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Modeling and calculation of solar gains through multi-glazing facades with specular reflection of venetian blind

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Abstract

A mathematical model is proposed for calculating the solar gains through the multi-glazing facades (MGFs) with venetian blinds considering specular reflection. Net radiation method is used to establish the solar radiation energy balance equations in the overall MGFs layers. Then, a mixed method combines ray tracing and radiosity methods is used to determine the optical properties of the venetian blind in this system. Numerical results are compared with the optical properties of venetian blind calculated by the radiosity method and the experimental results. The comparisons show that the proposed model results fit better with the experimental results. Some important impact factors on the total solar transmittance of the MGFs are analyzed including the venetian blind geometric dimension W/S ratio, the slat reflectance, the slat shining factor, the slat angle, and the sun profile angle. Moreover, the effect of the proportion of the beam radiation on the total solar transmittance is also considered. The impact of the W/S ratio, the slat reflectance, and the slat angle are not limitless, when the solar profile angle is greater than (90°-φ), the impact of them are not significant. Meanwhile, the impact of the shining factor and the proportion of the beam radiation depend on their intersection point. Before the slat angle intersection points, the higher the shining factor, the smaller the transmittance, but it is opposite for the proportion of the beam radiation.

Keywords: Multi-glazing facades; Venetian blinds; Solar gains; Mixed method; Experimental results; Impact factors

1. Introduction

Multi-glazing facades (MGFs) are one of the most popular envelopes in the modern buildings, especially in the commercial buildings for their good aesthetics, super visual comfort, and good acoustic. However, the overheating risk cannot be neglected due to large solar radiation energy transmits through the glazing facades in summer, such as in hot summer and cold winter region and hot summer and warm winter region in China (shown in Fig. 1).

MGFs are comprised of several glass layers with or without a shading device. An accurate optical model is essential for numerical simulation and load characteristics prediction of MGFs. MGF system without shading device, that is, inter-reflections will occur between the adjoining glazing layers. Therefore, the ray tracing method as described in EnergyPlus (2005) and ASHRAE Handbook (2005) is adopted to calculate the transmittance and reflectance. When the MGF system with a shading device, the net radiation method (ISO 15099, 2003; Zanghirella et al., 2011) is widely used to establish the energy balance equations for each layer and the recursion algorithm (Wright and Kotey, 2006) can be adopted to solve the equations. Nevertheless, the shading device layer has great influence on the overall optical properties of MGFs.

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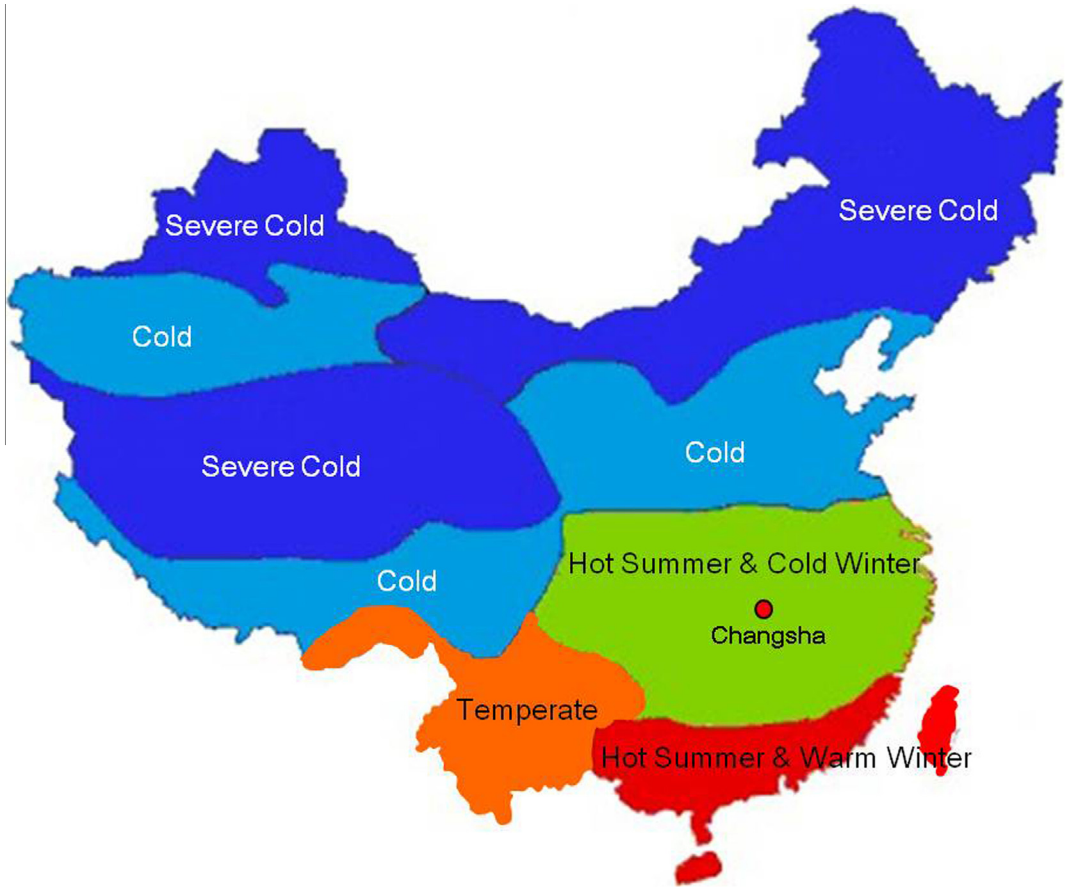

