Urban microclimate investigation of major squares in Athens

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Abstract: This paper presents the methodology and first results of an on-going research devoted to a systematic investigation of thermal comfort levels in selected public outdoor spaces in Athens. Furthermore basic parameters in the design and construction of each space (surface materials, water elements, vegetation, shading etc.) are evaluated in combination with selected uses, in order to contribute to the assessment of microclimatic conditions affecting their environmental performance. The aim of the research is to provide a set of quantitative, as well as qualitative data in order to investigate the architectural or urban design interventions in each area that would best contribute to the creation of a favourable microclimate.

Keywords: urban microclimate, environmental performance, thermal comfort, outdoor spaces, surface materials, PMV, ASV.

Introduction

In the past decade there has been a growing concern over the quality and maintenance of public outdoor spaces in major Greek cities. It is, in fact, widely recognised by architects, urban designers and the general public that these spaces can have a large impact on the quality of life in a city, acting as escape and pleasure havens for the city dweller, who is heavily taxed by urban pollution and noise.

However, due to the ever-increasing economic interest in and scarcity of such spaces in the centre of cities, there is a tendency for them to be either trespassed by other uses, or cluttered by objects overflowing from nearby stores or cafes. At the same time the city-dweller, whose everyday life is overwhelmed by important daily transportation routes and work schedules, has limited opportunity to enjoy leisure activities offered by public outdoor spaces. They are thus often reduced to simple passageways, offering merely visual contact with city landscapes. Progressive degradation of the natural environment is the result of such tendencies, as urban outdoor spaces are slowly converted from centres of social interaction in contact with nature, to places of social seclusion and isolation, used solely by certain categories of people or on particular occasions.

Recently, considerable initiatives have been undertaken by the state in order to redesign and upgrade urban outdoor spaces in many cities throughout Greece. Unfortunately, the outcome of such organised endeavours has not always succeeded in reviving open spaces or ensuring increased quality and comfort for their users. In Athens, some major squares at the centre of the city were redesigned as part of the works for the 2004 Olympic Games, following several well-publicised architectural competitions. As a result, the subject of revival of urban outdoor spaces was brought to public attention, with some of the realisations negatively judged by large segments of the population, including politicians and the media. It then became obvious that in order to improve the quality of life in the present dynamic urban environment, the complex phenomenon of urban accommodation in modern cities has to be further understood. This is a major challenge for architects, urban designers, planners and policy makers.

A crucial parameter in the design and evaluation of urban outdoor spaces is their environmental performance. As already investigated in indoor environments (Stamou et al. 2004, Jones 1998) increased environmental comfort can facilitate the use of public outdoor spaces in a more constant way by the population, by supporting a variety of activities, which can be enjoyed for longer periods of time and by more people. In order to create comfortable microclimatic conditions in outdoor urban spaces, several environmental factors, pertaining to the particular climate, design and materials of each space have to be considered, as well as the opinions of the users (Lee et al. 2009, Delavari-Edalat et al. 2010). Many studies have been devoted to thermal and visual comfort in outdoor spaces and their assessment (Katzner 2004, Givoni et al. 2003, Stathopoulos 2003), while others have focused on shading, ventilation or the choice of surface materials in urban spaces (Höppe 2002, Khandaker 2003, Kattmeier et al. 2007, Hien et al. 2010).

The relationship between the prevailing environmental conditions, the consequent thermal and visual comfort levels, and the patterns of use in urban open spaces has been analysed in numerous studies (Boussoualim 2000, Nicolopoulou et al. 2001, Gomez et al. 2004), including several international research projects (Katzner 2000, Chrissomalidou et al. 2002, Dessi 2002, Katzner et al. 2002, Nicolopoulou and Steemers 2003, Nicolopoulou 2004, Nicolopoulou and Lykoudis 2006). Furthermore, several studies relate bioclimatic design principles of urban open spaces with the overall sustainable development of the city (Gomez et al. 2004, Baycan-Levent et al. 2009, Sepe 2010, Toy and Yilmaz 2010), as they promote the use of environmentally friendly means of transportation (Pressman 1991, Höppe 2002, Marques de Almeida 2002, Southworth 2005), while others mostly deal with use and safety issues (De Schiller 1991).

This paper presents the methodology and first results of a research programme conducted by the National Technical University of Athens (NTUA) staff and students, in various open spaces in the centre of Athens, Greece. The aim of the research is to formulate a methodological procedure in order to support the systematic evaluation of thermal, visual and acoustic comfort levels in selected public outdoor spaces, in combination with their uses and basic physical parameters in their design and construction (materials, water elements, vegetation, shading, etc.). The intention of the authors is to provide a set of quantitative, as well as qualitative data in order to investigate the architectural or urban design interventions in each area that would best contribute to the creation of a favourable microclimate.

