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The influence of small green space type and structure at the street level on urban heat island mitigation

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ABSTRACT

The purpose of this study was to determine the types and structures of small green spaces (SGs) that effectively reduce air temperature in urban blocks. Six highly developed blocks in Seoul, South Korea served as the research sites for this study. Air temperature was measured at the street level with mobile loggers on clear summer days from August to September in 2012. The measurements were repeated three times a day for three days. By analyzing the spatial characteristics, SGs within the six blocks were categorized into the four major types: polygonal, linear, single, and mixed. The result revealed that the polygonal and mixed types of SGs showed simple linear regression at a significant level ($p < 0.01$). It indicated that the blocks' urban heat island (UHI) mitigation (ΔT_{Rmn}) increased in a linear fashion when the area and volume of these two types of green spaces increased. The area and volume of a polygonal SG with mixed vegetation, over 300 m^2 and 2300 m^3, respectively, lowered the ΔT_{Rmn} by 1 °C; SG with an area and volume of larger than 650 m^2 and 5000 m^3, respectively, lowered the ΔT_{Rmn} by 2 °C. The results of this study will be useful to urban planners and designers for determine the types and structures of urban green spaces to optimize the cooling effect, as well as how such green spaces should be designed and distributed.

1. Introduction

Rapid urbanization has increased environmentally negative impacts with the high demand of land use change, particularly in developing countries. Urbanization in 2014 accounted for 54% of the total global population, up from 34% in 1960. Urban populations are expected to reach 81% by 2030 (UNFPA, 2007). This urbanization affects the urban climate, creating urban heat islands (UHIs) (Oke, 1987; Asimakopoulos et al., 2001). UHIs cause higher temperatures in urban centers than in surrounding suburban and rural areas (Peng et al., 2012; Wang et al., 2015); this effect has become one of the urban disasters such as floods, inundation, and landslides, and has taken an increased toll on human health (O'Loughlin et al., 2012; Zhou et al., 2014).

The presence of green spaces in urban areas can mitigate these negative impacts by creating cooling buffer zones; in such zones, urban areas shaded by green spaces are cooler than other areas heated by direct solar radiation (Kim et al., 2016; Oliveira et al., 2011). These cooling areas improve microclimatic conditions and human health (Georgi and Dimitriou, 2010). Green spaces are important to reduce urban air temperature maximum and variation (Norton et al., 2015). Previous studies based on onsite observations have focused on measurements of air temperature in order to quantify the degree of cooling effect of certain structures and types of green spaces. Those studies have dealt with urban parks (Cao et al., 2010), small parks (Bowler et al., 2010), gardens (Oliveira et al., 2011), green roofs (Klein and Coffman, 2015), vertical greenery (Tan et al., 2014), street trees (Oke, 1988) and pocket parks (Lau et al., 2012), according to the shape and distribution of the space.

In the existing body of literature, only a few studies have investigated the density (Oliveira et al., 2011; Lehmann et al., 2014 Lehmann et al., 2014), size (Dimoudi and Nikolopoulou, 2003; Georgi and Dimitriou, 2010), shape (Fintikakis et al., 2011; Feyisa et al., 2014), and ratio of green spaces (Alexandri and Jones, 2008; Lehmann et al., 2014; Saito et al., 1990; Sun, 2011). However, despite the expectation that small green spaces (SGs) provide high cooling effects and thus, make air temperatures drop (Feyisa et al., 2014), such an effect in urban areas has been under-explored in

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comparison to well-documented UHI reducing effect of larger parks and urban forests (Oliveira et al., 2011).

The degree of cooling is affected by the type, structure, and size of green spaces (Spronken-Smith and Oke, 1999; Doick and Hutchings, 2013). For example, diverse types and compositions of green spaces in urban areas would have a stronger cooling effect than other green spaces comprised of simple structures have (Li et al., 2012, 2013). However, air temperature changes by SG type and structure are still challenging to measure at the street level in urban areas (Escobedo and Nowak, 2009; Manes et al., 2012) because the UHI mitigation effect of SGs can vary among different sites due to factors such as topography, traffic density, and other anthropogenic heat-release influences (Shashua-bar and Hoffman, 2000). In addition, although large urban forests and green spaces have been evaluated mainly as a cooling tool with remote sensing techniques used to measure land surface temperatures (Zhang et al., 2009; Cao et al., 2010; Connors et al., 2013; Wong and Lau, 2013; Asgarian et al., 2014), only a few studies have assessed the influence of the characteristics of SGs on air temperature changes at the street level.

Based on the existing gaps in the current literature, the objective of this study was to analyze the cooling effect of SGs at the street level, according to their types and structures. The results of this research will be useful for understanding the cooling effect of SGs on urban block units, which will facilitate the creation of more specific and effective master plans that incorporate SGs of the optimum size, distribution, and composition.

