Building and Environment 107 (2016) 64–78

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Modelling the spatiotemporal change of canopy urban heat islands

Jasim M. Ali [a, b, *], Stuart H. Marsh [a], Martin J. Smith [a]

[a] *Faculty of Engineering, The University of Nottingham, Nottingham, UK*
[b] *Faculty of Engineering, University of Anbar, Anbar, Iraq*

ARTICLE INFO

Article history:
Received 15 April 2016
Received in revised form
24 June 2016
Accepted 13 July 2016
Available online 15 July 2016

Keywords:
Urban heat island
High resolution measurements
Spatiotemporal change
Influencing parameters
Regression models

ABSTRACT

This study models the spatiotemporal change of Birmingham's urban heat island (UHI) using air temperature measurements made during the HiTemp project to study the atmospheric conditions over the city [1]. The study identifies the causative factors and their contributions to the formation of UHI, based on a number of data used to build 2.5 D model; land cover, land use, geometrical factors and shadow layers. The raw air temperature measurements were filtered, georeferenced and interpolated to create maps of temperature variations. The expected influencing parameters on the development of the UHI were derived and prepared for regression modelling. The results showed that the difference in temperature across Birmingham city through two years of ground measurements (June 2012–June 2014) reached up to 13.53 °C. The UHI's appeared daytime and night-time throughout the different seasons for approximately 56% of the total hours during the study period. However, the high intensity events happened during the calm and clear nights. Moreover, buildings' shadow provided up to 2 °C reduction to the air temperature, while the wind speed and direction are responsible for the size and distribution of hot spots. The built up area contributed to increase the UHI, whereas, the other types of land cover and the geometrical parameters, contributed less.

1. Introduction

The phenomenon of heat islands was first documented in 1818, when Luke Howard found an artificial excess of heat in the city centre of London compared to the surrounding country [2]. This excessive heat has been long observed in urban and suburban areas where air and surface temperature are higher than their adjacent rural areas. The traditional way of measuring the Urban Heat Island (UHI) is by measuring the air temperature using a pair of meteorological stations to calculate the Atmospheric Urban Heat Island (AUHI). Remote sensing (RS) techniques can capture the surface temperature as an indicator of the so called Surface Urban Heat Island (SUHI) [3]. The increase in availability of high spatial resolution satellite images has enabled researchers to study the spatial change of surface temperature patterns, but it does not always capture the temporal variation of heat islands [4,5]. The heat islands have been classified based on different attributes. Cermak et al. [6] classified the urban climate into three layers, the first layer describes a street and its surrounding buildings, which is called the canyon layer. Second, the canopy layer extends upwards from the surface to approximately mean building height. Third, the boundary layer is a layer of air up to 2000 m height above the canopy layer. Voogt and Oke [7] explained that there are three types of UHI. The surface heat island refers to the difference in surface temperature between the urban and rural areas. The canopy heat island indicates the difference in air temperature between urban and rural areas within the canopy layer. The boundary heat island measures the difference in air temperature between the urban and rural areas within the boundary layer. AUHI and SUHI have different spatiotemporal behaviour, and they are two different approaches to study the UHI phenomenon [8]. While, the expensive approach of RS is focused on the SUHI that lacks the temporal resolution; the AUHI employs the field measurements which usually have limited spatial resolution due to limited stationary network or mobile stations around a city [9]. This paper adopts a dense network of meteorological sensors to provide high spatial resolution as well as high temporal resolution of AUHI measurements within the canopy layer.

Environmental Protection Agency (EPA) [10] explained that the factors that might create UHIs include: reduced vegetation in urban areas, the thermal properties of urban material, urban geometry, anthropogenic heat emissions, weather, and topography. Some of these factors are natural occurrences and engineers cannot control

* Corresponding author. Faculty of Engineering, The University of Nottingham, Nottingham, UK.
E-mail address: Jasima094@gmail.com (J.M. Ali).

http://dx.doi.org/10.1016/j.buildenv.2016.07.010
0360-1323/© 2016 Published by Elsevier Ltd.