Methodology

The first stage of the research consists in the selection of representative open spaces in the centre of Athens to serve as case studies, based on a number of criteria summarised below:

- Centrality in the urban fabric (which affects the frequency and number of users).
- Proximity to high traffic roads or pedestrian ways.
- Architectural design features representative of many squares in Athens.
- Combination, in the same space, of areas both shaded and exposed to the sun.
- Use of commonly applied building materials.

- Combination of paved area with the use of vegetation and water.

The methodology of testing and analysis followed is described in detail below. For each open space, site plans and satellite photographs were collected and a spiral path starting from the periphery and ending at the centre was determined as a support for the measuring procedure. Along this spiral path, a number of stops were selected and numbered. On each stop measurements of air temperature, relative humidity and wind speed were recorded at a height of 1,80 above ground surface. Surface temperatures of materials were also recorded as placed, whether shaded or exposed to the sun. Each path was subsequently repeated in the opposite direction (starting from the centre and moving towards the periphery), with the same stops and recording points for calibration purposes. The whole measuring procedure was conducted once a month for a whole year.

The surface temperature readings were taken with portable IR608 Meterman Infrared (IR) thermometers. Kestrel 3000 pocket weather meters were used for wind speed, air temperature and relative humidity measurements and portable Gemini data loggers for continuous recording of air temperature and relative humidity values throughout the process. The parallel recording of air temperature and humidity values by both weather meters and data loggers was decided for calibration purposes.

In addition to the measurements, photographs were taken throughout the process, in order to record not only the environmental conditions, but also the patterns of use for each site. Finally, a questionnaire was filled in at major stops, where users were asked several questions concerning their personal evaluation of the specific open space (e.g. thermal comfort sensation, frequency of visit, type of use, reasons for satisfaction/dissatisfaction and proposals for improvement). User-related information (age, weight, height, clothing, purpose and duration of visit etc) was also recorded each time.

The data collected from the in-situ measurements for two of the four squares was combined with the information derived from the questionnaire, and used for the calculation of the Predicted Mean Vote (PMV) and Actual Sensation Vote (ASV), using the RayMan model (Matzarakis 2000) and the Ecotect software. The Predicted Mean Vote (PMV) as defined in thermal comfort research literature, expresses the mean value of thermal comfort for a large number of users of a space and is based on the energy balance of the human body, while the Actual Sensation Vote (ASV) expresses the subjective thermal comfort sensation of the users, based on their spontaneous responses to the questionnaires.

Finally, the values of the PMV and ASV indices are separated in classes and put in a diagram showing the frequency of each class. This way, a comparison is held possible so as to estimate the performance of the two squares studied as far as thermal sensation is concerned.

The case studies

Following the screening procedure described above, four squares were selected in the centre of Athens (Syntagma (a), Klafthmonos (b), Kotzia (c) and Omonia (d)) to serve as case studies for our research. Most of the data was collected by two students as part of their undergraduate dissertation (Diamantidou and Chryssicopoulos 2008). Satellite and on-site photographs were used for the introduction of basic space allocation elements (materials, vegetation, water elements, etc.) and uses on detailed site plans, thus transformed into working plans for each square. (Figure 1)

A comparison of these four working plans shows that the first two squares (Syntagma and Klafthmonos) are composed of a combination of green and paved areas, while the other two (Kotzia and Omonia) are entirely constructed of hard paved surfaces. The existence of surrounding car-circulation roads or pedestrian ways is another important parameter, as two of the squares (a and d) are major circulation nodes, while others (c and partly b) are mostly surrounded by pedestrian ways.

The experimental study which followed, comprised three phases. The first phase included the microclimatic investigation and recording of environmental parameters in each square and its surrounding spaces, whereas the second one involved the evaluation of thermal comfort conditions, based on a questionnaire, addressed to the users of each square. In the third and final phase of the study, the PMV and ASV indices were calculated, based on the analysis of the experimental data collected. The results of all three phases led to the microclimatic evaluation of the squares under investigation.

For three of the squares investigated (Klafthmonos, Kotzia and Omonia), the results of a previous research involving in-situ measurements of surface temperatures of paving materials are included so as to demonstrate the thermal behaviour of building materials during the over-heated summer period (Bougatioti 2006). The measurements mainly included horizontal surfaces of squares and streets, and were conducted with an Optex Thermo-Hunter PT-5LD Infrared Thermometer (IR Thermometer) at 30-minute intervals. The duration of the measurements was from 08:00 until 19:30 or 20:00, on summer days, which were characterised by predominantly clear skies and elevated air temperatures. Air temperature, relative humidity, and wind speed were also measured at each site.

