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Thermal comfort in urban open spaces: Objective assessment and subjective perception study in tropical city of Bhopal, India

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ABSTRACT

The present study was conducted in the tropical city of Bhopal, with the aim to understand the thermal comfort conditions in the open spaces during hot and dry conditions. Field surveys were conducted in three types of urban open spaces - urban parks, Lakefronts, and open lanes of a market. The study investigated the outdoor thermal comfort conditions in the three contrasting locations regarding objective environmental measurements and subjective evaluation of people's perception. The field measurements showed that the values of thermal comfort index (PET) in the urban parks was higher than the defined comfort limit (PET $<$ 30 °C) during the afternoon hours of the study. The subjective assessment also depicts parks to be perceived as thermally comfortable open spaces in the city. Inferential statistics illustrate that tree canopy density significant affected the thermal comfort index PET, and the globe temperature significantly influenced the subjective perception of the thermal environment. Results thus highlight the importance of shade and radiation reduction in attaining thermal comfort in the urban open spaces during the afternoon.

1. Introduction

Urbanization is leading to the warming of urban climate (Voogt and Oke, 2003; Kalnay and Cai, 2003). The anthropogenic activities of land use change leads to climate influences such as changes in surface albedo, evapotranspiration and runoff (Boroneant, 2002). The effect of climate modification, especially thermal outdoor conditions, has consequences such as increased health risks, and overall quality of life, in cities (Parsons, 2014; Chen and Ng, 2012).

The mitigation of the negative impacts of the urbanization can be done by planning cities for sustainable development. One of the prominent features of such developmental plans is to incorporate the network of open spaces. These open spaces in the form of green spaces and woodlands provide environmental, social, economic, and esthetic benefits (Konijnendijk et al., 2006). Over the past few decades, the goal of urban planning and design is to make open spaces attractive and usable to people (Maruani and Amit-Cohen, 2007). Among many factors that affect the quality of outdoor spaces, outdoor microclimate is an important issue. A well designed and well used outdoor space is the very foundation of thermally comfortable microclimate (Brown, 2010). The resultant microclimatic conditions affects the humans physiologically and psychologically (Nikolopoulou and Steemers, 2003). The people in outdoors are directly exposed to their immediate environment in terms of variations of sun and shade, changes in wind speed, and other characteristics. Thus, people's sensation of thermal comfort is largely affected by the local microclimate. The microclimate also influences decisions on whether to use the space. In the context of urban planning, how the thermal sensations of people influence their behavior

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and use of outdoor spaces is of utmost interest.

The study aims to quantify the thermal comfort conditions and the thermal perception of people in outdoor spaces of Bhopal during summers. Finding the actual thermal comfort and the perceived thermal comfort variations in summer afternoon under the influence of trees, water bodies, and built up structures is the scope of this study. Bhopal has tropical climate with very hot summers and mild winters. While the city experiences pleasant weather most of the year, conditions of heat stress are pronounced in the months of April, May and June during which the average ambient temperature is about 40 °C with extremes reaching 46 °C in the afternoon. Studies have shown that green spaces tend to reduce the thermal discomfort for the inhabitants in the city, positively affect their usability and visitation. In this regard, this study tries to assess if there is influence of green spaces on thermal comfort during the hot summer afternoon of Bhopal. It is assumed that if these green spaces can influence the thermal comfort during the extreme conditions, then they would be efficient during moderate conditions as well. This can also implicate the role of outdoor green spaces as a negative feedback to urban climate warming.

Thus the objectives of this study are, to evaluate and compare the thermal comfort in the three outdoor spaces during summer season using objective measurements and subjective responses, to assess the factors (either microclimatic, or socioeconomic) that affect the perception of the thermal environment in these outdoor spaces, and to quantify the impact of tree cover in reducing discomfort.

