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Solar and visible optical properties of glazing systems with venetian blinds: Numerical, experimental and blind control study

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ABSTRACT

The increasing use of glazed areas in the building envelope can lead to high solar gains and glare problems that can strongly impact the entire building energy consumption, peak loads and indoor comfort. An important and fundamental strategy in sustainable building design for controlling solar heat gains and daylighting through fenestration is the use of shading devices. Therefore, it is recommended to use detailed models that can accurately estimate the optical properties of the different types of shading devices (such as roller blinds and venetian blinds) and include their effects in the glazing system analysis.

This paper describes a net radiation method for determining both solar and visible optical properties of glazing with shading devices, particularly venetian blinds. Some numerical results were compared with in situ experimental measurements carried out in an outdoor test cell. The experimental work included the measurement of illuminance and irradiance fluxes and the determination of the visible and solar transmission properties of the fenestration system. The agreement between numerical predictions and experimental results was better for overcast than clear sky conditions. Moreover, a venetian blind control strategy that blocks direct solar radiation, whilst enabling the transmission of diffuse radiation to indoors, is implemented.

1. Introduction

Large glazed building façades are widely used in contemporary architecture for their lightness, aesthetics, transparency and daylighting characteristics, but can also lead to high cooling demands and thermal and visual discomfort problems, particularly in regions with long cooling seasons where non-overcast sky conditions prevail, such as Southern European areas. Thus, it is of the utmost importance to devise strategies and methods of evaluation that incorporate both the thermal and daylighting aspects in a way that solar protection can be efficiently achieved without the impairment of daylighting conditions. An important strategy in sustainable building design for reducing the potential overheating and glare problems due to fenestration should be the conscious selection of glazing and shading devices, along with an efficient solar control [1–7].

The detailed knowledge of the solar and visible optical properties of glazing systems with shading devices is particularly important in any strategy aiming at improving the thermal and daylighting issues of the building fenestration and at preventing overheating and glare problems in occupied spaces. A general algorithm for the determination of all illuminance and irradiance fluxes transmitted, reflected and absorbed within a multilayered glazing/shading system, based on the net radiation method, is herein presented for the daylighting and thermal performance characterisation of buildings.

There are a number of methods for calculating the multilayer solar optical properties of glazing systems when composed of any number of specular glazing layers. Usually, a one-dimensional centre-glass analysis is used and applied to the view area of the window since the solar gain of the frame can be ignored in most of the cases [8]. One of the most popular methods is the Edwards' recursion algorithm based on the net radiation method [9]. A similar algorithm was developed by Wright [10] through the ray tracing method. However, these algorithms cannot be applied when a shading layer is present because part of the incident radiation can be scattered by the shading device, introducing non-specular transmission and reflection components. An extension to the Edwards' algorithm [9], to take into account shading devices, can be found in Ref. [11]. An approach of increased complexity, involving bidirectional optical properties in the modelling of the

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Fig. 1. Test cell (a) and fenestration system (b) used in the experimental study.

glazing/shading system layers, was proposed by Klems [12–14], and Klems and Warner [15]. Although this approach can improve the accuracy, the level of detail required by the model input is, in general, hardly compatible with the data quoted by manufacturers.

In this study, a more practical and straightforward approach is used, based on the assumption that each layer can be characterized by spatially-averaged and (solar and visible) wavelength-integrated optical properties. Furthermore, shading devices materials are assumed as perfect diffusers and, hence, incident direct solar radiation that is scattered by the shading is diffusely reflected and transmitted to indoors. This simplified approach was also adopted in Refs. [16,17]. Although some models consider the shading devices with specular reflection [18–22], experimental results [21,23] show that usually only about 10% of direct solar radiation is specularly reflected on slats, with the remaining 90% being diffusely reflected. The venetian blinds are among the most commonly used shading devices. Unlike roller blinds, the optical properties of venetian blinds are dependent on the slat angle and on the solar incident angle. Thus, some preliminary calculations are necessary to estimate the overall optical properties of venetian blinds so that they can be treated as additional layers of the fenestration system. Although the first attempt in modelling venetian blinds has been probably made by Parmelee and Aubele in the 1950s [18], based on the 2-D ray tracing technique, until recently, their implementation and detailed simulation in building energy simulation software has been often neglected [24]. However, in recent years, a great effort has been made to model the properties of venetian blinds, by using either the ray tracing method [20,25] or the net radiation method [16,17,23,26–30]. A summary of several studies related to windows with shading devices, where venetian blinds are included, can be found in Ref. [31]. In the present work, a model for estimating the optical properties of venetian blinds, based on the net radiation method, was developed to be embedded in the general algorithm for calculating the multilayer solar and visible optical properties of glazing/shading systems. Although the mathematics of the presented models are known from other studies [9,11,23,28–30], with different degrees of complexity, the integrated approach given in this paper, involving the calculation of all components needed for the complete study of a fenestration system, is less common. Furthermore, in this paper an extended use of the models is given, with their application not only to the solar but also to the visible wavelengths of radiation.

The numerical results, obtained with the proposed algorithm, are compared with experimental measurements carried out in an outdoor test cell, which include the measurement of illuminance and irradiance fluxes and the determination of the visible and solar transmission properties of the fenestration system.

The present model can be used for different combinations of types of glazing, shading systems and sun incidence angles, and is suitable not only for comparing different glazing/shading solutions but also for establishing blind control strategies. A venetian blind control strategy, to avoid direct solar radiation but enhance daylighting, is also implemented. A proper blind control strategy should minimize HVAC and artificial lighting energy consumption, while maximizing daylighting and view to outdoors. Frequently, these goals conflict and a judicious balance should be achieved between daylighting/views and glare/solar gains. To help designers in this task, solar charts with the recommended slat angles are presented for venetian blinds. This type of tools aims at supporting the design process of complex fenestration systems, and thus, contributing to a sustainable architecture and a more efficient use of energy in buildings.

2. Experimental set-up

The experimental campaign was carried out in an outdoor test cell (Fig. 1) at the National Laboratory of Civil Engineering (LNEC) in Lisbon (38°7′N, 9°1′W). The glazing/shading system used in the experimental study is approximately South oriented (deviated from South 22° in East direction). The test cell is 2.5 m height and 3.5 m length, with a total gap depth of 0.20 m. The glazing/shading system consists of (from outdoor to indoor): a single clear glass 5 mm; an outer air gap; a white venetian blind with horizontal movable slats with both slat width and slat spacing of 50 mm; an inner air gap; and a double glazing unit 6–16–5 mm, with a spectral selective low-emissivity coating on the outer pane. The slats are almost flat with radius of curvature higher than slat's width. The outer and inner gaps can be ventilated through eight sets of movable horizontal louvres (allowing for different ventilation schemes), four of them located in the outer pane and four in the inner one. A detailed description of the experimental set-up and measured data can be found in Ref. [32].

The test cell was fully instrumented with illuminance and irradiance sensors (LI-COR cosine corrected LI-210 illuminance sensors and LI-200 irradiance sensors) enabling the measurement of the relevant quantities for a complete solar optical characterisation of the fenestration system.

The complete set of measurements includes (see Fig. 2): exterior vertical global ($E_{0,S}^{D+d}$) and diffuse ($E_{0,S}^{d}$) irradiance and illuminance on the plane of the façade; interpane vertical irradiances and