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Microclimatic analysis as a prerequisite for sustainable urbanisation: Application for an urban regeneration project for a medium size city in the greater urban agglomeration of Athens, Greece

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ABSTRACT

Integrating sustainability in urban design is a prerequisite for adequately addressing the urban challenges related to climate change, resource availability, environmental degradation and energy consumption. For the integration to be well formulated, urban planners need comprehensive microclimatic information at adequate spatial and temporal scales so as to define the bioclimatic design targets of the urban area concerned. In this study a medium size city (Acharnes, built at the southern foothills of Mt Parnitha, at a distance of 10 km north of Athens) is examined in terms of its thermal characteristics and the resulting thermal comfort conditions in municipal open spaces. Results show significant thermal loads for specific city areas as well as use of materials which result in adverse thermal conditions and in poor thermal comfort. On the basis of the results, specific guidelines are defined for the sustainable urbanisation of the city of Acharnes, in particular for an urban regeneration project concentrated at the centre of the city. The approach reflects a pattern which may be well applied in cities of respective size and urban characteristics and in similar climatic zones.

1. Introduction

The Mediterranean area has been the subject of several research studies in terms of climatic variations. In particular, the Attica basin in Greece is characterised by significant climate change as both the ambient temperature and the frequency of heat waves have increased (Cartalis, Synodinou, Proedrou, Tsangrassoulis, & Santamouris, 2001; Santamouris et al., 2001). In particular, heat island is the more documented phenomenon of climate change (Santamouris, 2007). It relates to higher urban temperatures compared to the rural or suburban ones due to the positive urban thermal balance. Heat island has a serious impact on the energy consumption of buildings for cooling purposes (Hassid et al., 2000), while it worsens the environmental quality of urban areas as well as the thermal comfort conditions of citizens (Watkins, Palmer, & Kolokotroni, 2007).

Various studies of the intensity and the characteristics of canopy layer urban heat island in Athens, Greece are performed and the phenomenon is well known (Livada, Santamouris, Niachou, Papanikolaou, & Mihalakakou, 2002; Mihalakakou, Flocas, Santamouris, & Helmis, 2002; Stathopoulou et al., 2009). According to existing studies, the intensity of the heat island phenomenon during the summer period is close to 8k (Mihalakakou, Santamouris, Papanikolaou, Cartalis, & Tsangrassoulis, 2004), while it is associated to higher ozone levels (Stathopoulou, Mihalakakou, Santamouris, & Bagiorgas, 2008), decreased levels of thermal comfort (Pantavou, Theoharatos, Mavrakis, & Santamouris, 2011), increased urban footprints (Santamouris, Paraponiaris, & Mihalakakou, 2007), and low indoor environmental conditions especially for the low income population (Sakka, Santamouris, Livada, Nicol, & Wilson, 2012).

Microclimatic conditions in urban open spaces are characterised by the morphology of the urban pattern and by the properties of urban surfaces. In street canyons, public places, and open spaces, the local microclimate depends directly on the physical properties of the surrounding surfaces and objects, producing well-known

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effects such as wind speed decrease, local jets, increased turbulence, or increased thermal loads (Kolokotroni & Giridharan, 2008).

Erell (2008) examined how research on urban climate can be beneficial for the design of cities, Dannevig, Rauken, and Hovelsrud (2012) developed a set of indicators for the assessment of the implementation of climate adaptation measures in municipalities and Gaitani, Michalakakou, and Santamouris (2007) documented that a climatic conscious design of urban open spaces and the appropriate use of bioclimatic components are key elements to reduce the non sustainable development of urban areas. In addition, Chrysoulakis et al. (2013) investigated sustainable urban metabolism as a link between biophysical sciences and urban planning.

Various mitigation techniques have been proposed involving the use of advanced materials presenting high reflectivity to the solar radiation and high thermal emissivity, increased plantation, the use of cool sinks and large applications with cool pavements (Akbari and Haider, 1992; Kolokotroni, Gowreesunker, & Giridharan, 2013; Kolokotroni & Kolokotsa, 2013; Santamouris, 2007, 2012, 2013). In addition Nikolopoulou, Baker, & Steemers (2001) approached thermal comfort as a human parameter and assessed its variations in outdoor urban spaces, Akbari and Konopacki (2005) calculated the energy saving potentials of heat island reduction strategies, Lin, Ho, and Huang (2007) examined the seasonal effect of pavement on outdoor thermal environments in subtropical Taiwan, Takebayashi and Moriyama (2007) calculated the heat budget on green rood and high reflection roof for the mitigation of urban heat island whereas and Stull, Sun, and Zaelke (2010) explored the potential of enhancing urban albedo to fight climate change and save energy. Lindberg and Grimmond (2011) examined the influence of vegetation and building morphology on shadow patters and mean radiant temperatures in urban areas and Zinzi and Agnoli (2012) promoted an energy and comfort comparison between passive cooling and mitigation urban heat island techniques for residential buildings in the Mediterranean region.

