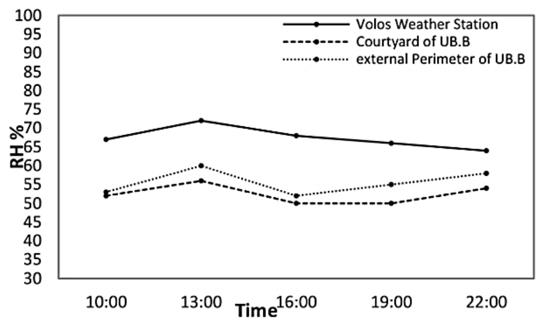
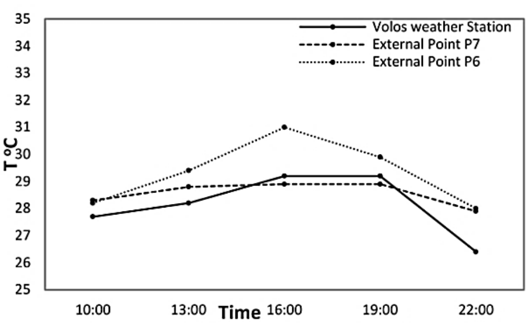
b)


Figure 12. a) Temperature, and b) Relative humidity fluctuation at UB.Bs' Courtyard and External Measurement Points, 01/08/13

a)


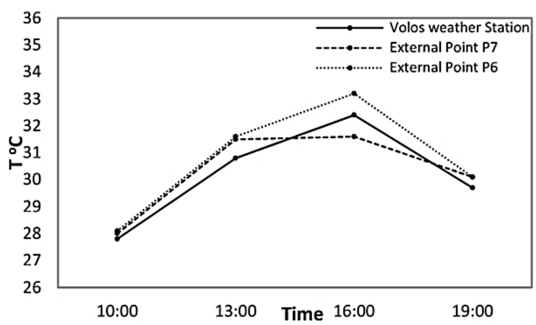
b)


Figure 13. a) and b) Temperature fluctuation at UB.Bs' External Measurement Points, 01-02/08/13

Agios Nikolaos Square (AG.S)

At the two measurement points (P8, P9) on the north and south part of the square, the temperature recorded during the monitoring campaign was generally 0.1°C to 1.8°C higher than the city's greater area. Similarly to the other recordings, higher temperature values were accompanied by lower percentages of relative humidity. The restricted vegetated surface and the scarce amount of trees without significant leaf area density are also instrumental facts in forming this state. Additionally, there were identified differences (up to 1.6 °C) in the temperature values between the two points which varies during the day as a result of different exposure to sunlight, i.e. the different orientation and duration and also different hours of the day.

For the time period 10:00-19:00 on August 7th 2013, the simultaneous recordings at the public square AG.S and the enclosed courtyard of UB.A have given higher temperatures at the square, up to 1.5 °C. Unlikely to what somebody would expect, the outdoor conditions at the larger and more spacious square proved to be warmer than those in the courtyard during the day. The low H/W ratio (0.3) of the public square and the scarce shading, contributed to increased air temperature values during daytime.

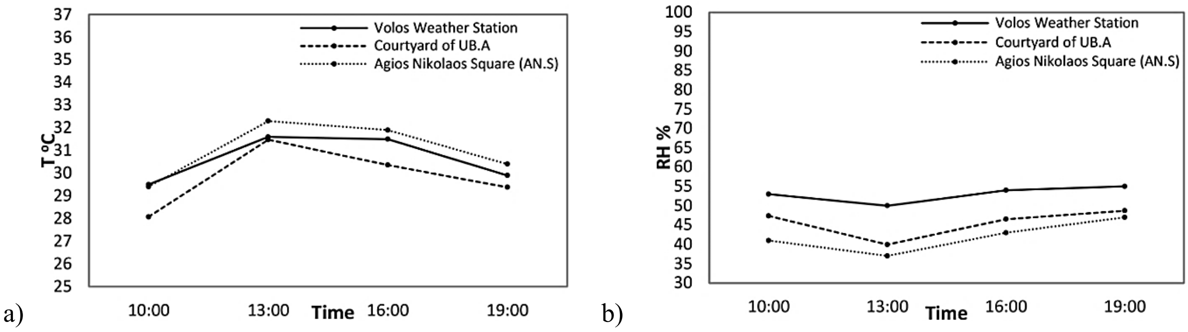


Figure 14. a) Temperature, and b) relative humidity fluctuation at the Public Square and at the UB.As' Courtyard and External Measurement Points, 07/08/13

