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A mathematical model for calculating total transmission of solar radiation through shuttle louvers and experimental verification

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ABSTRACT

The main problem of previous methods for the calculation of total transmission of solar radiation through shading louvers is that they can only deal with flat slats and pure diffuse reflection. Taking the radian and specular reflection of louvers into consideration, a new model of total solar radiation transmitted through shuttle louvers was established and experimentally verified in this paper. Firstly, taking two adjacent shuttle louvers as the object of study, the new calculation model was established, and a computer program based on the model was developed in MATLAB, which can be used to study the impact of shape, size, rotation angle, and surface optical properties of shuttle louvers on the transmission of direct and diffuse radiation. Secondly, an experimental set-up equipped with integrating sphere was built and experiments were performed to verify the new model, with the results showing that the model predictions compared well with the experimental data. Finally, the calculation errors of two conventional methods, the "flat slat model" and the "pure diffuse reflection model", were analyzed, and the results showed that the "flat slat model" can cause considerable error and the relative error increases with the rotation angle of the louvers, and the "pure diffuse reflection model" gives overestimated results when the rotation angle is positive and underestimated results when the rotation angle is negative.

1. Introduction

Shading is a rational way of dealing with solar radiation in many conditions such as solar heat gain blocking and natural lighting of buildings [1]. There are various kinds of building shades that are commonly used, especially shuttle louvers, which get its name from its weaving-shuttle-like appearance. Shuttle louvers are made of aluminum plate with several strengthening ribs. Louvers can be rotated on its axis within −90° to 90° to achieve reasonable shading and day-lighting. Compared with other louvers, the obvious advantages of shuttle louvers include streamlined appearance, good strength and adjustable rotation angle [2].

Solar radiation irradiating on building envelope includes beam radiation, sky diffuse radiation, ground-reflected radiation, and diffuse radiation reflected from surrounding buildings [3,4]. Based on pure geometrical analysis, Athanassios [5] presented analytical equations of direct transmittance to calculate projected view fractions of venetian blinds. These equations only took direct light transmission into consideration. Parmelee and Aubele [6] developed a mathematical model of solar radiation transmission based on an analytical method, which could only be used to calculate the effective optical properties of flat slats. Pfrommer et al. [7,8] introduced a parameter named "shining factor" to improve Parmelee and Aubele's model [6]. However, Pfrommer's model still could not handle shuttle louvers. Simmler et al. [9] developed a model named "Simmler model", which could be used to analyze the relationship between effective optical properties and surface reflectivity of slats. Based on the "Simmler model", Van Dijk et al. [10,11] developed a software package named "Advanced Windows Information System" to calculate the optical and thermal properties of windows with shadings. This method was adopted by ISO 15099–2003 [12] and Energy-plus [13]. Gomes [14] considered the case of pure diffuse reflection to calculate the optical properties of sunlight and visible light through glazing systems with venetian blinds. Chan and Tzempelikos [15] presented a hybrid ray-tracing and radiosity method for processing luminous flux in spaces equipped with horizontal venetian blinds. Although this method took both specular and diffuse reflection of slat surface into consideration, it could still only handle flat slats. In general, the main problems of the previous methods for calculating solar radiation transmission are that they can only deal with flat slats and pure diffuse reflecting surfaces. For shuttle louvers, new model

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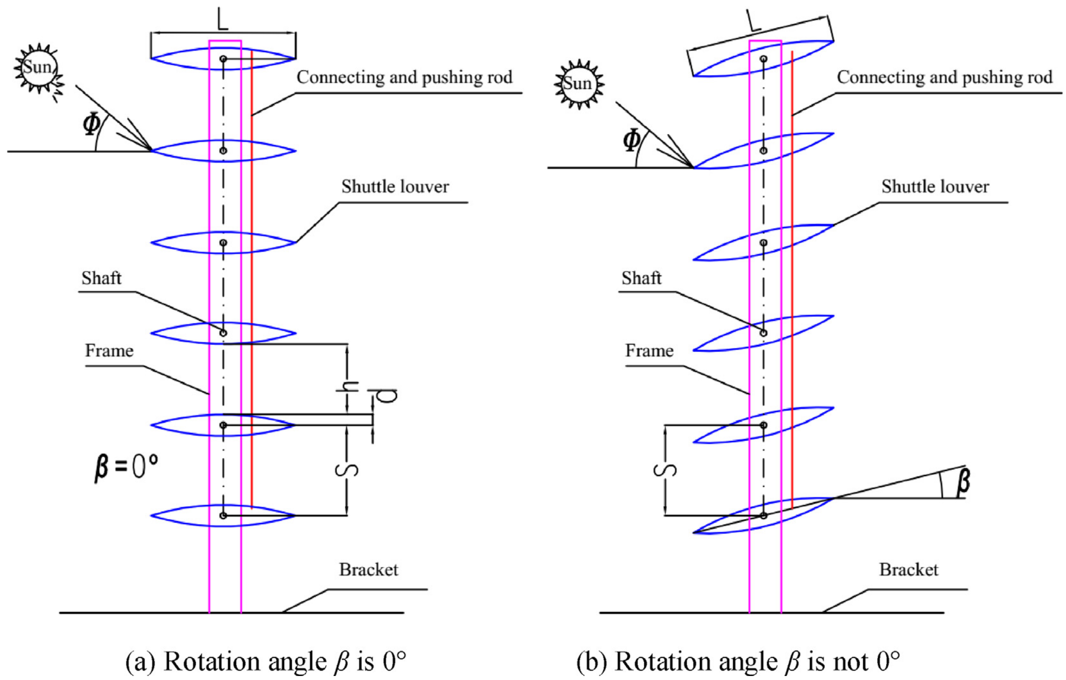