Several large scale projects involving advanced mitigation techniques have been designed and realised in Greece and the corresponding results have shown that it is possible to reduce peak ambient summer temperatures by several degrees (Fintikakis et al., 2011; Santamouris, Paraponiaris, et al., 2012; Santamouris, Xirafi, et al., 2012).

This study addresses a study of the microclimatic – and especially the thermal – characteristics of the city of Acharnes, located in the wider urban agglomeration of Athens. The area is characterised by high ambient temperatures during the summer period, low environmental quality and increased social problems. The main contribution of the study is the recognition of the state of thermal environment, the assessment of collateral issues with the potential to affect the quality of life at the local level (e.g. the concentration of particulate matter – PM) and the definition of thermal comfort at the city level. All this information is required for the development of an integrated approach towards the bioclimatic design of open spaces in the urban environment which ensures comfortable thermal comfort conditions at the pedestrian level. A concise description of the procedure presented herein is formulated as follows: (a) current microclimatic conditions are measured; (b) the concentration of particulate matter is also measured; (c) thermal comfort conditions at pedestrian level are assessed through the estimation of specific thermal comfort indices.

2. Field survey

As concerns the average weather conditions of the surveyed area, it should be mentioned that a temperate Mediterranean climate dominates, which corresponds to hot and dry summers and cool, humid winters.

2.1. Area of interest

Acharnes is located about 10 km north of Athens; it is the most populous municipality in East Attica as according to the 2011 census, has a population of 107,500 inhabitants. The area of interest for the regeneration project is depicted in Fig. 1 and reflects the specific parts of Acharnes which have been decided by the local authority to undergo regeneration using sustainable bioclimatic strategies. In particular Areas A and C are considered as high-density built-up consisting of approximately 80–100% construction materials, which are typically old commercial, residential, and few industrial buildings. Area B is considered as low-density built-up consisting of 50–80% construction materials, which have mostly been constructed in the last two decades, and frequently contains some small open space.

Finally it should be mentioned that the main objective of the city of Acharnes has been the selection of the appropriate interventions leading to the improvement of microclimatic conditions (decrease of ambient temperatures during the summer period and improvement of the thermal comfort conditions).

2.2. Field measurements of microclimatic parameters

The environmental parameters which were monitored during the course of the field campaign were wind speed, air temperature, and relative humidity.

Data loggers (Tiny Tag TGP-4500) were used for the measurements of air temperature and humidity at selected locations for each of the three areas. Data loggers were placed into weather stations located at a height of 1.80 m.

As expected the urban character of the terrain (densely constructed low and medium height buildings with few open spaces; roads of limited width) influenced the wind either by decreasing the speed and changing the direction, or by increasing the wind speed. For area A, the measurements indicated that the wind varied between 0.4 m/s and 2.7 m/s, for area B between 0.3 m/s and 2.9 m/s while for area C, the respective wind variation was in the range of 0.4–2.4 m/s.

Air temperature and humidity measurements for area A, were performed on 26th April, 2013. The results indicated that the mean maximum air temperature was 30.0 °C while the mean minimum was 24.5 °C. The range of temperature was found to relate to the geometrical characteristics of the roads (i.e. dense network of roads of limited width oriented at a rectangular basis, limited number and degree of horizontal or vertical curves) and the construction materials (mainly concrete and asphalt). Furthermore the anthropogenic heat as emitted during the day affected the temperature profile. Regarding the relative humidity, the mean maximum value was recorded at 31% while the mean minimum at 24%.

Air temperature and humidity measurements for area B were performed on 29th May, 2013. Results indicated that the mean maximum air temperature was 31.9 °C and the mean minimum 27.0 °C. Regarding the humidity measurements the mean maximum relative humidity was 42% and the mean minimum 35%.

Air temperature and humidity measurements for area C were performed on 21st May, 2013. Results indicated that the mean maximum air temperature was 33.1 °C and the mean minimum 28.5 °C. Regarding the humidity measurements the mean maximum relative humidity was 39.6% and the mean minimum 25.9%.

2.3. Study of the materials

An important parameter regarding the state of microclimate of an area is related to the thermal properties of the materials that the area is composed of. For this reason the surface temperatures of paving, asphalt and other building materials of the urban