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Outdoor thermal comfort and outdoor activities: A review of research in the past decade

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ABSTRACT

Outdoor spaces are important to sustainable cities because they accommodate pedestrian traffic and outdoor activities, and contribute greatly to urban livability and vitality. In the global context of climate change, outdoor spaces that provide a pleasurable thermal comfort experience for pedestrians effectively improve the quality of urban living. The influence of thermal comfort on outdoor activities is a complex issue comprising both climatic and behavioral aspects; however, current investigations lack a general framework for assessment. This paper presents a review of research over the past decade on the behavioral aspects of outdoor thermal comfort. The article focuses on perceptions of outdoor thermal comfort and the use of outdoor space in the context of urban planning. We further discuss a general framework for assessing outdoor thermal comfort based on behavioral aspects and the need for predicting tools in the design and planning of outdoor thermal comfort.

Introduction

Outdoor spaces are important to sustainable cities because they accommodate daily pedestrian traffic and various outdoor activities and contribute greatly to urban livability and vitality. Encouraging more people on the streets and in outdoor spaces will benefit cities from various perspectives, including physical, environmental, economical, and social aspects (Hakim et al., 1998; Hass-Klau, 1993; Jacobs, 1972; Whyte, 1988). With more than half of the world's population now living in cities (Population Reference Bureau, 2009), downtown areas are particularly vulnerable to extreme weather conditions in the global context of climate change. Under these circumstances, ensuring that pedestrians are well served by outdoor spaces is essential to high-quality urban living. Over the past few decades, making outdoor spaces attractive to people, and ultimately used by them, has been increasingly recognized as a goal in urban planning and design (Carr, Francis, Rivlin, & Stone, 1993; Gehl & Gemzøe, 2004; Marcus & Francis, 1998; Maruani & Amit-Cohen, 2007).

Among many factors that determine the quality of outdoor spaces, the outdoor microclimate is an important issue. In contrast with car commuters, pedestrians 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 greatly affected by the local microclimate. The microclimate also influences decisions on whether to use the space. For example, in his seminal work, "Life Between Buildings: Using Public Space," Gehl (1971) first studied the influence of microclimate on outdoor activities by counting people sitting on sunny and shady benches. He showed that local sunny or shady conditions significantly impact the desire of people to either stay or leave. In the past decade, broad applications in urban studies of concepts and equipment used in biometeorology and urban climatology have yielded a vast number of research projects on outdoor thermal comfort in various climates around the world (Ahmed, 2003; Ali-Toudert & Mayer, 2006; Cheng & Ng, 2006; Cheng, Ng, Chan, & Givoni, 2010; Givoni et al., 2003; Gulyas, Unger, & Matzarakis, 2006; Höppe, 2002; Nikolopoulou & Lykoudis, 2006; Spagnolo & De Dear, 2003; Stathopoulos, Wu, & Zacharias, 2004; Tseliou, Tsiros, Lykoudis, & Nikolopoulou, 2009). Some studies have focused on modeling and assessment methods from a thermophysiological perspective (e.g., Gulyas et al., 2006; Höppe, 2002), whereas others have conducted detailed investigations of the climatic parameters that determine the thermal comfort level of humans (e.g., Cheng & Ng, 2006; Spagnolo & De Dear, 2003). In the context of urban planning, how the thermal sensations of people influence their behavior and use of outdoor spaces is of utmost interest. Given the range of literature along these lines, a general framework for assessing the behavioral aspects of outdoor thermal comfort conditions will be beneficial for both researchers and planning practitioners. Such a framework has yet to be discussed in great depth.

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The focus of this review is twofold. First, we provide a brief introduction to the most widely used models and indicators in outdoor thermal comfort assessment. Second, we present a comprehensive literature review of outdoor thermal comfort research over the past decade from a behavioral perspective, with a focus on the link between outdoor thermal comfort and outdoor activity and the use of outdoor space in the context of urban planning. Subsequently, we discuss a general framework for assessing the behavioral aspects of outdoor thermal comfort and identify the need for predicting tools in design and planning that address outdoor thermal comfort.

An introduction to outdoor thermal comfort assessment methods

Steady-state assessment methods

A number of biometeorological indices have been developed to describe human thermal comfort level by linking local microclimatic condition and human thermal sensation (Task Committee on Outdoor Human Comfort of the Aerodynamics, 2004). A major group of such indices are the so-called steady-state models. These models are based on the assumption that people's exposure to an ambient climatic environment has, over time, enabled them to reach thermal equilibrium, and they provide numerical solutions to the energy balance equations governing thermoregulation. Nagano and Horikoshi (2011) provided a good summary of indices in this category. One of the most widely used indices is the Predicted Mean Vote Index (PMV) (Fanger, 1982), which predicts the mean thermal response of a large population of people. It is often measured on a seven-point scale (+3 = hot, +2 = warm, +1 = slightly warm, 0 = neutral, −1 = slightly cool, −2 = cool, −3 = cold). In practice, PMV is also commonly interpreted by the Predicted Percentage Dissatisfied Index (PPD), which is defined as the quantitative prediction of the percentage of thermally dissatisfied people at each PMV value. PMV has been included in the International Organization for Standardization ISO standard (ISO, 1994). Originally developed as an indoor thermal comfort index, PMV has also been commonly adopted in outdoor thermal comfort studies in which large groups of people are being surveyed (Cheng et al., 2010; Nikolopoulou, Baker, & Steemers, 2001; Thorsson, Lindqvist, & Lindqvist, 2004).

