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A simplified assessment of how tree allocation, wind environment, and shading affect human comfort

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ABSTRACT

Urban areas encounter a common problem called the heat island effect. Public-space plantings and parks have become a crucial countermeasure for decreasing urban temperatures. In this study, field measurements were carried out in a subtropical park in the summer to investigate the effect of plantings on microclimate and the thermal environment of pedestrian areas. It was found that obstructions affected the wind field; although cold air enters parks, an overcrowding of plants resulted in temperature rises in downstream areas. Shading is a key to thermal comfort in both tropical and subtropical regions, and its effect is augmented by ventilation. Trees that are planted without proper planning can decrease wind movement, which in turn has a detrimental effect on thermal comfort, especially downwind. Wind corridors through urban parks can promote both shading and ventilation, improving thermal comfort, and should thus be considered when designing the layout and trimming of plantings. Data from both fixed- and mobile-type measurements were used to validate the feasibility of a computational fluid dynamics simulation model. It was observed that wind speed and shading are the two main variables that influence the human comfort index, based on which a simpler human comfort assessment was proposed to replace the conventional index, standard effective temperature (SET*). The proposed method can be used as a guideline for landscape architects when designing planting locations.

1. Introduction

Many countermeasures are available to mitigate the heat island effect and alter undesirable microclimates in urban areas. Urban green spaces contribute to improving urban environments and create quality urban landscapes (Dimoudi and Nikolopoulou, 2003; Jan et al., 2012). Evapotranspiration can decrease the surrounding air temperature, reducing building energy use (Gómez-Muñoza et al., 2010; Kabisch et al., 2015; Akbari et al., 2001). There is evidence that ground surface coverings and shading by man-made objects and trees significantly affect the thermal environment (Lin et al., 2007, 2010). As one of the most popular measures for improving outdoor environments, urban vegetation has been proven to play an important role in mitigating the heat island effect (Zhang et al., 2013; Hong and Lin, 2015). Parks have a cooling effect because of the combined impact of shading and evapotranspiration (Shashua-Bar and Hoffman, 2000). Plant evapotranspiration has been observed to improve urban microclimate conditions. Moreover, the microclimate condition of urban green belts has been shown to affect human thermal comfort (Georgi and Dimitriou, 2010). Researchers have thus paid more attention to the importance of shading and planting.

The cooling effects of urban streets and courtyards with trees have been investigated, and the benefits of plantings in the surrounding areas have been identified in several studies (Shashua-Bar and Hoffman, 2000, 2004; Kong et al., 2014; Abreu-Harbich et al., 2015). There is a clear indication that the density of vegetation in parks plays a vital role in enhancing the cooling of daytime air temperature (Feyisa et al., 2014; Gromke et al., 2015). It has been revealed that canopy density, canopy area, and tree height also play important roles in the cooling effect. A commonly used method for the assessment of the benefits associated with parks in outdoor areas is to measure climate factors on site and then analyze the measurement results. Most studies on the cooling effects of urban vegetation have involved measurements within a single park, with few studies examining the cooling effect of parks on surrounding

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areas (Bowler et al., 2010). Parks are important planting areas in cities and have a significant effect on the overall environmental conditions. For outdoor thermal environments, the proper layout of plants is important, and thus optimal plant arrangement should be considered (Ooka et al., 2008). Both grass and trees can effectively cool surfaces and thus provide regional cooling, helping reduce the urban heat island effect during hot weather (Armson et al., 2012; Klemm et al., 2015).

Although the temperature effect in parks is often discussed, less attention has been given to the blockage of the wind in such areas (Jan et al., 2013). In warm climates, vegetation can have negative effects, such as trees reducing wind speeds (Yoshida et al., 2006; Gromke et al., 2008). Regarding wind assessment, classification of wind speeds is traditionally done according to the Beaufort wind force scale. Wind speed, an important factor impacting thermal comfort, has been shown to have various impacts on pedestrians depending on the specific surrounding conditions (Mochida and Lun, 2008; Janssen et al., 2013; Hsieh et al., 2010). Human thermal comfort is usually assessed using six major factors: air temperature, relative humidity, mean radiant temperature, wind speed, human body activity, and clothing (Walton et al., 2007). In order to explain how wind speed affects thermal comfort, past studies have attempted to classify wind speed. Classification standards of wind speed in specific regions vary with environmental conditions (Hsieh et al., 2014). As a result, researchers have proposed various wind speed classifications according to the climate of their local regions. Outdoor thermal comfort was investigated based on wind speed using the physiological equivalent temperature (PET) in Hong Kong (Yuan and Ng, 2012). An experimental study by Shashua-Bar et al. (2009) in hot environments found that shade provided by trees cools the air significantly more than does the same amount of shade provided by other means. Trees reduce the surface temperature of shaded areas, and shading affects human comfort. Through investigation of subjective perceptions and calculation of comfort indicators in local areas, the regional standard effective temperature (SET*) and users' acceptable ranges of comfort can be obtained.

