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Comparison of human thermal responses between the urban forest area and the central building district in Seoul, Korea

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ABSTRACT

This study elucidated the thermal effects of urban forests on physiological and psychological responses; changes in skin temperature, thermal sensation, and thermal preferences. The air temperature, relative humidity, air velocity, and globe temperature were measured in an urban forest and a central building district (CBD) area. Changes in skin temperature were analyzed for 12 subjects in both areas. A total of 790 individuals were interviewed on the actual thermal comfort. The results showed that air temperature and outdoor standard effective temperature (OUT_SET*) in the summer and autumn were higher at the CBD than at the urban forest area ($p < 0.01$). In summer, the mean skin temperature was 35.0 °C at the CBD and 34.0 °C at the urban forest area, respectively. In autumn, it was 33.3 °C and 31.3 °C. During the summer, 60.3% of participants felt hot sensation in the CBD (23.8%, in the forest), while 79.3% felt comfortable in the urban forest (31.1%, in the CBD). The comfortable air temperature range in the urban forest area was 12.1 to 21.6 °C, it was broader than in the CBD. People in the urban forest area felt more comfortable than did those in the CBD. These findings suggest that urban forests increase thermal comfort and widen the comfortable temperature range.

1. Introduction

Urbanization has been proceeding rapidly over the past several decades. As a result, the air and surface temperatures in urban areas have increased (Voogt and Oke, 2003); these temperature increases can lead to heat stress (Watkins et al., 2007). Because people are more likely to experience heat-related discomfort during the summer, participation in outdoor recreation activities declines consistently as temperatures increase (Johansson and Emmanuel, 2006). Thus, an essential aspect of city planning is to evaluate the thermal environment and ultimately devise strategies for enhancing thermal comfort.

It is well-known that environmental factors affecting human thermal comfort include air temperature, humidity, air velocity, and radiation (ISO 7730, 1994). Among these factors, heat exchange by radiation is quite different between indoor and outdoor environment. Indoors, heat transfer by radiation is decided by the mean radiant temperature, which can be calculated using the temperature of the surrounding surfaces and their orientation with respect to the human body (ISO 7726, 2003; Parsons, 2002). On the other hand, outdoors, thermal exchange by radiation is decided not only by surface temperatures but also by solar radiation. Especially during hot summer days, solar radiation is strong; thus, it is one of the most essential factors in deciding thermal comfort outdoors. The radiant temperature is a suitable measure for stress on the human organism (Jendritzky et al., 1979).

The thermal environment determines human thermal comfort. Thermal indices have been developed to evaluate human thermal comfort. Predicted mean vote (PMV; Fanger, 1972), effective temperature (ET*), and standard effective temperature (SET*) indices have been applied in the evaluation of indoor environments. On the other hand, the OUT_SET* (Spagnolo and de Dear, 2003) and physiologically equivalent temperature (PET; Höppe, 1999) indices have been suggested for outdoor use. Wet-bulb globe temperature (WBGT) has been used to assess the working environment of outdoor workers (ISO 7243, 2003).

Several researchers have examined human thermal comfort outdoors using thermal indices. Researchers have used PET to investigate thermal conditions according to landscape type in urban parks (Mahmoud, 2011), according to biotope type (Joo et al.,

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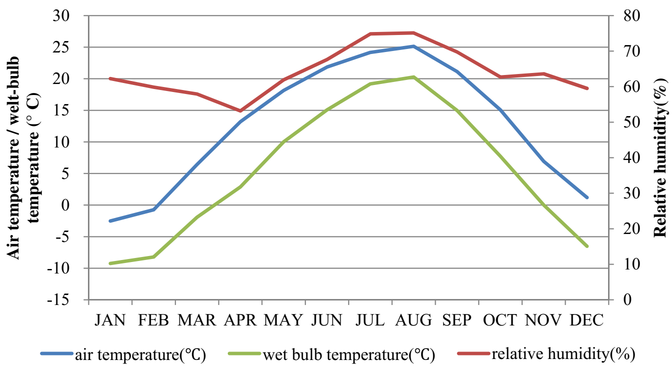

Fig. 1. Typical meteorological data in Seoul, South Korea (1998–2010).

2008), and according to seasonal changes (Lin et al., 2011). Several researchers have argued that human thermal comfort in outdoor environments is distinct from that in indoor environments due to psychological, behavioral, and physiological factors (Hwang and Lin, 2007; Lin, 2009; Nikolopoulou et al., 2001; Spagnolo and de Dear, 2003). Lee et al. (2001) measured participants' skin temperature and heart rate variability for 1 h in an indoor thermal environment. To determine the human thermal response, several researchers surveyed human physiological and psychological responses. Participants' thermal sensations were used to assess psychological responses, and their skin temperature and heart rate variability were measured as an index of physiological responses (Song, 2014; Yao et al., 2007).