Fig. 1. The whole structure of a shutter louver shading device.

needs to be developed to overcome the shortcomings of the previous methods.

Many researchers studied experimental methods to verify the calculation models of shade systems. Chantrasrisalai and Fisher [16] put forward an in-situ experimental method to validate the optical model of a slat-type blind. Two sets of solar pyranometers were installed to measure ambient and indoor total radiation, and diffuse radiation, respectively. The pyranometers installed outside the test room were used to measure the incident solar radiation, and those installed inside the test room were used to measure the transmitted solar radiation through the test specimen. This method was also employed by Wang et al. [17] to validate their optical model of a complex multi-glazing facades system with venetian blinds, and the model predictions agreed well with the experimental results. However, this method is not suitable for shuttle louvers, because the dimensions of shuttle louvers are bigger than those of venetian blinds, and measurement uncertainties can inevitably arises from the inhomogeneity of the blind layer and the locations of pyranometers. Gomes et al. [14] carried out experiments to study the effect of venetian blinds on solar optical characterization of a fenestration system. Three irradiance sensors (LI-200) were installed behind the venetian blinds to reduce the measurement uncertainties caused by the inhomogeneity of the blind layer. The problem was that the spectral response of the LI-200 (370–1100 μm) used in the experiment did not include the entire solar spectrum, making the results unable to reflect the true solar transmission; besides, the blocking effect of irradiance sensors also led to measurement errors. Thus it is clear that new experimental method needs to be developed for shuttle louvers to solve the above-mentioned problems, such as the measurement uncertainties caused by the inhomogeneity of blind layer, the measurement uncertainties caused by the location of pyranometers, the loss of spectral response, and the blocking effect of irradiance sensors.

In this paper, both direct and diffuse transmission mechanisms of solar radiation between shuttle louvers are discussed, and then a calculation model is set up to describe the effect of shape, size, rotation angle, and surface optical properties of shuttle louvers on total transmission. A new experimental set-up equipped with integrating sphere was developed for studying the radiation transmission between shuttle louvers. The calculation results are experimentally verified, and also compared with the data in [12].

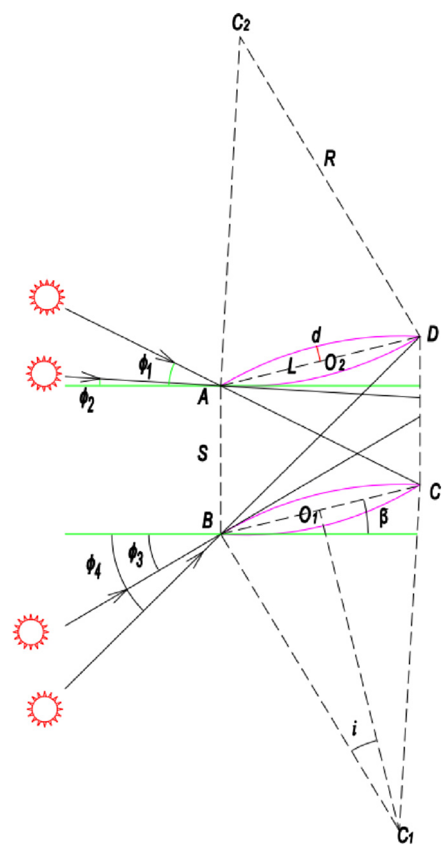

Fig. 2. Key parameters of shuttle louvers.