Available online at www.sciencedirect.com
ScienceDirect
Solar Energy 82 (2008) 986–998
SOLAR ENERGY
www.elsevier.com/locate/solener

Urban heat island intensity in London: An investigation of the impact of physical characteristics on changes in outdoor air temperature during summer

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Received 11 December 2007; received in revised form 7 May 2008; accepted 8 May 2008
Available online 6 June 2008

Communicated by: Associate Editor Matheos Santamouris

Abstract

The study looks at the potential of physical characteristics in mitigating the urban heat island intensity (UHI) in London during summer. This research uses six on-site variables namely aspect ratio, surface albedo, plan density ratio, green density ratio, fabric density ratio and thermal mass for the investigation in six data sets. The climatic variations in summer are controlled by classifying the data into clear sky, partially cloudy and cloudy periods. Geographical variation is controlled by classifying the data into core, urban and semi urban areas. Maximum daytime UHI of 8.9 °C is found in semi-urban area during partially cloudy period while maximum nocturnal UHI of 8.6 °C is found in urban area during clear sky period when the wind velocity is below 5 m/s. The most critical climate and geographical location in determining the changes in outdoor air temperature in London are partially cloudy periods and urban areas respectively. Among the variables studied, most critical variable that determines the daytime and nocturnal changes in outdoor air temperature is surface albedo.

Keywords: Urban heat island intensity (UHI); Sky cloud conditions; Core; Urban; Semi-urban; On-site variables

1. Introduction

Most cities around the world face undesirable thermal impacts due to fast decline in natural land surfaces (Oke, 1987; Santamouris, 2001a). This is largely due to rapid urbanization. Changes in urban surfaces have altered the radiative, thermal, moisture and aerodynamic properties of the environment (Oke, 1987; Givoni, 1998; Giridharan et al., 2007). This has caused concentration of heat in urban areas compared to surrounding rural areas, and this phenomenon is known as urban heat island intensity (UHI) which has caused alarming effects in many cities (Givoni, 1998; Mcgregor and Nieuwolt, 1998; Santamouris et al., 2007a).

Research studies have confirmed the extent of UHI within many cities in Europe (Cartalis et al., 2001; Santamouris, 2007b). Studies have also confirmed the impact of the UHI on energy demand by buildings in hot climates in Europe (Santamouris et al., 2001b; Hassid et al., 2000). Recent UHI studies conducted in London indicate that urban population could be affected severely in terms of energy consumption and health, especially in summer if the current urbanisation trend continues (Kolokotroni et al., 2006; GLA, 2006). First person to indicate the presence of UHI in London was Luke Howard as reported by Landsberg (1981). At the turn of the 19th Century, he

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0038-092X/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.solener.2008.05.004

discovered −0.2 and 2.0 °C during daytime and night respectively. Mid 60's to early 80's researchers such as Chandler (1965) and Landsberg (1981) carried out notable studies on London UHI and indicated the presence of UHI in the order of 4–6 °C during night. In 1999 and 2000, extensive field measurements were carried in London and results indicated the presence of UHI as high as 7 °C (Watkins et al., 2002a). The work so far focused on the UHI in relation to energy demand by buildings. In papers published already, the average variation of air temperature has been indicated during the summer months for specific times and on average (Graves et al., 2001; GLA, 2006) as well as the strong correlation between UHI and distance from the London centre (Watkins et al., 2002a). In addition, the effect on passive design and in particular night ventilative cooling (Kolokotroni et al., 2006) and cooling (and heating) energy demand have been investigated (Kolokotroni et al., 2006, 2007; Watkins et al., 2002b). Some indications of the additional effects of urban physical characteristics such as urban canyon geometry, albedo and vegetations has been identified in published articles but has not been studied in detail until now (Kolokotroni et al., 2007; Watkins et al., 2007).

This paper continues the work by investigating the impact of physical characteristics on changes in outdoor air temperature of London during the summer months while controlling the geographical and climatic changes. The analysis is broadly divided into trend and regression analysis of daytime and nocturnal data. Both on-site and off-site variables will influence the changes in the outdoor air temperature (Giridharan et al., 2007). The immediate and frequent changes are caused by on-site variables while off-site variables represent the macro level environmental changes over a long period; for example surface albedo is an on-site variable while location quotient is an off-site variable. This paper will limit its regression analysis to on-site physical variables due to logistical and resource constraints while off-site variables as well as UHI during the heating season is the subject of continuing further work.

2. Controlling and selection of variables

The time and space as a function of meteorological, geographical and urban characteristics will determine the extent of UHI of a particular environment (Oke, 1987; Golany, 1996; Livada et al., 2002). Considering the complex variations in seasonal (meteorological) and geographical variables in different environments, it is important to control seasonal and geographical variables as much as possible to understand the location specific impacts on changes in outdoor air temperature (Giridharan et al., 2007, in press). This paper reports on work in which the seasonal variation was broadly controlled by focusing on the *summer period* (May to September) in London. In temperate climates, May to September is usually specified as the cooling period for many applications as for example the determination of cooling loads for buildings. This period includes the highest solar radiation intensity (June) and the highest air temperatures (July–August). Further, more specific controls within the summer are considered in terms of *sky conditions and wind*.

Sky conditions were classified into three categories; clear-sky (CSP), partially-cloudy (PCP) and cloudy periods (CP) as defined in Table 1. The classification range was worked out based on similar studies conducted in other parts of the world (Giridharan et al., 2007; Lam, 1998). It adapts from the official classification of skies for daylighting calculations according to CIE to reflect prevailing conditions in London. According to CIE, clear sky has less than 30 % cloud cover, partly cloudy sky has between 30% and 70% and cloudy sky has more than 70% cloud cover.

London sky is characterised by very regular overcast conditions (cloud cover 7–8 octas for more than 55% of the hours in the summer of 2000) and this was taken into account in this classification. For the classification in this paper, CSP sky model includes all hours during which the cloud cover ranges between 0 and 3 oktas (approximately 15% of all hours in the summer of 2000). For these conditions global solar radiation intensity during the day is more than 500 W/m^2. PCP sky includes all hours which the cloud cover ranged between 4 and 6 oktas (approximately 27% of all hours in the summer of 2000). The solar radiation intensity ranges between 300 and 500 W/m^2. CP sky includes all hours during which the could cover was 7 to 8 oktas and this accounted for approximately 58% of all hours; in this case the global radiation intensity was less than 300 W/m^2 during the day. For the analysis, day time classification mainly follows the solar radiation intensity while the night time classification follows the cloud cover. The climatic conditions of London according to this classification are summarised in Table 2 separately for day and night.

Three meteorological wind ranges were defined as below 10 m/s, below 5 m/s and below 2.5 m/s. This study considers wind velocity data from Heathrow meteorological station. Therefore, on most occasions, at any location under this study, one could expect lower wind velocity than what is specified above.

The geographical variations in London are controlled by classifying the data into core, urban and semi urban as shown in Table 3. The categorisation of geographical zones mainly follow the distance from the centre of London as distance has been identified as one of the main parameters influencing UHI (Kolokotroni et al., 2007; CIBSE, 2006). This has been conformed by extensive site visits to identify the development pattern, buffer zones, density of development etc.

The on-site variables selected for this research work are aspect ratio, plan density ratio, green density ratio, fabric density ratio, surface albedo and thermal mass (Table 4). These variables are selected based on the research findings of Graves et al. (2001), Kolokotroni et al. (2006, 2007) and GLA (2006). Selection of variables was also guided by similar research work done in different parts of the world to