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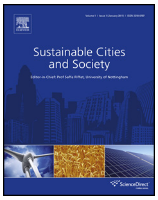

Experimental investigation of microclimatic conditions in relation to the built environment in a central urban area in Thessaloniki (Northern Greece): A case study

Athena Kantzioura, Panos Kosmopoulos, Argyro Dimoudi, Stamatis Zoras*

Laboratory of Environmental and Energy Efficient Design of Buildings and Settlements, Department of Environmental Engineering, Democritus University of Thrace, Greece

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ABSTRACT

This paper presents the effects of the geometric and other morphological characteristics upon the urban environment in a city area in Thessaloniki, Greece. A number of experimental procedures were carried out in order to investigate the affect of urban planning on microclimatic conditions. The data gathered investigate the variation of air temperature, surface temperature, wind speed and wind direction on a 24 h basis within an urban canyon. A thermal camera and weather station were used to measure surface temperature and microclimatic parameters. Also, the research studies the correlation between microclimatic parameters and geometric characteristics of urban morphology.

The results of the analysis conclude that the surface temperatures and microclimatic conditions differentiated along the streets, on different heights and orientations. The results of the investigation could contribute at the optimum design solutions in response to climatic changes, and toward the sustainable development of the contemporary cities.

1. Introduction

Many studies investigate the urban microclimate in contemporary cities in order to analyze the thermal comfort conditions inside the urban centers, the energy consumption and to suggest environmental and bioclimatic design solutions.

Cities occupy 2% of the earth's surface. Under certain conditions, the heat from solar radiation and different urban activities can make city temperatures rise because of the way in which the city is structured. This effect is known as the urban heat island (UHI) (Gago, Roldan, Pacheco-Torres, & Ordóñez, 2013). The city had the capacity to modify local climate, and even created environmental conditions that could be regarded an urban microclimate. The most prominent features of this microclimate are a temperature increase, a reduction in the daily temperature range, a distinctive wind distribution in the city resulting from friction with buildings and the channeling of air flows through the streets, and a water budget that differs from that in rural environments (Gago et al., 2013; Giridharan, Ganesan, & Lau, 2004). According to Wong et al., there are three elements that affect urban temperature on a local scale: buildings, green spaces, and pavement (Wong et al., 2011).

The thermo-physical properties of covered and construction materials in contemporary cities and the urban geometrical characteristics affect the microclimatic conditions inside urban centers. Measurements in conventional materials (asphalt, pavement tiles) in a city center reported surface temperatures up to 50–56 °C during the summer period (Dimoudi et al., 2014).

The distribution of urban buildings and structures in a city affects the formation of the urban heat island since this distribution can determine the absorption of solar energy and the formation of wind streams. The urban response to solar radiation and air flows can be controlled by means of urban design (Gago et al., 2013; Ratti, Raydan, & Steemers, 2003).

In street canyons the net radiation on the building facades, being the sum of solar and long wave radiation including multiple reflections, is higher than for facades of stand-alone buildings. Therefore higher facade surface temperatures can be found in urban than in rural areas. These higher temperatures of the building facades directly cause higher air temperatures and higher space cooling. Also, the aspect ratio of the street canyon plays an important role, as in wider street canyons more solar radiation may enter leading to more radiation entrapment. In narrow street canyons radiation entrance is decreased during day time due to shadowing, while

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* Corresponding author. Tel.: +30 6944840073; fax: +30 2541079744.
E-mail address: szoras@env.duth.gr (S. Zoras).

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during night-time the blockage of long wave radiation to the sky increases (Allegrini, Dorera, & Carmelieta, 2012). So, the urban geometry of urban canyons affects the microclimatic conditions and the intensity of urban heat island.

Also, according to previous studies configuration of a city can assist wind circulation and affects wind velocity which in turn impacts temperature variations. The urban morphology directly affects the movement of the wind within it depending on its design (Taleb & Abu-Hijleh, 2013).

Morris, Simmonds, and Plummer (2001) investigated the association between urban heat island intensity and wind speed and cloud cover. They concluded that calm winds and clear skies result in increased means of urban heat island values. In summer, when the results were most pronounced, it was found that an increase of wind speed by 1 m/s the UHI variation was −0.139 °C.

Additional, in a study in North Greece, the air temperatures in the urban area were about 5.0–5.5 °C higher than in the suburban area, during the afternoon and night time. Instead, during the morning the air temperatures in the city were 7.0 °C lower. This was due to the urban configuration that obstructs the air flow and city's ventilation. The constructive materials with high thermal conductivity and heat capacity storage heat during the day and released it at night, maintaining the temperature of ambient air on high levels. This increased the intensity of the phenomenon of urban heat island in the city (Dimoudi, Kantzioura, Zoras, Pallas, & Kosmopoulos, 2013)

So, many studies results that the urban geometry is one of the most relevant parameter which is responsible for the microclimate variation (Bourbia & Boucheriba, 2010).