Experimental results

Syntagma Square

This square is situated in front of the Parliament Building, but at a lower level. It is paved with white, rough marble slabs. Its long sides are separated from the adjacent streets with linear water elements (water walls). The square is also characterised by the presence of numerous mature trees and a fountain.

Microclimate measurements in the square and their results for a winter day are seen in Figure 2. The analysis of the microclimatic data shows that there is a considerable difference in air temperature and relative humidity between the central part of the square, which is characterised by sufficient planting, and the more exposed areas on the sides and surrounding streets, equal to 2,5^{o}C and 6-7% respectively. On the other hand, the linear water elements and the rows of trees, which are situated on the perimeter of the square seem to operate as “buffer zones”, protecting the central sitting areas from adverse conditions due to the surrounding high-circulation streets.

Klathmonos Square

This square is paved with white and black gravel-concrete and is surrounded by asphalt-paved streets. It is divided into two distinct parts, of which one is totally exposed to the sun, while the other has dense vegetation and several large sitting areas.

The analysis of microclimatic data shows that there is a difference in air temperature and relative humidity equal to 1.0^{o}C and 2% respectively between the two parts of the square, as seen in Figure 3. Furthermore, the transition between these two parts, due to their design and surface treatment is very abrupt, forming a virtual and psychological boundary. This influences the distribution of uses on the square, the lower part of which is rarely used by city inhabitants and often gives shelter to clandestine dwellers.

The results of the in-situ measurements in Klathmonos Square demonstrate that during the over-heated summer period (on June, 21st the mean air temperature during the measurements was 32.2 ^{o}C), the gravel concrete, which is exposed to solar radiation, tends to overheat and reach an absolute maximum surface temperature of 50-53 ^{o}C (white-coloured) and 51-56 ^{o}C (dark-coloured), with mean temperatures equal to 41.6-43.2 ^{o}C and 44.1-45 ^{o}C, respectively. On the contrary, the shaded parts of the square remained cooler than the air throughout the measurement. It should also be noted that, around sunset, the temperatures of the exposed surfaces, were 3 to 10 ^{o}C hotter than the air. (Table 1, Figure 4)

Kotzia Square

The square is paved with slabs of black-and-white and dark grey granite with a rough surface. The low-traffic streets, which form its northern and southern boundaries, are paved with dark-coloured stone blocks (cobblestones) and are separated from the square with narrow planted strips. In the centre of the square, there is a jet fountain with intermittent function.

Microclimatic data analysis shows that although there is a favourable influence of water elements existing on the square since air temperature is lower by 1.5 ^{o}C and relative humidity higher by 6% in the area surrounding the fountain as compared to the rest of the square for a winter day (Fig. 5), the absence of planting and the proximity of Omonia Square seem to negatively influence its environmental performance. There seems to be little environmental variety on the square, and this is aggravated by the total absence of shading as well as of essential urban dispositions for sedentary uses. As a result, the square is used almost solely as a pedestrian passageway.

In Kotzia Square, the in-situ measurements for a hot, summer day (mean air temperature = 33 ^{o}C) clearly show the effect that the unobstructed solar access has on the temperatures of the materials, which form the horizontal surfaces of a public open space. In fact, very high surface temperatures were found, both for the grey-coloured (absolute maximum T = 58 ^{o}C, mean T = 46.4 ^{o}C), and the black-and-white granite slabs (absolute maximum T = 56 ^{o}C, mean T = 44.2 ^{o}C). The surface temperatures of the cobbled street were found to be even higher (absolute maximum T = 61 ^{o}C, mean T = 48.2 ^{o}C), probably due to the dark colour of the cobbles and their irregular placement. On the contrary, the shaded segments of all the materials were very cool. Similar to Klafthmonos Square, it was here noted that the exposed surfaces were 7 to 8 ^{o}C hotter than the air around sunset. Finally, concerning vegetated and water surfaces, it was noted that well-irrigated grass and water remain very cool throughout the day, with surface temperatures that are pronouncedly lower than the corresponding air temperatures. (Table 1, Figure 6)

Omonia Square

The design of this square is the result of a national architectural competition. It is characterised by its strictly urban character: its paving is composed of rough, grey granite slabs, while there are also smaller surfaces of wooden boards and terrazzo. In the centre of the square there is a large sitting-area made of concrete, while at its northern end, there is a fountain. On the whole, the square is characterised by almost total absence of vegetation, which is restricted to its boundaries near the surrounding buildings, in the form of palm trees and planted pots, due to a refurbishment right before the 2004 Olympic Games, and as a result of negative criticism of press and the public.

Microclimate data analysis shows that due to the use of materials such as granite, concrete and asphalt and the total absence of shading, planting or water surfaces, this square exhibits worse environmental performance at its centre than at its periphery. Thus, on a winter day, at the central area, air temperature is 2.5 ^{o}C higher and relative humidity 8% lower than at the perimeter of the square, as seen in Figure 7.

