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Research Paper

Assessment of pedestrian wind environment in urban planning design

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HIGHLIGHTS

- A space-based pedestrian wind environment assessment system can be applied in urban planning.
- Tolerance factor can be incorporated in the mechanical comfort and danger model for pedestrians.
- CFD is a suitable technique to assist urban planners in evaluating pedestrian wind environment.

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ABSTRACT

Pedestrian wind environment is one of the urban physical environments that have a significant impact on the overall wellbeing of a city and its dwellers. It is important to be able to assess pedestrian wind environment in the urban planning design stage. Such assessment is intrinsically an in-design assessment and should be based on spatial analysis. The methodology developed considers the probabilistic nature of the assessment by determining an 80-percentile ambient wind speed as the boundary condition for wind environment simulation. The assessing criteria include mechanical comfort, safety, and amplification factor. Their threshold values are based on comparisons of existing criteria. In addition, the concept of tolerance factor, which takes into account the psychological effects of different urban spaces on people, is integrated into the assessment system. The assessment methodology can be used by urban planners in parallel with the process of designing urban physical spaces. A case study of the downtown area of an urban planning project near Lake Tai in China is conducted to demonstrate the application of the assessment methodology. Two limitations of the methodology need to be noted. First, it relies on CFD techniques to obtain the wind environment and therefore, the simulation must be conducted with considerable care and circumspection. Secondly, the methodology does not include the thermal and ventilation effects of pedestrian wind.

1. Introduction

One of the major consequences of urbanization is the increasing number of megacities all around the world, especially in East Asia, South America, and some African counties. For example, China alone has 13 cities with more than 10 million people in 2010 (City Population, n.d.) and therefore, its urbanization has been extensively studied (Cook, Gu, & Wu, 2012).

While rapid urbanization offers benefits in many ways such as providing better infrastructure, higher quality of education, generally more advanced health care, more convenient daily life, etc., it has not been immune to problems including the significant deterioration of the urban physical environment. The urban physical environment includes, but is not limited to, thermal environment, acoustical environment, lighting environment, and wind environment. These physical environments directly affect the overall wellbeing of a city and its dwellers. Examples of severe urban physical environmental problems range from those in the early industrial age (Aplin, 2012) to the latest so-called smog in Beijing, China (Coghlan, Marshall, & Slezak, 2013).

1.1. Natural wind environment and urban wind environment

Research into the wind environment is important for the work of urban planners, architects, civil and structural engineers, urban and building physicists, environmental scientists, real estate

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developers, city managers, and other stake holders. Although the meaning of wind environment seems to be self-explanatory, there are noteworthy differences between the pedestrian wind environment, natural wind environment, and urban wind environment that refer to the wind environment in different situations. Understanding the differences among them is the basis of this paper.

First of all, wind environment, in the most generic sense, is the condition of wind in an area with spatial and temporal distributions. Theoretically and mathematically speaking, wind environment can be described by Eq. (1).

$$\vec{v} = \vec{v}(x, y, z, t). \tag{1}$$

Here, the wind velocity at a certain location and a particular time is represented by a vector $\vec{v}$; x, y, and z are three Cartesian coordinates of the location; t denotes time.

In Eq. (1), the z coordinate represents the height above the ground at which the wind environment is of interest. For the pedestrian wind environment, 1.5 m is commonly used for the z value. Note that professionals in different scientific and engineering fields concern themselves with different z values. For example, urban physicists typically study the wind environment close to the ground. Structural engineers, when analyzing the wind force on high-rise buildings, consider the wind environment much higher than 1.5 m, sometimes over 100 m, above the ground. Urban climatologists focus on the wind environment at even higher altitudes. While wind environments at different levels all have impacts on cities, the pedestrian level wind environment is most important in urban planning design.

Another pair of wind environments that need to be differentiated are natural wind environment and urban wind environment. Our planet earth has had wind environment from the very first day when the atmosphere was formed, probably over four billion years ago. At that time, cities did not exist. This wind environment, without any disturbance from manmade cities, can be called natural wind environment. Urban wind environment refers to the wind environment in built-up cities. It is an altered natural wind environment by the existence of cities, mainly buildings and to a less extent other objects such as trees.