Street canyons and UHI are critical in terms of space cooling demand, due to the important effect of entrapment of the solar radiation and the wind sheltering by neighboring buildings (Allegrini et al., 2012). The UHI effect influences the energy demand for space cooling and heating of buildings, and it has a large impact on the thermal comfort and health of the people living in urban areas (Moonen, Defraeye, Dorer, Blocken, & Carmeliet, 2012). According to available data Santamouris (2014) calculates that the average increase of the cooling load because of the heat island is statistically significant and in average is close to 13%. The average global energy penalty per unit of surface and degree of UHI intensity is close to 0.74 kWh/m^2/K and the global energy penalty per person and per degree of the UHI intensity is around to 70 kWh/p/K. Also, the average increase of the cooling demand of representative buildings during the period 1970–2010 is close to 23%. So, the urban warming has a very significant impact on the global energy consumption of buildings (Santamouris, 2014).

As regard the thermal comfort conditions in outdoor spaces of urban centers, studies results that the phenomenon of UHI is responsible for deterioration of thermal comfort sensation in contemporary cities (Pantavou, Theoharatos, Mavrakis, & Santamouris, 2011; Santamouris et al., 2012).

At the present study the effects of the geometric and other morphological characteristics in the urban microclimate in the city of Thessaloniki, Greece are analyzed.

According to Koroneos and Tsarouhis (2012), in the summer the design ambient air temperature in Thessaloniki is 34 °C dry bulb (DB) and 24 °C wet bulb (WB), with an external daily temperature range of 11 °C. In the winter, the lowest medium ambient temperature is 5.5 °C.

Giannaros et al. (2012), aims to describe the spatial and temporal characteristics of the UHI by analyzing a 1-year dataset of hourly air temperature and humidity measurements carried out at 6 urban sites and 1 semi-rural site in the greater area of Thessaloniki. The urban heat island in Thessaloniki is stronger in the nighttime than in the daytime and decreases with increasing wind speed, while there are indications that it is more pronounced during the warm half of the year. Observations of the maximum urban heat island intensity range from 2 °C to 4 °C and from 1 °C to 3 °C during the warm and the cold part of the year, respectively, showing a smaller variability during the summer months than in the winter. Greatest values are more usually observed following sunset, whereas minimum values are detected during solar peak hours (Giannaros, 2012).

The study of Giannaros and Melas (2012) includes air temperature data from 7 points in the city of Thessaloniki (6 urban measurement points and one in a semi-rural area), over a year (March 2008–February 2009). The analysis of air temperature data indicates the store of large amounts of heat in the urban areas. As a result, an increase of air temperature is observed, especially at night and early morning hours and found that the maximum UHI intensity ranged from 2 °C to 4 °C during the warm part of the year. Comparing the intensity of the urban heat island between the hot and cold season of the year, it is concluded that the phenomenon is more intense in the hot season. They also found that the UHI had a negative impact on thermal comfort on most of the observed occasions. In Thessaloniki, most of the population suffered discomfort in 76% of the heat waves days. The analysis showed that the intensity of discomfort conditions was related to the spatial coverage and the population of the urban agglomeration (Papanastasiou, Melas, & Kambezidis, 2015).

Vardoulakis, Karamanis, Fotiadi, and Mihalakakou (2013) referred that the mean heat island intensity (°C) is about 2.0–4.0 °C during the summer.

Papadopoulos (2007) investigates the warming of the city and the energy demands for cooling in an urban canyon in Thessaloniki. The air temperature can be increased by 6 °C because of the external air conditioning units on the buildings facades.

Stathopoulou and Cartalis (2007) estimated that the air temperature difference between the urban center and the rural area around Thessaloniki, on May is 2.7 °C. The suburban areas have 1.2 °C lower air temperature then the urban center and 1.5 °C higher T_{air} than surrounding rural areas.

The UHI intensity between the central urban and surrounding rural areas of the city is estimated about of 2.7–4 °C according to Mihalakakou, Santamouris, Papanikolaou, Cartalis, and Tsangrassoulis (2004). Also, the urban zone of Thessaloniki is heated more quickly and effectively than the suburban surroundings, especially in early morning hours (Giannaros, Melas, & Kontogianni, 2010).

Also, in the previous study, the microclimatic characteristics of the urban center of Thessaloniki and the configuration of surface temperature are investigated (Kantzioura, Kosmopoulos, & Zoras, 2012).

2. Methodology

A number of experimental procedures were carried out in order to investigate the effect of urban planning on microclimatic conditions. The study area is located in Triandria, Thessaloniki, Greece (Fig. 1) and it consists of high building blocks for residential use. It is adjacent to the urban center of the city. Data from different measurement points along the streets, from different heights and orientation were collected. The data gathered investigate the variation of air temperature, surface temperature, wind speed and wind direction on a 24 h basis. The measurements took place during all seasons of the year. The field surveys involve surface temperature measurements by a thermal camera and microclimatic monitoring with portable mini-weather stations (Table 1). The mini weather stations for monitoring the microclimatic conditions were placed in specific fixed measurements points (MP) in the study area, in different heights along the street. Also, data from one local meteorological station in the urban center and form the suburban area

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