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Shortwave thermal performance for a glass window with a curved venetian blind

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Abstract

This paper presents a study of thermal performance for a glass window with a curved venetian blind installed on the indoor side in terms of heat gain in the shortwave part of radiation. The curved venetian blind, whose optical properties are considered nonspecular, is modeled as an effective layer. The mathematical model of the combined glass window and venetian blind is developed by combining the mathematical model of glass window and the mathematical model of a curved venetian blind using the matrix layer calculation method. The experiment is performed in a test room to measure the heat gain due to solar radiation passing through the glass window with a curved venetian blind installed in the shortwave part of radiation. The predicted results from the developed model are compared with the experimental results. The agreement between the predicted results and the experimental results is good. From the study it is found that installing a curved venetian blind to the glass window causes a significant reduction in heat gain compared to the plain glass window. The heat gain through the glass window with blind in the shortwave part of radiation (solar heat gain coefficient in the shortwave part of radiation (ShW SHGC)) is analyzed. It is found that the ShW SHGC is mainly affected by the slat properties, slat angle and solar profile angle. The glass window using blind with a lower value of slat reflectance, will have a smaller value of ShW SHGC. The slat distance also affects the ShW SHGC. The glass window using blind with a lower value of slat distance has a lower value of ShW SHGC. The effect of the slat curvature on the ShW SHGC is small when compared to the effect of other parameters. The effects of the investigated parameters on the ShW SHGC for diffuse radiation are similar to the effects on the ShW SHGC for direct radiation. When installing blind to different kinds of glass window other than clear glass window, it is found that the thermal performance is similar to the case of clear glass window. The magnitude of the ShW SHGC for the glass window with blind is also dependent on the optical properties of the glass window used. The glass window with blind using a lower value of the glass transmittance has a lower value of the ShW SHGC. The absorptance of the glass window has direct effect on the solar heat gain coefficient in the longwave part of radiation (LoW SHGC).

Keywords: Venetian blind; Glass window; Solar heat gain coefficient; Shortwave radiation; Thermal performance

1. Introduction

Commercial buildings, which usually have building envelope made of glass, receive plenty of heat gain into buildings from the incident solar radiation, especially in countries located in the tropic zone near equator. To remove this solar heat gain and maintain the thermal comfort for the occupants in the building, an air conditioning system is usually required. A large amount of energy is used in the air conditioning system to perform such tasks. But when the building is actually used, the occupants usually install the venetian blind as an indoor shading device to control the light transmission (prevent the glare) and protect the privacy of the occupants. Therefore the building envelope that receives solar radiation becomes the glass

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window with a venetian blind installed instead of the plain glass window alone. The venetian blind is considered as diathermanous (i.e. it transmits both shortwave and longwave radiation) and a nonspecular optical element. Much work has been done on heat transmissions through the glass windows with venetian blinds installed. But most of the works (Klems, 1994a,b; Klems et al., 1996; Klems and Warner, 1997; Collins and Harrison, 2004; Pfrommer et al., 1996; Chantrasrisalai and Fisher, 2004; EnergyPlus, 2005; Yahoda and Wright, 2004) deal with the flat slat blind. Khun (2006a,b) has studied on the solar control system including the venetian blind with an arbitrary shape of slat and its specular properties. Wright et al. (2008) developed a simplified method to calculate the thermal performance of the glass window with a shading device system. Chaiyapinunt and Worasinchai (2009a,b) have developed a mathematical model to calculate the shortwave optical properties for a curved slat venetian blind with thickness and a mathematical model to calculate the longwave optical properties for a curve slat venetian blind by including both the effect of slat curvature and the effect of slat thickness in the mathematical model. With an accurate model for the optical properties of the curved venetian blind, the thermal performance of the glass window with a curved venetian blind installed can be accurately predicted. Since the solar heat gain through the glass window with a curved venetian blind installed can be divided into the heat gain in the shortwave part and in the longwave part. To really understand the thermal performance of the glass window with a curved venetian blind installed, the effect of the related parameters of the system on the thermal performance should be separately investigated. Chaiyapinunt et al. (2005) have also shown that the heat gain in the shortwave part is one of the major effects on the thermal performance of glass windows in terms of thermal comfort for the occupants who live near the glass window. The understanding of the characteristics of the heat gain in the shortwave part is also an important part for the analysis of the thermal performance of the glass window with venetian blind installed in terms of thermal comfort as well. Therefore in this article the study of the effect of related parameters on the thermal performance of glass windows with a curved venetian blind installed in terms of heat gain in the shortwave part of radiation is performed.