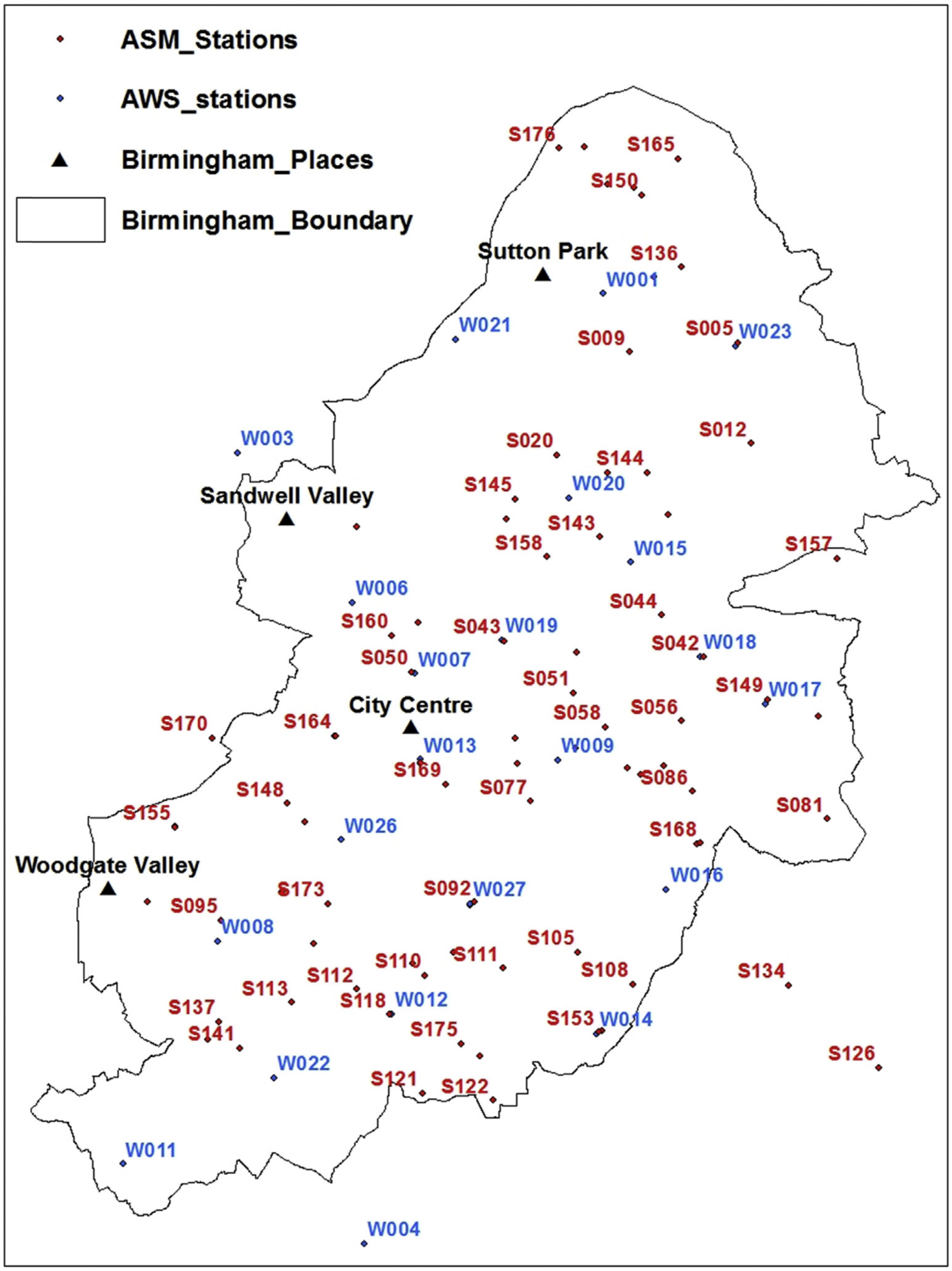

Fig. 1. HiTemp Station locations in Birmingham.

them such as weather and geographic location. However, some other factors can be changed by design, such as the properties of building materials. The negative consequences of UHI include increased energy consumption, greenhouse gases, human discomfort, and impaired water quality [11]. Mirzaei et al. [12] explained that increased peak demand, mortality, and morbidity are the most important negative consequences of UHI. Indeed, whilst some communities might benefit from the excessive heat in winter in terms of energy consumption, the summer penalty is much larger and it can affect a community's environment and quality of life [10]. Sailor [13] explained that the canopy UHI is most relevant with respect to direct effects on building occupants, particularly in the summertime, buildings located in or near the centre of a large city tend to have the largest energy consumption in the early morning hours. Conversely, Berger, et al. [14] in their study concluded that hottest locations in moderate climates tend to reduce energy demands in the wintertime. From that, the identification of UHI events in terms of location, time and magnitude would help building designers for the more accurate simulation of building energy usage particularly for air conditioning and refrigeration [14]. So, urban planners should take into account the impacts of UHI for future cities, and work on the possible solutions to mitigate theme in existing cities.

The recent AUHI studies within the canopy layer presented in the literature have not used high spatial and temporal resolution temperature together. Furthermore, they have not modelled all the important controllable factors that potentially affect the development of UHI. For example, Busato, et al. [15] have reported their experimental results for three years of mobile traverses, which covered prefixed paths in the city of Padua in Italy. However, this