In fact, Omonia Square as a whole does not offer a favourable microclimate for the city of weller, but is directly influenced by the surrounding area of which it forms part. As a result, even its use as a passageway for pedestrians is limited, especially during the summer: people prefer to cross the square through the underground passage of the metro station or walk on its periphery, where the surrounding high-rise buildings provide shading.

The results of the in-situ surface temperature measurements, which were conducted in Omonia Square, during a hot summer day (mean air temperature = 33 ^{o}C), are consistent with those of the previous three squares. The grey-coloured granite slabs develop very high surface temperatures (absolute maximum T = 58 ^{o}C, mean T = 46.6 ^{o}C), due to their dark colour and their rough surface. It is interesting to note that the surface temperatures of the terrazzo surfaces and the concrete sitting-area were also in that order. Furthermore, all the surfaces were significantly warmer (6 to 8 ^{o}C) than the air at the time of sunset. Finally, it is interesting to note the thermal behaviour of wood, as it is depicted by its daily surface variation. Its absolute maximum temperature reached 68 ^{o}C, while its mean temperature was 51.7 ^{o}C. Nevertheless, after noon, its temperature started to steeply drop reaching the air temperature around sunset (19:30) and dropping below it at 20:00. This contradictory thermal behaviour is a direct result of wood's thermophysical properties: wood has low thermal conductivity and density values, which drastically influence its ability to diffuse and store heat through its mass. As a result it heats up considerably until noon, but cools down rapidly (3 to 4 ^{o}C every half hour) after 13:00 to 14:00, with its surface temperatures dropping below the air temperature by sunset (19:30 to 20:00). (Table 1, Figure 8)

Calculation of thermal comfort indices

In this part of the research an attempt was made to study the perception of users with respect to thermal sensation in relation to the microclimate data of two of the squares selected (Syntagma Square and Omonia Square). The selection was based on the fact that these two squares had a completely different microclimate performance. Syntagma square had a more favourable microclimate formed in its centre whereas Omonia square showed an increase of air temperature in its centre.

Following the collection of basic meteorological data, questionnaires were also used in order to collect information concerning age, sex, activity, weight and clothing of each user (population size: 109 people). The next step was to calculate, based on the collected data mentioned before, the Predicted Mean Vote (PMV) using RayMan software on thermal comfort in open spaces. (Matzarakis A, 2000). The meteorological data was used to calculated the Actual Sensational Vote (ASV) (Nikolopoulou M, 2004).

Intermediate season results for each square are shown in Figure 9 and Table 2 where a comparative evaluation of subjective thermal sensation and predicted mean vote for thermal comfort in each square is illustrated. For both squares it is observed that there is a shift of the PMV curve to the right showing that the majority of people feel neutral even though the calculated thermal index indicates otherwise. This could be partially explained by the adaptive behaviour of users and the inadequate way to quantify comfort conditions outdoors, emphasising the need to investigate this field. The results of this study are consistent with those of previous studies, which also found a marked difference between the PMV and the ASV indices.

Conclusions

Although this is part of an ongoing research programme, the first results, described in this paper, show that environmental comfort levels are rather low for all case studies described. During the over-heated summer period, thermal comfort conditions deteriorate and thermal stress occurs as a direct result of the absence of shading, vegetation and water elements. In turn, the absence of shading elements affects the surface temperatures of the materials, which form the paving and other horizontal surfaces (e.g. sitting areas) of urban open spaces. All the above have a considerable influence on the variety of uses in each area, thus seriously affecting the frequency and type of activities for each one of the public outdoor spaces studied.

The study of microclimatic parameters is very important in order to point out the positive and negative aspects in the environmental performance of each space and propose specific interventions for the improvement of environmental quality in each case. This is imperative in order for public open spaces to once again become the poles of attraction for everyday urban life as well as on special occasions, offering all citizens ways to express their participation in collective activities and through them forge a collective identity.

This can be achieved if systematic criteria for outdoor comfort are established in order to correctly evaluate urban microclimatic conditions and provide a design reference for architects and urban designers which should be taken into account in new or retrofitted interventions for improving and reviving public open spaces in the city (Southwork 2005, Ng et al. 2006, Sepe 2010, Toy and Yilmaz 2010).

In any case, the use of vegetation and water elements should constitute a priority for both bioclimatic and aesthetic reasons. Vegetation affects urban surface temperatures in two distinct, but equally important ways: by shading the various materials, and by maintaining low surface temperatures through the process of transpiration (Hien et al. 2010). Water elements also have a very positive contribution to the microclimate, because of the high heat capacity of water (1160 Wh/in3K), and its ability to evaporate, which causes considerable air and surface temperature depression, with a simultaneous increase of relative humidity levels (Gomez et al. 2004, Gaitani et al. 2007). Apart from the above, vegetation and water can contribute decidedly to the aesthetic improvement of the urban environment and to the improvement of the inhabitants' quality of life (Gomez et al. 2004, Baycan-Levent et al. 2009, Toy and

Yilmaz 2010). Furthermore, these are elements, which are seen by city-dwellers with affection and pleasure (Lynch K. 1960, Lee et al. 2009, Delawari-Edalat et al. 2010).

