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Three years of study of the Urban Heat Island in Padua: Experimental results

F. Busato, R.M. Lazzarin, M. Noro*

Department of Management and Engineering, University of Padova, Stradella S. Nicola, 3, 36100 Vicenza, Italy

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ABSTRACT

The Urban Heat Island effect concerns the higher air temperature in urban environment with respect to the rural one. This phenomenon has been well known for hundreds of years, but it has been experimentally studied only for the last few decades and in large metropolis. The paper reports on the experimental results obtained during the period 2010–2011 in a medium size city of Italy by the research group of the Department of Environmental Agronomy and Crop Productions of the University of Padua. During the summer of 2012 the work has been developed by the authors, in cooperation with Co.Ri.La. (Venice) within the European Project "UHI – Development and application of mitigation and adaptation strategies and measures for counteracting the global Urban Heat Islands phenomenon" (3CE292P3). The main thermo-hygrometric variables (air temperature, relative humidity, global solar radiation) have been measured along some different paths fixed in advance, crossing different zones of the city area: urban, sub-urban and rural. The high number of mobile surveys implemented in different time bands during the day and after the sunset allows to characterize the phenomenon. The results indicate a presence of the UHI in urban zones of the city up to 6 °C. Some measurements in situ have been further conducted in order to evaluate the mean radiant temperature as well as in some characteristic sites of the city area: historic center, high and low density populated residential zones, industrial zone, rural zone.

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1. Introduction

Urban environment is characterized by some typical features: high density of population and buildings, high energy consumption and shortage of green areas. A main consequence is the Urban Heat Island phenomenon (UHI), which is the systematic higher air temperature of urban environment with respect to rural one. The main outcomes are (Lazzarin, 2011):

– a deterioration of the summer outdoor climate conditions;
– an increase of energy consumptions;
– an increase of polluting emissions.

Many authors specified that causes and effects of UHI are different depending on the atmospheric layer studied (Akbari & Bell, 2008; Oke, 1982). Here only causes of UHI phenomenon at surface and canopy layer will be briefly considered.

It is nowadays known that UHI causes are several and linked together. A first classification could be in controllable and uncontrollable factors as shown in Fig. 1 (Rizwan, Leung Dennis, & Chunho, 2008). The controllable and uncontrollable factors could further be categorized as the temporary effect variables (i.e. wind speed and cloud cover), permanent effect variables (i.e. green areas and building material) and cyclic effect variables (i.e. solar radiations and anthropogenic heat sources). The UHI mainly depends on the modification of energy balance in urban areas which is due to several factors: urban canyons (Landsberg, 1981), thermal properties of the building materials (Montavez, Rodriguez, & Jimenez, 2000), substitution of green areas with impervious surfaces that limit evapotranspiration (Imhoff, Zhang, Wolfe, & Bounoua, 2010; Takebayashi & Masakazu, 2007), and decrease in urban albedo (Akbari & Konopacki, 2005). Many studies established the correlation between an increase in green areas and a reduction in local temperature (e.g. Susca, Gaffin, & Dell'Osso, 2011; Takebayashi & Masakazu, 2007), suggesting the augmentation of urban vegetation as a possible mitigation strategy for the UHI. For (Lopes et al., 2001) the UHI phenomenon is characterized by an important spatial and temporal variation related to climate, topography, physical layout and short term weather conditions. So the unique characteristics of each city determine the effects. They state that the main factors that influence the heat island effect include:

- canyon radiative geometry that contributes to decrease the long wave radiation loss from the street canyons due to the complex exchange between buildings and the screening of the skyline;
- thermal properties of materials that increase storage of sensible heat in the fabric of the city during the daytime and release the stored heat into the urban atmosphere after sunset;

* Corresponding author. Tel.: +39 0444 998704; fax: +39 0444 998884.
E-mail addresses: busato@gest.unipd.it (F. Busato), renato@gest.unipd.it (R.M. Lazzarin), noro@gest.unipd.it, marco.noro@unipd.it (M. Noro).

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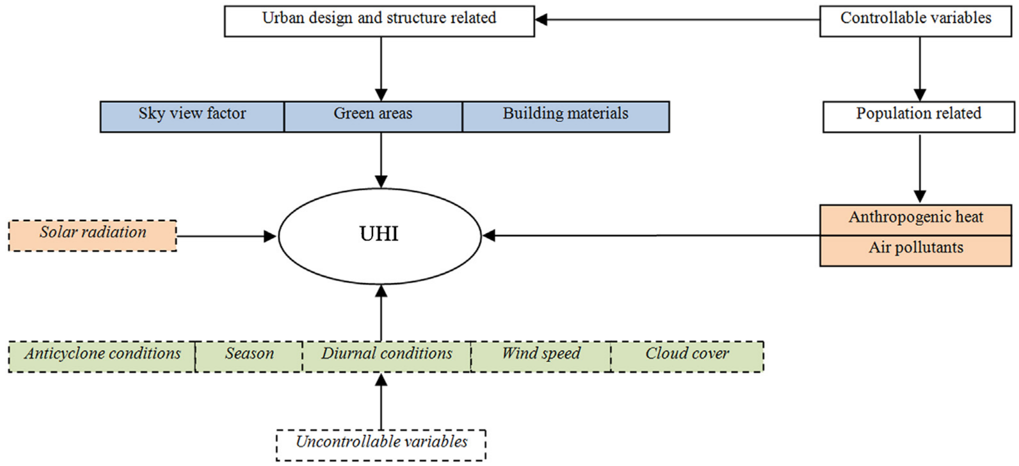