2. Mathematical model for the glass window with a curved venetian blind installed

The venetian blind in this study is modeled as an effective layer. Fig. 1 shows the example of the fenestration system having a venetian blind installed as an interior shading device.

The expression for the heat gain through the fenestration system can be written as

$$q = \{\mathrm{SHGC}(\theta, \psi)\}I + U\Delta T \tag{1}$$

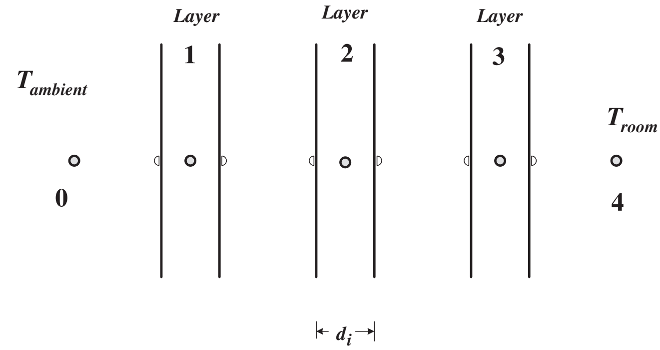

Fig. 1. The blind is modeled as an effective layer (layer 3) behind the double glass window (layers 1 and 2).

where q is the heat gain (W/m^2). SHGC is the solar heat gain coefficient. U is the overall heat transfer coefficient (W/(m^2-K)). ΔT is the temperature difference between the indoor and outdoor condition (K). I is the incident solar radiation (W/m^2). θ is the solar incident angle (degree). ψ is the azimuth angle (angle of the incident radiation measured from the horizontal axis on the plane of the glass window) (degree).

The solar heat gain coefficient for the combined glass window and the venetian blind (referred to as the complex fenestration by Klems (1994a)) can be written as

$$\mathrm{SHGC}(\theta, \psi) = T^{fH}_{\{1,M\}}(\theta, \psi) + \sum_{k=1}^{M} N_k A^{f}_{k,\{1,M\}}(\theta, \psi) \tag{2}$$

where $T^{fH}_{\{1,M\}}$ is the directional-hemispherical front transmittance of a fenestration system with M layers. $A^{f}_{k,\{1,M\}}$ is the directional absorptance of the kth layer in the system and N_k is the inward–flowing fraction of the absorbed energy for kth layer in the system. The solar profile angle (the angle of incidence in a plane that is perpendicular to the window and perpendicular to the slat direction) is also introduced in this analysis. The relationship between the solar profile angle and the incident angle and the azimuth angle can be written as

$$\phi_s = \tan^{-1}(\sin\psi \tan\theta) \tag{3}$$

where ϕ_s is the solar profile angle.

The expression of the solar heat gain coefficient for a complex fenestration system (glass window and a venetian blind) in Eq. (2) can be further divided into the solar heat gain coefficient in the shortwave part ($T^{fH}_{\{1,M\}}(\theta, \psi)$) and the solar heat gain coefficient in the longwave part $\left(\sum_{k=1}^{M} N_k A^{f}_{k,\{1,M\}}(\theta, \psi)\right)$.

Chaiyapinunt and Worasinchai (2009a,b) have shown that the optical properties of the venetian blind (considered as an effective layer) are dependent mainly on slat properties, slat angle, the nature of interreflection of the radiation between the slat surfaces and solar profile angle. The slats are assumed to be perfect diffusers and all the slats have the same optical properties. Using the assumption of perfect