Fig. 1. Climatic regions in China.

As one of the most common shading devices, venetian blinds are widely used to remove the solar gains through the MGFs. However, its optical properties become complex since the beam-beam radiation, the beam-diffuse radiation, and the diffuse-diffuse radiation coexist simultaneously in the solar energy transmission process. It is necessary to establish an accurate model to calculate the optical properties of the MGFs with venetian blind.

A number of methods are proposed to calculate the optical properties of venetian blinds. The radiosity method (Kotye et al., 2009; Kotey and Wright, 2006; Xu and Yang, 2008; Glória Gomes et al., 2012, 2014) is the most common method used to describe the optical properties of venetian blinds. In this method the venetian blinds are treated as pure diffusers. When the beam radiation strikes on the slats of venetian blinds, the optical properties is characterized as the spatially averaged diffuse radiation. The radiosity method is also used by Chaiyapinunt and Worasinchai (2009a,b) and Chaiyapinunt and Khamporn (2013) to calculate the optical properties and the surface temperature of a curved slat venetian blind. However, the specular characteristics of the blinds in these studies are not taken into account. Yahoda et al. (2005) consider both the specular and the scattering characteristics of the slat, and the ray tracing method is used for the optical properties calculating, whilst the diffuse–diffuse radiation is not detailed described and the model is lack of the experimental validation. Pfrommer (1995), Pfrommer et al. (1996) also consider the scattering characteristics of the slat, and the beam-diffuse radiation is only considered the parts between the illuminated area and the outside and the inside. In the research, the calculation of the diffuse reflected transmittance is similar to the calculation of the beam-diffuse radiation. Chan and Tzempelikos (2012) proposed a hybrid ray-tracing and radiosity method based on the Monte-carlo approach. However, this is a time-consuming method and the calculations greatly depend on the computational speed. A state of the art method (Klems, 1994a,b; Klems and Warner, 1996) called bidirectional method is used to determine the optical properties of the complex fenestration systems (CFS). This method takes both the incident and emerging directions into account. Combining with the bidirectional transmission (or reflection) distribution functions (BTDF or BRDF) and the corresponding data (measured or calculated) is significant for the accurate modeling (Andersen et al., 2005; Andersen and Boer, 2006; Boer, 2006; Nilsson and Jonsson, 2010; McNeil et al., 2013). Although an accurate modeling result can be obtained, it is a complex and a time-consuming work to get the bi-directional scattering distribution functions (BSDF) data for researchers or manufacturers.