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Table 1: Overview of surface temperature measurements in June for three urban open spaces selected.

Material	T range 13:30 - 16:30	Absolute max T	Absolute min T	Mean T	Mean Tair	T at 19:30	Tair at 19 :30
Klafthmonos Square (b)							
Gravel concrete, white	50-51	51	22	41.6	32.2	42	32
Gravel concrete, white	52-53	53	33	43.2	32.2	37	32
Gravel concrete, white	48-53	53	24	40	32.2	35	32
Gravel concrete, white, shaded	27-31	31	24	27.8	32.2	29	32
Gravel concrete, black	52-56	56	23	44.1	32.2	44	32
Gravel concrete, black	54-56	56	23	45	32.2	37	32
Gravel concrete, black	51-56	56	24	42.5	32.2	35	32
Gravel concrete, black, shaded	28-32	32	25	28.5	32.2	30	32
Concrete slabs, red gravel	51-52	52	24	42.5	32.2	43	32
Concrete slabs, red gravel, shaded	29-33	33	25	28.3	32.2	29	32
Earth, dry, shaded	27-29	29	21	25.5	32.2	27	32
Grass	33-35	35	15	29.9	32.2	27	32
Kotzia Square (c)							
Granite, black&white	50-56	56	22	44.2	33	39	32
Granite, black&white, shaded	35-37	37	26	31.4	33	27	32
Granite, grey	55-58	58	25	46.4	33	40	32
Granite, grey, shaded	35-37	37	26	31.4	33	27	32
Cobblestones	56-61	61	27	48.2	33	42	32
Cobblestones, shaded	30-32	32	23	28.3	33	30	32
Grass	29-32	32	16	26.4	33	22	32
Water	26	21	26	24.1	33	23	32
Omonia Square (d)							
Concrete sitting area	54-58	58	28	46.6	33	40	32
Terrazzo	55-58	58	28	46.6	33	40	32
Terrazzo	55-57	57	29	46.4	33	38	32
Granite, black&white	55-58	58	27	46.6	33	41	32
Granite, black&white, shaded	29-30	30	23	27.6	33	29	32
Marble, white	32-41	41	22	32.5	33	29	32
Granite, black	54-61	61	20	44.7	33	39	32
Marble, dark grey	57-60	60	21	45.6	33	38	32
Wood	57-68	68	28	51.7	33	32	32

Table

Table 2: Thermal sensation rating for Syntagm, Kotzia and Omonia Squares

Thermal sensation (ASV)	Rating	Percentage of answers [%]
Syntagma Square(a)		
Very cold	-2	0.00
Cold	-1	6.33
Comfortable	0	55.70
Warm	1	32.91
Hot	2	5.06
Total		100
Kotzia Square (c)		
Very cold	-2	0.00
Cold	-1	0.00
Comfortable	0	53.33
Warm	1	40.00
Hot	2	6.67
Total		100
Omonia Square (d)		
Very cold	-2	0.00
Cold	-1	3.33
Comfortable	0	33.33
Warm	1	26.67
Hot	2	36.67
Total		100