2. Material and methods

2.1. Study site

The City of Seoul (Seoul) (37°34′0″N, 126°58′4″E) is the capital of South Korea. Since 1960, Seoul has been quickly urbanized and become densely populated. Seoul's climate is characterized by hot and humid summers with high air temperatures that occasionally climb to over 35 °C. The annual average temperature, humidity, and rainfall are 12 °C, 64.4%, and 1,450.5 mm, respectively. The study sites for this research are located in the Jongno-gu and Jung-gu districts showing high built-up ratios; (15.4% of Jongno-gu, and 37.6% of Jung-gu) (see Fig. 1).

To identify the UHI mitigation effect of SGs on microclimates and make this effect easy to apply in urban policies, plans, and designs, we selected six actual urban blocks as study sites from the two districts. The urban block is the smallest urban planning unit and comprised of various landcovers such as buildings, pavements, and green spaces. The six urban blocks selected were divided into three pairs (Block 1/Block 2, Block 3/Block 4, and Block 5/Block 6) (see Table 1); they had a homogeneous microclimatic urban structure, based on the local climate zone (LCZ) model (Stewart and Oke, 2012). This theoretical climatic model was developed and applied to explain the local climatic homogeneity to prove the relationship between the urban microclimatic characteristics and urban landcovers spatial characteristics such as disposition, purpose, and form of buildings within an urban block (Stewart et al., 2014; Stewart and Oke, 2012). The LCZ model helped to conceptualize our experimental method, which was based on each urban block pair having mutual urban settings with one distinct characteristic of the green spaces. This model ensured that the observations would be representative of the microclimate of the particular green space's structure and type (Runnalls and Oke, 2000). The selected blocks had identical microclimatic conditions with buildings ratios greater than 35%, whereas the SGs ratios ranged from 2.4% to 38% and the average heights of the buildings ranged from 30 m to 45 m (see Table 1).

2.2. Air temperature measurements

Air temperature measurements were performed based on mobile transect surveys at the street level in each block. The mobile transect survey is more economical, accessible, and safer than stationary measurements when a block-sized urban area with various urban settings is measured on a fine scale (Oke, 2006; Grimmond et al., 2010; Stewart, 2011). It produces multiple points across a single block, which record detailed temperature measurements of urban microclimatic factors, and do not require calibration when the measurement is conducted with slow travel speed such as walking (Aguilar et al., 2003; Sun, 2011). The type of air temperature measurement logger used in this research was the Testo 174H (Testo Inc, 2012, Germany), which can measure from −20 °C to +70 °C; its accuracy is ±0.5 °C, and resolution is 0.1 °C. The thermometer was an NTC sensor whose temperature response speed is under 1 s. We set the loggers to record every 1 min.

The air temperature was recorded in the summer, at daytime, for a total of twelve days (from August 9 through September 11, 2012) (see Table 2). The measurement thermometer was sensitive to wind and direct solar radiation; therefore, we shielded it with white plastic (Erell et al., 2003). The observations were assumed to represent the best synoptic meteorological conditions for each of the selected urban blocks.

Measurement points were 1.5 m above the ground. In addition, these selected points were set on mid-width of sidewalks, alleys, and pathways shaded by trees, buildings or exposed to sunshine (Bohnenstengel et al., 2011; Martin et al., 2000; Oke, 2004; Runnalls and Oke, 2006; Sun, 2011; Unger, 2004) (see Fig. 2). To collect reliable data from each single measurement point, we measured the air temperature repeatedly up to nine times through a mobile transect survey (Bowler et al., 2010; Grimmond et al., 2010). The survey routes were established to measure air temperature at the same time and for the same number of measurement points to determine the mutual synoptic conditions for paired blocks, based on LCZ (see Table 2) (Stewart and Oke, 2012). This method was effective in reducing errors in air temperature measurement by mutually setting the control conditions of the test to the pairs used in the mobile transect surveys (Oke, 2004; Bowler et al., 2010; Stewart, 2011).

2.3. Data analysis

In this study, linear regression analysis was used to determine the cooling effect of SGs and their significant types of patches and structures, for use in UHI mitigation planning and design. In previous studies, the structure and type of individual SGs were generalized with specific crown shapes (VanPelt and North, 1997; Lehmann et al., 2014), because these forms are effective in calculating tree characteristics (Georgi and Zafiriadis, 2006). The type and structure of an SG was expected to have an impact on its cooling effect (Hongbing et al., 2010; Napoli et al., 2016). It was unclear, however, what effects would result from various SG types and structures. Thus, we defined the type and structure of each SG through the use of aerial images and field surveys (Forman, 1995; Lehmann et al., 2014): a "polygonal type" of SG, which was shaped like a circle or regular polygon; a "linear type" of SG, which formed a line or bar planted with one or two rows; a "mixed type" of SG, with multilayered vegetation structures composed of tall trees, arbors, and shrubs; or a "single type" of SG, with a single layer of vegetation of only one species. Based on those four types, each SG was categorized in a combination of two types based on its form (polygonal or linear) and vegetation characteristics (single or mixed).

To calculate the volume and area of each SG, a method that included information about the tree height (H), crown radius (r), height of the tree canopy, and crown density was employed; the relevant data were collected through a field survey (Yui, 1969;