It is obvious that trees (urban greening) relax the stressors caused by the urban microclimate in the extremely hot summer season because they obstruct solar radiation. Green areas in urban environments enhance human thermal comfort by reducing the air temperature (Robitu et al., 2006). In addition, trees block and protect people's skin from harmful ultraviolet (UV) radiation (Heisler et al., 2003). Moreover, green areas affect the cooling of urban heat islands (Honjo et al., 2002; Jansson et al., 2007). Because green spaces ameliorate the effects of extreme heat in urban environments, increasing green space in urban areas might increase participation in outdoor activities. Research studies on green space planning in urban areas are necessary to mitigate the difficulties caused by urban areas' thermal environments.

The purpose of this study was to measure the physical thermal environment and associated human psychological and physiological responses in the summer and autumn seasons in the central

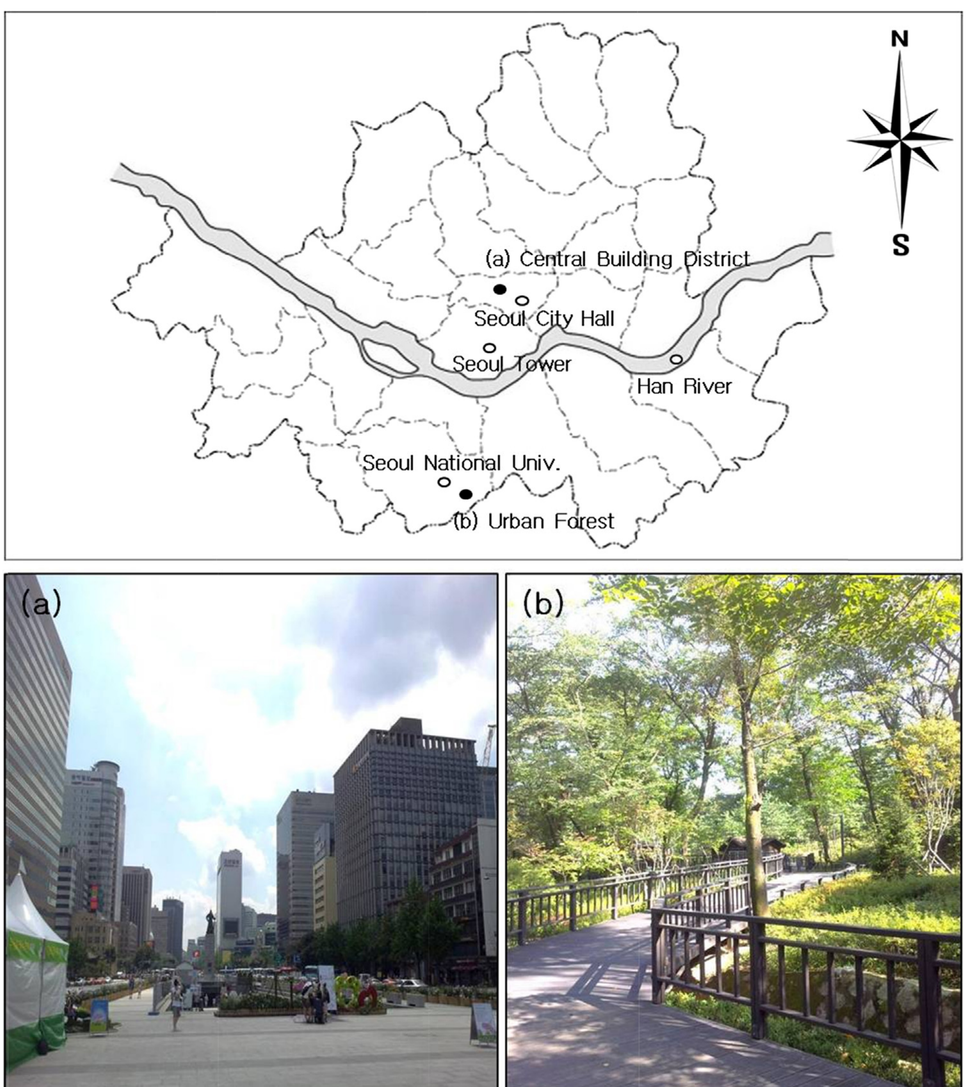

Fig. 2. Location of survey area in Seoul, South Korea; (a) central building district: Gwanghwamun square and (b) urban forest: Mt. Gwanak.