Available online at www.sciencedirect.com

SciVerse ScienceDirect

Solar Energy 94 (2013) 128–144

SOLAR ENERGY

www.elsevier.com/locate/solener

The urban heat island effect in a small Mediterranean city of high summer temperatures and cooling energy demands

E. Vardoulakis *, D. Karamanis, A. Fotiadi, G. Mihalakakou

Department of Environmental & Natural Resources Management, University of Ioannina, Seferi 2, Agrinio, Greece

Received 21 January 2013; received in revised form 10 April 2013; accepted 25 April 2013
Available online 2 June 2013

Communicated by: Associate Editor Matheos Santamouris

Abstract

The results of an urban heat island (UHI) study during summer and winter through a full year period (2010–2011) in a small city of western Greece are presented and analyzed. The specific research target was to identify the existence of the phenomenon, measure its intensity and investigate the parameters that may be associated with the appearance of the UHI. A network of air temperature sensors was installed in nine different locations of the city and measurements were recorded every 10 min. Extensive statistical analysis revealed strong UHI intensities reaching values up to 6.0 °C with a mean intensity of 3.8 °C during nocturnal hours of August. Heat island in the city proved to be a night dominating phenomenon while wind velocity was found to wield great impact on the ventilation and cooling effect of the city. During summer, early in the morning many locations in the city centre remained cooler than the rural environment while a heat island was observed on a monthly basis during winter. In order to determine the variation of the current energy needs due to the UHI effect, the heating degree hours during winter were calculated and were found to be much lower in the city centre than in the rural area (12.6–14.2% reduction). During summer, a high increase in the cooling degree hours of the city was observed in comparison to the rural environment, with a maximum difference of 36.3% for August 2010.

Keywords: Urban heat island; Microclimate; Heating; Cooling energy needs

1. Introduction

The world has experienced unprecedented urban growth in recent decades. In 2008, there were more than 400 cities over 1 million and 19 over 10 million. More developed nations were about 74% urban, while 44% of residents of less developed countries lived in urban areas. However, urbanization is occurring rapidly in many less developed countries. It is expected that 70% of the world population will be urban by 2050, and that most urban growth will occur in less developed countries (Population Reference Bureau, 2010).

Changes of land surface in cities affect the storage and radiative transfer of heat and its partitioning into sensible and latent components. Thus air temperature values in areas of high building density are usually higher than those of the surrounding rural country. This phenomenon, referred as UHI, was first documented by Howard in 1883, and is the most validated phenomenon of climatic change, consisted the strongest feature of urbanization (Landsberg, 1981). The highest air temperature difference between urban and rural areas defines the urban heat island intensity (UHII). Elevation of air temperature increases the building cooling energy demand, which results in higher pollution emissions. The opposite effect of lower air temperature of the urban central area

* Corresponding author. Tel.: +30 26410 74210; fax: +30 26410 39576.
E-mail addresses: evardoul@cc.uoi.gr (E. Vardoulakis), dkaraman@cc.uoi.gr (D. Karamanis), afotiadi@cc.uoi.gr (A. Fotiadi), pmichala@cc.uoi.gr (G. Mihalakakou).

0038-092X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.solener.2013.04.016

Nomenclature

$\Delta T_{U\text{–}R}$	urban–rural temperature difference
CDCs	cooling degree hours
HDCs	heating degree hours
H/W	height to width ratio
RCMs	Regional Climate Models
S.D.	standard deviation
SPSSs	Statistical Product and Service Solutions
t_{bal}	base temperature
T_u	urban station temperature
T_r	rural station temperature
UHI	urban heat island
UHII	urban heat island intensity
UCI	urban cool island

compared to rural areas or the so called Urban Cool Island (UCI), especially during the morning has been also reported (Shigeta et al., 2009; Watkins et al., 2002a; Chang et al., 2007). In general, among the main mechanisms contributing to the UHI phenomenon are building and road geometry, thermal and optical properties of materials used in urban spar, anthropogenic heat and lack of evaporation in the cities (Kolokotroni and Giridharan, 2008; Santamouris et al., 2001; Rizwan et al., 2008). It also may be affected by air pollution and aerosols. Thus, it is critical to understand and improve our knowledge for the phenomenon in small cities, to upgrade energy efficiency in the urban building stock and achieve higher quality of life standards.

UHI has many harmful effects like high city temperatures, environment degradation and increase of energy demand. In many cases higher death rates had been reported during summer heat waves (Buechley et al., 1972; Smoyer, 1998; Johnson and Wilson, 2008; Gabriel Katharina and Endlicher, 2011; Hattis et al., 2012). Hence, many researchers around the world have intensively studied the UHI effect in the last 30 years. In Barcelona, a methodology of recording temperature transects along the road by car was used (Carmen Moreno-Garcia, 1993). By examining annual means of temperature differences, it was found that the city centre was slightly cooler than the periphery during day. In contrast, the city centre was 2.9 °C warmer than the airport during night. Additionally, average values along the transects verify that the highest UHI intensity exceeded 8.0 °C, but rarely extended above 9.0 °C.

Unger (1996) showed that the heat island effect reaches 2.9 °C during anticyclonic conditions in a medium-sized town in Hungary. This intensity is mainly achieved during days of clear sky, calm or slight wind and absence of precipitation, conditions that favour the development of heat island. In general, this analysis shows that the UHI intensity in medium sized towns depends on the general meteorological conditions to a large extent.

In Paris, Dupont et al. (1999) compared measurements between two different sites (urban and rural) that were collected during an experiment that has been performed during winter of 1995. It was found that the heat island intensity lies between 0 °C and 6.0 °C with a maximum value at 8:00 in the morning.

In a small city in coastal Portugal, Pinto and Orgaz Manso (2000) measured temperature differences between urban and rural areas by using the method of driving car for 48 nights during summer, autumn and winter, between 23.00 and 01.00 h. Results show that Aveiro, although a small city, has an urban morphology and climate that occasionally reaches a heat island intensity of 7.5 °C.

In Bassel, Switzerland an experimental network of seven stations was established and data were recorded during 2001–2002. Results show a heat island intensity of 3.0 °C, which was observed after sunset, while during night, intensity values were lower (Christen and Vogt, 2004).

In Sweden, a study was carried out by Svensson (2004) in Göteborg, by using 16 permanent stations and examining fish-eye photographs to analyze height/width ratios and sky view factor. Also, air temperature measurements were performed by using specially equipped cars. Results show a strong relationship between sky view factor and air temperature during clear, calm nights.

In Rome, an urban canopy layer model was developed to simulate and describe urban climate and heat storage in an urban setting, by taking into account many atmospheric parameters (Bonacquisti et al., 2005). Both simulated results and experimental observation agree that the phenomenon is nocturnal and is present both during winter (2.0 °C) and summer (5.0 °C).

Kolokotroni and Giridharan (2008) have recently indicated that the intensity of the phenomenon in London area reaches 8.9 °C on occasion, while there are time periods, where a cool island is observed. The selection of the variables to analyze the UHI in every city and its attribute to the changes in outdoor temperatures is crucial. As demonstrated by Okada et al. (2008), the mean temperature in Tokyo has increased 3.0–4.0 °C in the last 100 years. Also, the number of nights where temperature does not fall below 25.0 °C has risen from 10–15 nights before a decade, to 40 nights at 2008.

In Greece, a number of research projects-most of which were carried out in Athens-using temperature dataloggers and meteorological stations have been published during the last decade and proved the existence of the