To develop a pedestrian wind environment assessment system suitable for urban planning, it is obvious that the absolute magnitude of urban wind must be considered. However, it is less obvious that the difference between the natural and urban wind environments should be equally emphasized. This difference reflects how much the natural wind environment is altered by the city, thus an appropriate parameter to capture the effect of urban planning design on the natural wind environment.

The focus of this study is on the pedestrian level urban wind environment. To avoid verbosity, it is referred to as pedestrian wind environment throughout the paper.

1.2. Importance of urban wind environment

The urban wind environment is of great interest in many aspects of science and engineering. Structural engineers and researchers have long studied urban wind environment because wind induced lateral load is one of the primary loads a structure must resist, especially for high-rise buildings, long-span bridges, arenas, and sports stadiums. The pioneering works of Davenport (1961) and others put wind engineering onto the map of modern applied science and engineering. Another important group of professionals who are interested in urban wind environment are urban and building physicists who generally concern themselves with the pedestrian wind environment at lower levels than structural engineers. Wind effects, wind comfort, wind danger, and wind climate are the subjects of interests (Blocken & Carmeliet, 2004). Other professionals such as climatologists also study urban wind environment, sometimes with different focuses and other times overlapping interests.

Assessment of urban wind environment should start with analyzing what aspects of cities it affects? A holistic view should be taken to answer this question. Urban wind environment affects at least the following aspects of city performances.

- Mechanical comfort of people,
- Thermal comfort of people,
- City ventilation,
- Natural ventilation potential for buildings,
- Structural wind loading on buildings,
- Other ecosystems.

Even if we only focus on pedestrian level urban wind environment, at least three of the above six aspects remain, i.e., mechanical comfort of people, thermal comfort of people, and city ventilation. Examination of important review works and comparative studies in this field (Blocken, Hooff, & Janssen, 2013; Koss, 2006; Ratcliff & Peterka, 1990) shows that most pedestrian wind assessment studies only address mechanical comfort, with a few exceptions considering other factors such as thermal comfort (Soligo et al., 1998; Szücs, 2013).

1.3. Assessing pedestrian wind environment from an urban planning design point of view

To assess pedestrian wind environment in urban planning design, the difference between post-occupancy assessment and in-design assessment needs to be clarified. Post-occupancy assessment is defined as examination of the effectiveness for human users of occupied and designed environments (Reizenstein & Zimring, 1980). Although its definition does not exclude cities, most publications use this term on buildings. Post-occupancy assessment of buildings has been a major research field. The assessment can be conducted to a variety of physical aspects, such as thermal environment (Gou & Lau, 2013), energy consumption (Bouchlaghem, Buswell, Crippsa, & Menezesa, 2012; Hokoi, Ogura, Fu, & Rao, 2013), subjective satisfaction (Hes, Jensen, Padovani, & Raj, 2011), and green building performance in general (Fowler, Henderson, Kora, & Rauch, 2010). Similarly, post-occupancy assessment can also be done to cities despite that the word “occupancy” is usually used on buildings. The essence remains the same, that is, to assess a whole or part of a city using data that can be collected after the city is built and occupied.

In-design assessment, on the other hand, intends to evaluate the performances of a building or a city in design stage. Clearly, in the design stage these performances cannot be physically measured. Instead, theoretical calculations or simulations are often used to quantify the performances based on the design. Results are obtained and evaluated to provide guidance for design adjustment and optimization. In essence, in-design assessment is based on predicting the performances of built environment. It should occur simultaneously with the design and play an important role in design evolution.

Comparing post-occupancy assessment with in-design assessment, the following observations can be made.

- Post-occupancy assessment is generally more reliable since it uses physical measurements to assess a building or a city. The quality of in-design assessment is highly dependent on the accuracy of performance calculation, prediction, and simulation.
- In-design assessment is generally more convenient and less time-consuming than post-occupancy assessment. It often relies on performance simulation techniques and therefore, can be completed in a relatively short period of time. On the contrary,