2. Literature review

Generally, humans are comfortable within a relatively small range of temperature and humidity conditions, roughly between 20–26.7 °C and 20–80% relative humidity (RH), referred to on psychrometric charts as the “comfort zone.” These provide a partial description of conditions required for comfort. Other variables include environmental indices – radiant temperature and rate of airflow – as well as clothing and activity (metabolic rate). While such criteria describe relatively universal requirements in which all humans are “comfortable,” there are significant differences in and varying tolerance for discomfort and conditions in which stress is felt, depending on age, sex, health, cultural conditioning, and expectations (Loftness and Haase, 2013). Thermal comfort is defined as the ‘condition of mind in which satisfaction is expressed with the environment’ (*ASHRAE Handbook*, 2008), whereas thermal sensation is the state of mind expressing the person's evaluation of its thermal environment (Zhang and Zhao, 2009).

Over the recent decades more than hundred thermal indices have been developed to assess the thermal conditions of surrounding environment for humans (Blazejczyk et al., 2012). Although majority of these indices were developed for assessing the indoor conditions, they have also been applied in outdoor environments, such as PMV (Predicted Mean Vote), SET (Standard Equivalent Temperature), Physiological equivalent temperature (PET), and Equivalent Temperature (ET). The outdoor thermal comfort is different from indoors because of three identified aspects: psychological, thermo-physiological and heat balance differences (Höppe, 2002).

During the last decade, interest in the assessment of thermal comfort has increased because of climate changes and increased heat load and stress in cities. Urban land forms with components of natural vegetation and water bodies act as driving forces to modify and affect the outdoor thermal comfort. Outdoor thermal comfort is an important implication for city development because urban outdoors and daily activities contribute to urban livability and vitality (Chen and Ng, 2012). Aljawabra and Nikolopoulou (2010) argued that solar radiation influence the number of visitors and activity in these spaces. In Indian context, only one study from Chennai, assessed the impact of urbanization of thermal comfort (Rose, 2010). The study revealed significant decrease in the thermal comfort conditions due to urbanization and increasing discomfort in daytime temperatures over years. da Silveira Hirashima et al. (2016) surveyed the two squares located in the city of Belo Horizonte, Brazil to assess their thermal comfort using PET index over summer and winter seasons. The study suggested the incorporation of design strategy such as shading, exposure to the wind and providing increased environmental diversity to improve urban environments.

Studies have demonstrated that green infrastructure within cities has the ability to effectively reduce heat and improve outdoor thermal comfort (Bowler et al., 2010; Dimoudi and Nikolopoulou, 2003; Gill et al., 2007; Heusinkveld et al., 2014; Steeneveld et al., 2011). Plants have a profound impact on the environment as its primary mechanism to alter microclimate of a space. The evapotranspiration process by a tree can reduce air temperature and increase the humidity of a space. Previous studies proved that tree planting are the most effectives influence microclimate of a space. The application of tree planting to shade building and spaces provides an efficient passive method of solar control (Parker, 1983). Tree shade was studied in comparison with artificial shade in a study by Shashua-Bar et al. (2011). The study argued that the effect of trees was more pronounced in reducing discomfort. Urban parks have been studied to investigate their thermal comfort using field measurements and questionnaire. Solar radiation and wind speed have been found to be affective inn influencing thermal comfort (Mahmoud, 2011; de Abreu-Harbich et al., 2015).

There is significant lack of information on thermal comfort conditions in different outdoor spaces in India. Comparisons of both objective as well as subjective thermal comfort in different outdoor spaces in developing city like Bhopal would enrich the urban landscaping measures. While many studies have proved that urban greenery and vegetation are important in reducing the thermal discomfort, there is need to know what percentage of tree cover is effective in increasing outdoor thermal comfort significantly in the context of hot summer's conditions in India.

3. Study area

The physical study was conducted in the city of Bhopal, which is the capital of state Madhya Pradesh in central India. This city is a tier III developing city and is characterized by a tropical savanna climate (Koppen climate classification Aw). Within Bhopal 5 green