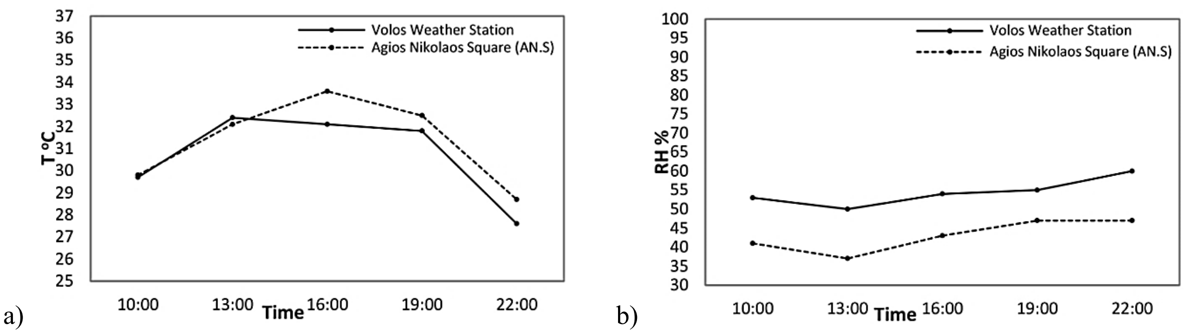


Figure15. a) Temperature and b) relative humidity fluctuation at the Public Square, 08/08/13

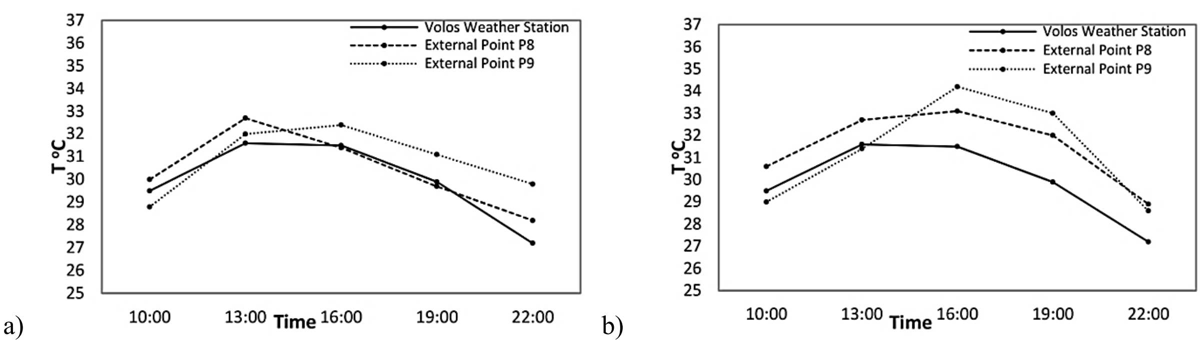


Figure16. a) and b) Temperature fluctuation at the two Measurement Points of the Public Square, 07-08/08/13

The different exposure to solar radiation due to urban morphology primarily, the different paving materials and the scarce amount of vegetated surfaces and trees are responsible for this variety of microclimate in spaces in such proximity. As cited at Ketterer and Matzarakis (2014) "*The intensity of the intra-urban differences of thermal conditions as well as of the UHI depends strongly on the sky view factor (SVF), built-up ratio (aspect* *ratio) and green surface ratio (Oke, 2006; Unger, 2004)"* (Ketterer & Matzarakis, 2014, p. 81).

4. Conclusions

According to the recorded data of the field measurements, the three different case study sites presented diversified microclimatic conditions. The two different types of urban block have shown inverse thermal conditions in their enclosed courtyards during daytime. In the UB.As' courtyard the values of temperature were recorded to be lower during the day both than those recorded for the greater area of Volos and the ones recorded in the UB.Bs' courtyard. Moreover the air temperature recorded in the UB.Bs' courtyard was higher in average than that of the city's greater area (up to 4°C).