Figure

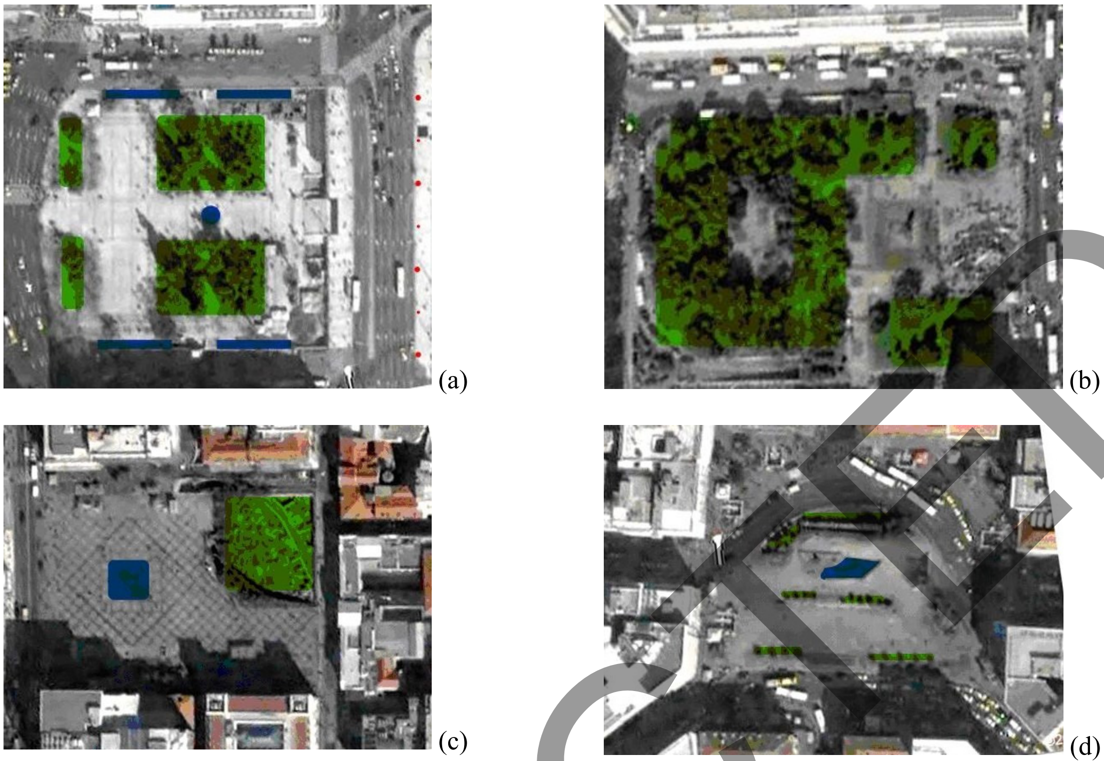

Figure 1. Working plan of surface use allocation for
(a) Syntagma Square, (b) Klathmonos Square, (c) Kotzia Square and (d) Omonia Square.

Figure

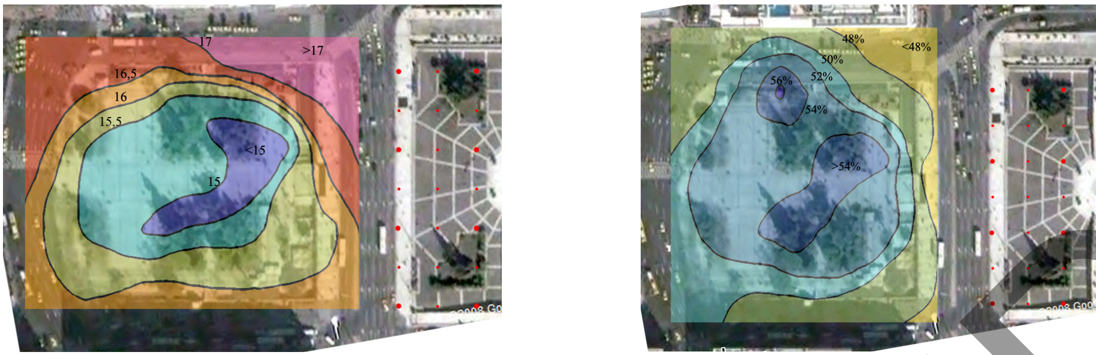

Figure 2. Microclimatic measurements of (a) air temperature and (b) relative humidity for Syntagma Square in January.

Figure

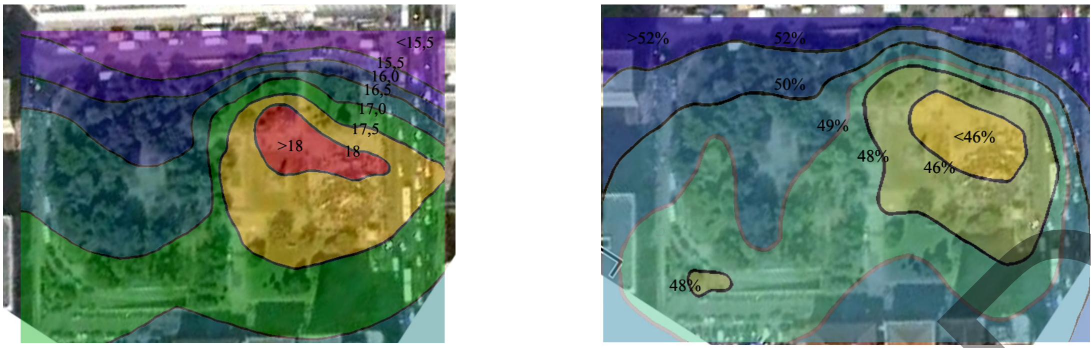

Figure 3. Microclimatic measurements of (a) air temperature and (b) relative humidity for Klafthmonos Square in January.