Computational fluid dynamics (CFD) has been widely used in the study of wind in urban areas (Hsieh et al., 2011; Zhuang et al., 2015). At the pedestrian level, the influences of small obstacles such as trees are significant. In most previous CFD simulations of flow around buildings, only the influences of topographic features and building geometry were considered (Mochida et al., 2008). The effects of trees have been neglected in most conventional CFD predictions of wind environments. Studies on planting and microclimate have discussed cases involving a single tree or a regular arrangement of trees in parks. Nunobiki et al. (2008) used a three-dimensional (3D) calculation model to predict the impact of a single tree on air flow and compared the results to those obtained from wind tunnel experiments. Yoshida et al. (2006) assessed the mitigation effect of plants on an outdoor thermal environment and compared various distributions of wind speed, ground surface temperature, mean radiant temperature (MRT), and SET* for a 3D tree-crown model in three cases. Sasaki (2007) established tree crown shape using CFD and solved the thermal radiation transfer formula, among other measurements, in order to find the impact of tree arrangement, spacing, and shape on the outdoor thermal environment and air quality in Sendai, Japan.

Researchers have previously conducted studies on the impact of a single tree on the environment, with CFD rarely used to simulate large numbers of trees. Although large-scale planting is commonly adopted in urban parks, the details of the effects of tree groupings on the thermal environment have not been discussed. The objectives of the present study are to quantitatively investigate the influence of factors affecting thermal comfort and to analyze the effect of ventilation and shading in a typical urban park located in a climate zone close to the Tropic of Cancer. The shading and wind obstruction effects of vegetation on human comfort based on tree characteristics are analyzed through the use of onsite measurement data and a simulation model. The CFD numerical planting model is validated with onsite measurement data and then used to simulate the thermal environment of a typical summer day in the study area. The distribution of the human comfort indicator (SET*) in the park is obtained. A simplified human comfort assessment based on the wind environment and shading conditions is then proposed for landscape architects. The rest of this paper is organized as follows. The next section introduces the research methodology, including the CFD model and classifications of wind and shading. The simulation results are given next. Then, a discussion on parameter choices and advice for landscape architects are provided.

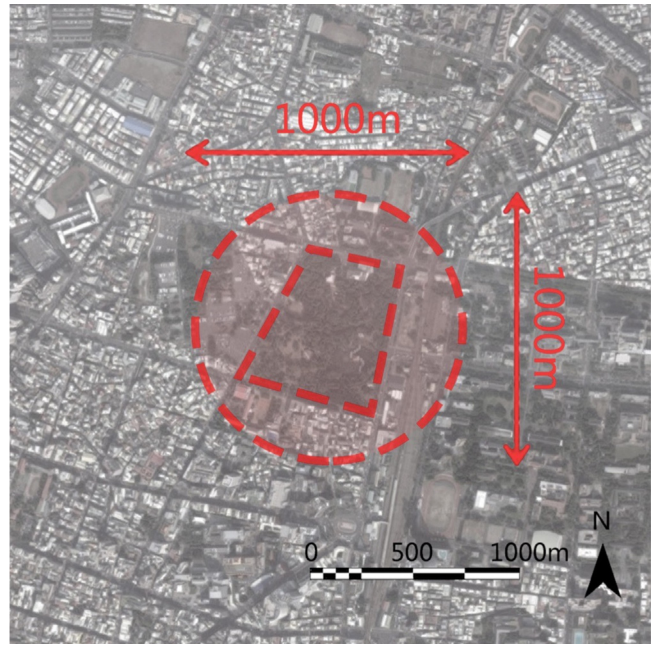

Fig. 1. Study area.

2. Methodology

2.1. Study area

This study investigates the thermal environment and human comfort in Tainan Park, Tainan, Taiwan, located at latitude 23°0′N (120°13′E), which is in the tropical zone according to the Koeppen-Geiger classification. This is very close to the Tropic of Cancer (23°26′N), which divides the subtropical zone and tropical zone. Tainan Park is a metropolitan park, covering a land area of 14.8 ha (Fig. 1). It is the key node in a circular green parkway system consisting of a park and street trees. This area is close to a railway station and is thus densely populated. Its surrounding land is mainly used for educational and residential functions.

A climate analysis of the study area was conducted based on recent ten-year meteorological data from the Tainan City Weather Station, at which the climatic measurement equipment was installed at a height of 12.9 m above ground level, or 40.9 m above sea level. As shown in Fig. 2a, the average air temperature around noon is above 30 °C, and the hottest hour of the day is 13:00. The study area is located on the west coast, and a westerly wind dominates at noon, as shown in Fig. 2b. Summer is defined as June–September in this study.