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Numerical simulation studies of the different vegetation patterns' effects on outdoor pedestrian thermal comfort

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Abstract

Vegetation has positive effects on the outdoor pedestrian comfort and thermal environment. Throughout the three numerical simulation experiments and a presupposition of a same total leaf area for all greening cases, the differences of vegetation patterns on the pedestrian thermal comfort have been studied with an evaluation index as (Standard Effective Temperature) SET . Firstly, in comparison with grass and shrub patterns, greening with tree does not always have better effects for improving pedestrian thermal comfort in summer in all directions around buildings. The reasons include the relatively negative function of tree to decrease the wind velocity and the hourly change of the sun's location. However, if considering the average SET around the pedestrian space, greening with tree is still better than others are. Secondly, the difference for the three vegetations for pedestrian comfort is affected by the arrangements and orientation of buildings. Thirdly, there is an optimized pattern with a lower SET distribution for the configuration of trees (including the shapes and arrangements) around buildings. In this situation, the average SET in the pedestrian space has a slight difference and should be carefully compared for better outdoor pedestrian comfort.

Keywords: Numerical simulation; Vegetation; Outdoor thermal comfort; SET; Leaf area

1. Background

The urban thermal environment has been worsened in the past decades due to the fast development of urbanization as well as due to change of the underlaying structures and the

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increasing heat discharge from vehicles and buildings (Haider, 1997; Argiro and Marialena, 2003). The urban manager and researchers have been always seeking mitigating measures to reduce the effects of urban heat island in order to improve the outdoor thermal environment.

Planting is regarded as one of the most effective methods to improve the outdoor climate. Considering landscape design and the effects of vegetation on the outdoor thermal environment, there are generally three kinds of plants, namely tree, grass and shrub. Although it is easy to point out their different effects on the outdoor thermal environment, it is difficult to give a quantitative comparison for them or to find an optimal landscape scheme with an effective vegetation-configuration pattern. For example, practice has proved that a tree effects the surrounding environment, including decreasing wind velocity, blocking sunshine and moderating air humidity. These effects counteract with the pedestrian thermal comfort in summer. Due to the inadequate understanding mentioned above, clear suggestion cannot be given for the landscape design (Argiro and Marialena, 2003; Mochida et al., 2005). Recently, there is a poor trend for greening design in landscape planning, which is just to provide a beautiful view-surface and has little contribution to improving the outdoor thermal environment in summer. One may wonder if there is a possible method to predict the quantitative effects of different vegetation-configuration patterns and then to optimize outdoor environmental design from the conceptive design phase. Recently, it has led to numerous researches on this topic as one of the major concerns.

With the quick development of computational fluid dynamics (CFD) technologies because of the improvements in software and hardware, a pedestrian-level numerical simulation and prediction of the thermal environment around buildings have become possible. In order to reproduce the effects, the aerodynamics and thermodynamics functions of vegetation are also conducted into the flow, momentum and energy processes by coupling extra items into the basic equations (Michael and Heribert, 1998; Hagishima et al., 1999; Chen and Ooka et al., 2003). Based on the numerical experiments, a discussion has been carried out here in order to compare the effects of different greening patterns on pedestrian thermal comfort, including plant selection and configuration.

2. Introduction of a simulation platform

Here simulation platform for outdoor thermal environment (SPOTE) is adopted for the numerical study, consisting of an air model, a vegetation model, a underlying surface model and a general radiation calculation model SPOTE, validated by a field measurement in the summer of 2002 (Lin et al., 2005a, b), and could deal with the coupled calculation of radiation, convection, conduction and air flow when the plants exist. The details of the sub-models of SPOTE are introduced as below.

2.1. Air model

A standard k–ε model is employed here by applying extra terms in flow, momentum and energy equations for the aerodynamics effects of vegetation. The drag force of vegetation canopy is presented with a term F_i added in the i component of momentum equation, as well as F_k and F_ε added into the transport equations of turbulent energy (k) and energy dissipation rate (ε), respectively, for denoting the effects on turbulent flow field. These