Regarding the external measurement points at the perimeter of the selected urban blocks, higher temperature values than those of the weather station (up to 2.2 °C for UB.A, 1.6 °C for UB.B) were observed during the day and even more in late evening. Similarly, at the public square of Agios Nikolaos slightly higher temperature values than those from the weather station were detected. Contrary to the daylight recordings, in late evening and during the night, the temperature of the greater area of Volos was lower than that of the selected sites in the city centre, except that of the UB.As' courtyard on the heatwave day. The above results point the following:

a) Reveal the presence of higher temperatures inside the densely built up centre of Volos than the greater urban area, namely the existence of urban heat island effect. It is worth mentioning that several studies in the Greek city centres have previously detected the UHI effect, even for the city of Volos (e.g. Papanastasiou & Kittas 2012)

b) Indicate mainly the influence of morphology on microclimate of the present urban open spaces; This urban property involves parameters such as the form and height of buildings, the street geometry, the urban blocks' and courtyards' size etc., The urban geometry is a key factor expressed by the Aspect Ratio H/W and the Sky View Factor, that affects the environment together with other parameters such as orientation, paving surfaces, the amount and the quality of the vegetated area.

Since UB.A and UB.B share the same orientation, construction and paving materials, their differences mainly concern: a) geometry, i.e the occupied surface area, the courtyards' size, the Aspect Ratios (H/W) and the Sky View factors, and b) the amount of vegetation inside the courtyards (i.e the two existing trees at the south part of UB.As' courtyard).

Urban geometry combined with impervious urban surfaces of high thermal capacity and low reflectance materials (such as asphalt, bricks, cement) influences substantially the thermal environment of the outdoor spaces (Santamouris, 2001). Therefore, open spaces consisting of such surfaces, as in the ones studied, when exposed extensively to solar radiation, their surfaces storage excessive heat during daytime that hardly can be radiated to the sky during night, due to low SVFs (i.e obstructed skyline) characterizing the spaces' geometry.

In order to mitigate urban heat island effect and the deteriorating environmental conditions, certain mitigation urban strategies are being implemented by the policy makers worldwide. The most common strategies implemented at the urban scale constitute on: a) the use of high albedo materials such as cool materials and cool pavements, and other materials based in new technologies (e.g. thermochromic materials), b) the addition of vegetation, c) the use of water bodies, permeable and water retentive pavements, and the e) the use of renewable sources at building and city scale (Gaitani, 2011; Taleghani et al 2014; Santamouris, 2012).

Recently, such strategies have been implemented by Policy makers in Greece at the level of the single building, the public open space (e.g. Gaitani, 2011; Santamouris, 2012) and the urban scale. These strategies comprised: a) the 'Pilot Program of Bioclimatic Redesign of Public Open Spaces', i.e. the regeneration of public open spaces by implementing the above mentioned strategies and the bioclimatic design principles (CRES, 2011a), b) the 'Pilot Program of implementation of Green Roofs at the Public Buildings' (CRES, 2011b), c) the 'Program of Energy Efficiency at Buildings', i.e. the improvement of the energy performance of residences and apartments, by promoting also the use of renewable energy systems, through the partial subsidy with European and national economic sources (Ministry of the Environment, Energy and Climate Change, 2012).

None of the above policies had significant effects on the urban heat island phenomenon in greek cities; first, the Pilot Program of Bioclimatic Redesign of Public Open Spaces', involved fifteen projects so far. These projects were medium-scaled including one or two public open spaces (squares, pedestrian streets etc.) and the immediately surrounding urban blocks (4-6).Thus, this policy has been inefficient to tackle deteriorating environmental conditions. Second, the other two programs have been sporadically applied on individual apartments or buildings in different urban blocks, thus, not clustering and having an important positive effect at urban scale. The environmental disadvantages of densely-built greek cities and the heat island effect, as described in the introduction, still remain an unsolved urban problem and the urban sustainability question in greek cities is still open.

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