The Physiological Equivalent Temperature (PET) (Mayer & Höppe, 1987) is another notable example of a steady-state model. PET is a temperature dimension index measured in degrees Celsius (°C), making its interpretation comprehensible to people without a great deal of knowledge about meteorology. PET is based on the Munich Energy-balance Model for Individuals (MEMI) (Höppe, 1984) and is defined as the air temperature at which, in a typical indoor setting, the human energy budget is maintained by the skin temperature, core temperature, and sweat rate equal to those under the conditions to be assessed (Höppe, 1999). PET is particularly suitable for outdoor thermal comfort analysis in that it translates the evaluation of a complex outdoor climatic environment to a simple indoor scenario on a physiologically equivalent basis that can be easily understood and interpreted. PET has been widely applied in areas with various climatic conditions (Ali-Toudert & Mayer, 2006; Cheng et al., 2010; Lin, 2009; Matzarakis, Mayer, & Iziomon, 1999; Thorsson, Honjo, Lindberg, Eliasson, & Lim, 2007).

Other steady-state evaluation methods include the Index of Thermal Stress (ITS) (Givoni, 1976), the fuzzy-PMV (Hamdi, Lachiver, & Michaud, 1999), the OUT-SET* (Pickup & De Dear, 1999), and the COMFA outdoor thermal comfort model (Kenny, Warland, Brown, & Gillespie, 2009). These all serve as analytical tools to assess human thermal responses to the local thermal environment.

Non-steady-state assessment methods

The problem with steady-state methods is that they cannot effectively account for the dynamic aspects of the course of human thermal adaptation. For example, Höppe (2002) explicitly showed the difference between the dynamic thermal adaptation process of a pedestrian and the steady-state condition using a simple "sunny street segment" simulation case (Fig. 1). A similar analysis was conducted by Bruse (2005). As opposed to the various indicators developed to assess steady-state thermal comfort, the methodologies for dynamic assessment show a scattered picture. Höppe stated as early as 2002, "The problem we face today is that there are no internationally accepted non-steady-state indices for the solution of this problem. (p. 664)" The picture remains unchanged today. Most methods for assessing human dynamic thermal adaptation are based on the Pierce Two-Node model (Gagge, Fobelets, & Berglund, 1986; Gagge, Stolwijk, & Nishi, 1971). As the name implies, this model treats the human body as two isothermal parts, skin and core, based on which thermoregulation (i.e., heat exchange equations) is constructed for the passive state. Effectively, core temperature, skin temperature, and mean body temperature can all be derived by their deviation from the set points. Other thermoregulatory indicators such as sweating rate and skin blood flow can also be calculated accordingly.

Although these assessment methods can provide detailed investigations of the dynamic course of human thermal adaptation, they have two major drawbacks when applied in outdoor thermal comfort studies. First, the indicators used, such as skin temperature, require extensive monitoring of human subjects, which is hardly feasible and practical in outdoor cases. Therefore, the current studies are restricted mainly to indoor cases (Foda & Sirén, 2010; Zhang, Huizenga, Arens, & Wang, 2004) or simulation cases in the virtual world (Bruse, 2005; Havenith, 2001; Huizenga, Zhang, & Arens, 2001). Second, these indicators require domain knowledge in biometeorology and physiology and are not informative enough to provide useful implications for planning practice. Nevertheless, the assessment of unsteady outdoor thermal comfort

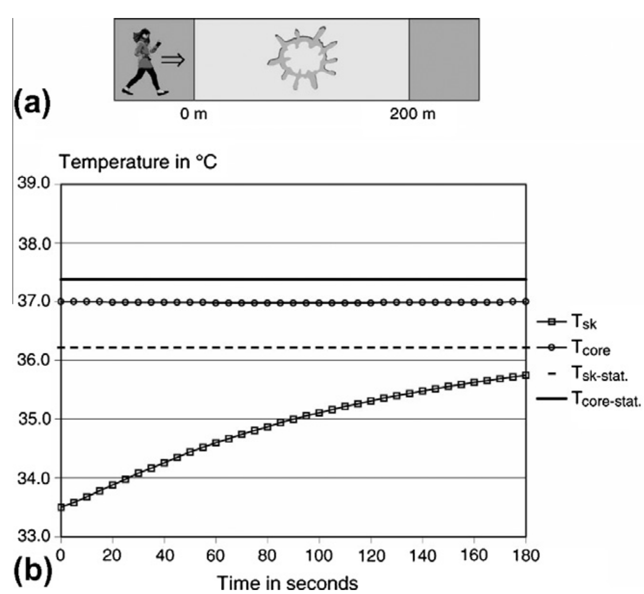

Fig. 1. An illustration showing the difference between a dynamic thermal adaptation process of a pedestrian and its steady-state condition: (a) scenario "sunny street segment"; (b) temporal variation of a pedestrian's physiological conditions, described by skin temperature (T_{skin}) and core temperature (T_{core}). T_{skin}-stat. and T_{core}-stat. are steady-state skin temperature and core temperature, respectively. Source: Höppe (2002).