Fig. 1. Main causes of the Urban Heat Island effect. ( ) is related to permanent effect variables; ( ) is related to temporary effect variables; ( ) is related to cyclic effect variables; ( ) is related to controllable variables; ( ) is related to uncontrollable variables.

- anthropogenic heat that is released from combustion of fuels either from mobile or from stationary sources and the animal metabolism;
- the urban greenhouse effect that contributes to increase the incoming long wave radiation from the polluted urban atmosphere;
- reduced evaporating surfaces in the city that puts more energy into sensible heat and less into latent heat.

Akbari and Bell (2008) identified factors communities are focusing on (reduced vegetation in urban regions and properties of urban materials), future factors to consider (urban geometry like the height and spacing of buildings and anthropogenic heat emissions) and additionally factors (weather conditions, like clear skies and calm winds, and geographic location, such as proximity to large water bodies and mountainous terrain). Other Authors deal with the UHI phenomenon and its causes in a more general way (Bonafè, 2006; Lazzarin, 2011; Santamouris, 2001; Taha, 1997).

To be able to understand how these causes are related and linked together it has to be considered that the Urban Heat Island effect must be firstly the result of urban and rural energy balance differences. The surface energy balance was first proposed by (Oke, 1982) and recalled by (Mirzaei & Haghighat, 2010):

$$Q * + Q_F = Q_H + Q_E + \Delta Q_S + \Delta Q_A$$

where Q^* is the net all-wave radiation, Q_F, Q_E and Q_H are respectively the anthropogenic heat release, the turbulent latent and turbulent sensible heat flux. ΔQ_S is the sensible heat storage (represents all energy storage mechanisms within elements of the control volume, including air, trees, building fabrics, and soil) and ΔQ_A is the net heat advection (Mirzaei & Haghighat, 2010).

Since the parameters of the equation depend on city location and characteristics, it can be concluded that the energy balance inside a city alters when these parameters varies. This means that UHI intensity is not similar in different cities. For instance, radiation absorption can be a dominant factor for diurnal UHI in equatorial climate, especially when the sky is calm and cloudless. However, anthropogenic heat release can be the main cause of nocturnal UHI in high-rise and dense metropolitan areas when the sky is cloudy (Mirzaei & Haghighat, 2010).

Accurate approaches to the study of UHI in different cities might point out that causes of UHI phenomenon are different from case to case (Bonafè, 2006). In effect, UHI has been studied worldwide (Athens, London, Berlin, Vancouver, Montreal, New York, Tokyo, Hong Kong) since sixties of the past century (Santamouris, 2007). Table 1 lists a few examples for studies which concentrate on several types of UHI in major climate regions.

Important heat island studies have been performed in Europe over the last 15 years. The work is based either on statistics of temperature differences between pairs or on groups of urban and rural stations (Beranova & Huth, 2005; Bohm, 1998; Eliasson & Holmer, 1990), on results obtained by networks of fixed stations in a city (Karaca, Tayant, & Toros, 1995; Santamouris, 2001; Szymanowski, 2005), or by using mobile stations across an urban area (Alcoforado & Andrade, 2006; Montavez et al., 2000; Szymanowski, 2005).

In Italy, some studies have been carried out recently in large cities like Bologna (Zauli Sajani, Tibaldi, Scotto, & Lauriola, 2008), Milan (Bacci & Maugeri, 1992; Picot, 2004), Florence (Petralli et al., 2006; Petralli, Massetti, & Orlandini, 2009, 2011). Very few data are available concerning the presence of the Urban Heat Island phenomenon in medium size cities (say less than 100,000 inhabitants), the most diffuse in Italy (75% of Italian population lives in

Table 1
Studies on UHI in different climate regions of the world.

Climate region		Typical city	Study
Tropical	Humid	Singapore, Kuala Lumpur	Tso (1996)
	Dry-humid	Mumbai	Kumar et al. (2001)
	Highland	Mexico	Jauregui (1997), Doran et al. (1998)
	Desert	Kuwait City, Phoenix	Nasrallah et al. (1990)
Subtropical		Johannesburg	Goldreich (1992)
Mediterranean		Athens	Philandras et al. (1999)
Temperate	Coastal	Tokyo	Saitoh et al. (1996)
	Continental	Moscow	Shahgedanova et al. (1997)
	Complex terrain	Santiago de Chile	Romero et al. (1999)
Higher latitudes		Göteborg	Eliassen and Holmer (1990)

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