Figure

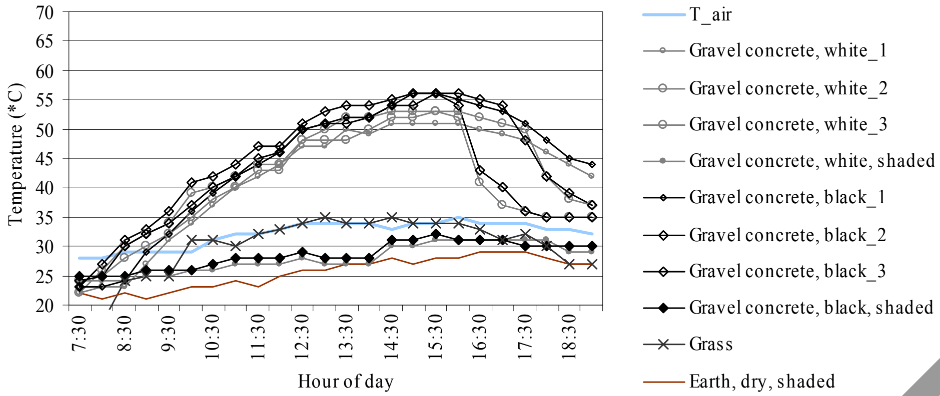

Figure 4. Surface temperature measurements in Klafthmonos Square in June.

Figure

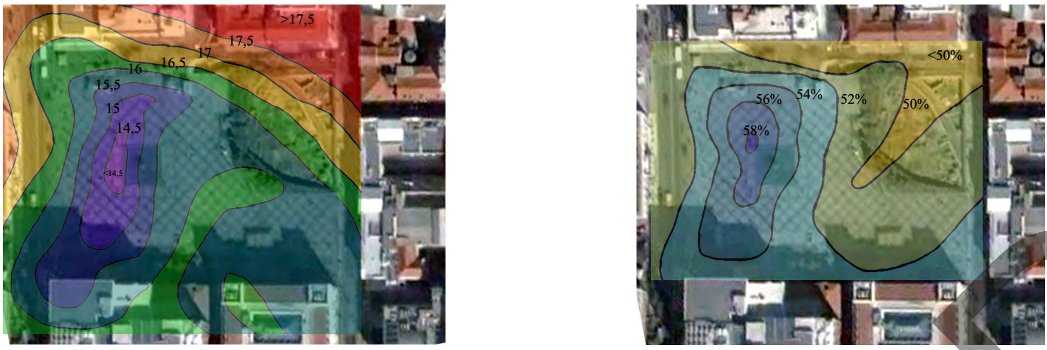

Figure 5. Microclimatic measurements of (a) air temperature and (b) relative humidity for Kotzia Square in January.

Figure

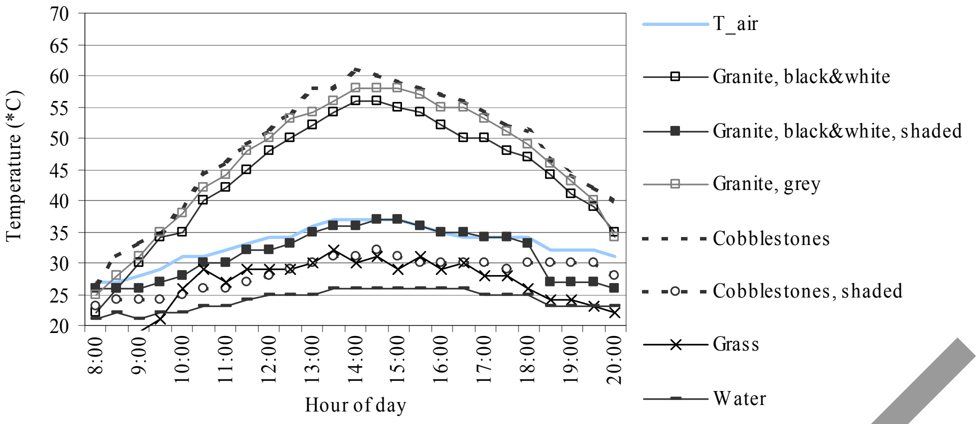

Figure 6. Surface temperature measurements in Kotzia Square in June.

Figure

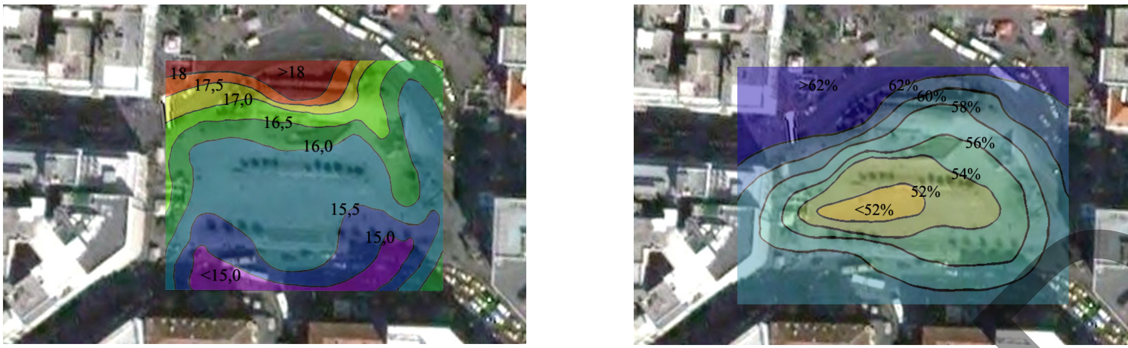

Figure 7. Microclimatic measurements of (a) air temperature and (b) relative humidity for Omonia Square in January.

Figure

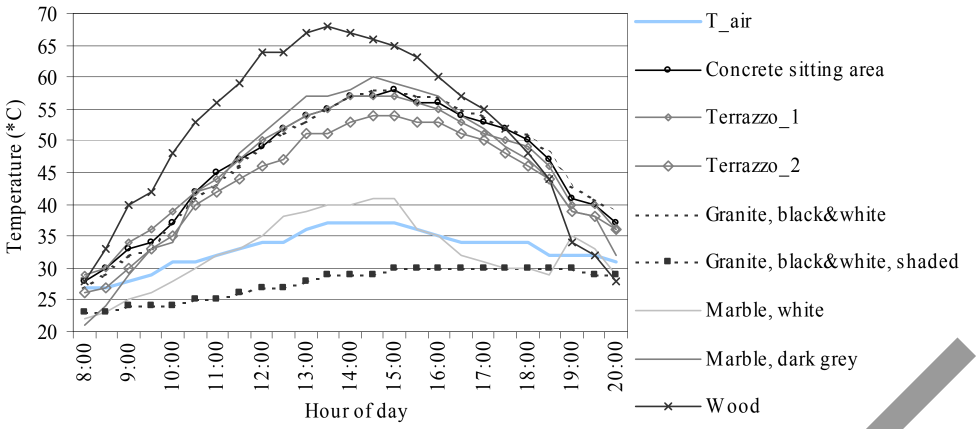

Figure 8. Surface temperature measurements in Omonia Square in June.

Figure

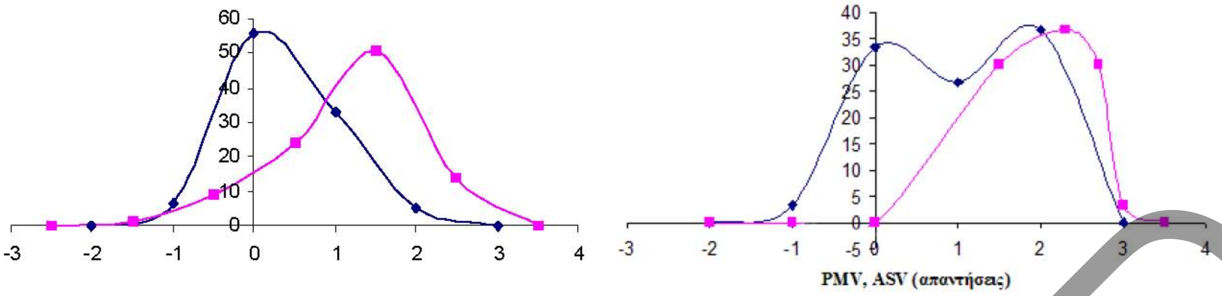

Figure 9. Comparison of Thermal Sensation and PMV indices for Syntagma Square and Omonia Square. (blue line: ASV, magenta line: PMV)

Figure captions list

Figure 1. Working plan of surface use allocation for (a) Syntagma Square, (b) Klathmonos Square, (c) Kotzia Square and (d) Omonia Square.

Figure 2. Microclimatic measurements of (a) air temperature and (b) relative humidity in Syntagma Square in January.

Figure 3. Microclimatic measurements of (a) air temperature and (b) relative humidity for Klafthmonos Square in January.

Figure 4. Surface temperature measurements for Klafthmonos Square in June.

Figure 5. Microclimatic measurements of (a) air temperature and (b) relative humidity for Kotzia Square in January.

Figure 6. Surface temperature measurements for Kotzia Square in June.

Figure 7. Microclimatic measurements of (a) air temperature and (b) relative humidity for Omonia Square in January.

Figure 8. Surface temperature measurements for Omonia Square in June.

Figure 9. Comparison of Thermal Sensation and PMV indices for Syntagma Square and Omonia Square. (blue line: ASV, magenta line: PMV)

Table captions

Table 1: Overview of surface temperature measurements in June for three of the urban open spaces selected.

Table 2: Thermal sensation rating for Syntagma and Omonia Squares.