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Reprint of "Assessment of approaches for modeling louver shading devices in building energy simulation programs"

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ABSTRACT

In this paper a ray-tracing method is developed to describe the global solar transmittance of louver shading devices. The method is integrated in the dynamic building energy simulation program TRNSYS to assess the cooling demand and required peak cooling power in a south oriented office room. The proposed integrated approach allows calculating the solar transmittance for each time step. As the method is quite complex and requires an important computational effort, this research contrasts the results against the performance of simplified modeling and implementation approaches to assess the performance of louver shading devices. The use of view factor models not accounting for reflections in the shading device underestimates the cooling demand and the peak cooling power. It is shown that representing the shading device as a fixed reduction factor, independent of orientation and shading typology is an unacceptable simplification. However, the use of a simplified implementation of shading factors based on ray-tracing calculations is possible within acceptable margins of error. Best results are achieved by implementing solar radiation weighted monthly averages allowing to estimate the cooling demand and peak cooling power within 3%.

1. Introduction

Exterior shading devices are very well suited to provide good protection against excessive solar radiation. They reduce the overall cooling load and lower the peak cooling power efficiently reducing the energy use and cost and the investment in expensive equipment for active cooling [1–4]. From an energetic point of view, the need for solar protection, however, depends on the actual energy demand. When heating is required, the shading device can be retracted or allow a maximum of transmitted solar radiation providing no glare is produced on critical areas like working stations in the case of office buildings. If cooling prevails, an efficient protection is required. A good understanding of the solar properties of shading devices is essential to conceive sustainable and energy efficient buildings.

This research focuses on the performance of exterior shading devices made of louvers. This shading system is used under different forms. Retractable venetian blinds that are used as internal or external shading are a well-known application, but contemporary designs also use different kinds of large fixed external louver systems made of e.g. aluminum.

The analysis of the performance of these devices differs substantially from more traditional screens as their performance not only depends on the solar properties of the used materials but also on the position of the sun with respect to the louvers. In order to capture this complexity, models predicting the solar transmittance of louver shading devices have to be integrated into building energy simulation (BES) tools in which typically simplified approaches are available for integrating shading devices. While most BES-tools can include angle dependent solar properties for glazing and solar screens, this is often less straightforward for shading devices with fixed elements such as louvers. Here, more advanced modeling techniques are required.

This paper first presents a literature survey in which an overview of models to calculate the solar properties of shading devices and approaches to implement these results into BES-tools are outlined. Subsequently the ray-tracing (RT) method that has been developed to calculate the instantaneous solar transmittance of louver shading devices is outlined. This RT-method is then integrated in the dynamic building energy simulation program TRNSYS to assess the cooling demand and required cooling power in an individual office room facing south. The RT-method is quite complex and requires an important computational effort. Therefore this research contrasts the results of this ray-tracing method against the results of simplified implementations and other modeling approaches to

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assess the performance of fixed louver shading devices. The results are compared with simple implementations typically found in less complex energy assessment tools based upon EN ISO 13790. In particular, the proposed method is compared with the implementation of the Flemish Energy Performance Regulation (EPR) [5].

2. Literature survey

2.1.1. Total solar energy transmittance (TSET)

The thermal impact of the facade system with exterior louvers is generally assessed by the total solar energy transmittance (TSET) or g-value, which is the sum of the short-wave solar transmittance (τ) and the secondary heat gain (q_i) divided by the incident total solar radiation (E_s) on the window system (Eq. (1)).

The fraction of solar transmittance (τ) is the ratio of the short-wave solar transmittance ($E_{T,sw}$) to the incident global solar radiation (E_s) (Eq. (2)) and $E_{T,sw}$ is the result of direct, diffuse and reflected short-wave irradiation (Eq. (3)). The direct component ($E_{T,dir}$) is often referred to as direct-to-direct transmittance. $E_{T,sw}$ and τ depend on the solar beam angle, the slat tilt angle, the slat geometry and the glazing and slat material properties.

$$\text{TSET} = g = \tau + \frac{q_i}{E_s} \quad (1)$$

$$\tau = \frac{E_{T,sw}}{E_s} \quad (2)$$

$$E_{T,sw} = E_{T,dir} + E_{T,dif} + E_{T,ref,dif+dir} \quad (\text{W/m}^2) \quad (3)$$

The reflected irradiation is produced from direct (beam) and from diffuse radiation and depends on the slat surface reflection coefficient (ρ) (Eq. (4)). The beam and diffuse irradiation produces both specular and diffuse reflection depending on the surface specular characteristics (Eq. (5)). When slat surfaces are considered to be Lambertian bodies, the reflected fraction from direct radiation is often referred to as direct-to-diffuse transmittance.

$$1 = \alpha + \rho + \tau_{slat} \quad (4)$$

$$\rho = \rho_{spec} + \rho_{dif} \quad (5)$$

The secondary heat gain (q_i) is the portion of the absorbed energy by the louvers and glazing layers transferred to the interior space through long-wave radiation and convection (Eq. (6)).

$$q_i = q_{lw} + q_{conv} \quad (\text{W/m}^2) \quad (6)$$

2.2. TSET calculation methods

Several mathematical models exist to calculate the TSET through slat-type shading devices located at the interior and exterior side of the facade [6–15] and integrated between the glass panes [16]. Most of these models were developed to be integrated into BES-tools as part of the description of the solar optical and thermal characteristics of multilayer shading and glazing systems.

The effect of planar shading devices – like overhangs and awnings – on the solar transmittance through glazing facades can be calculated with relative straightforward geometrical algorithms. However, complex physical phenomena need to be described in facades with non-planar scattering and air-permeable shadings like louvers and blinds accounting for the interaction between the environment, the slats, the glazing pane(s) and the interior. For a given shading/glazing facade system multiple time and angular dependent factors like the direction of the incident solar radiation, the sky and wind conditions, and the optical characteristics of the different layers of the facade system influence the TSET.

As a result of this complexity also models to calculate TSET are quite complex. Therefore, efforts on developing TSET models through slat-type shading devices for integration in BES-tools have been directed toward achieving accuracy while reducing the computational load. Based on assumptions and on sensitivity analyses, some simplifications have been made concerning optical and geometrical properties of the slats as well as concerning the time and angular dependency of the TSET. Some of these simplified models have been integrated into BES-tools like TRNSYS [17], ESP-r [18] and TAS [19] while a less simplified model, based on the work of Simmler et al. [20], has been implemented in EnergyPlus [21]; which is similar to the slat model in the standard EN ISO 15099. These simplifications can be split up in simplifications for calculating the direct solar gains and for the secondary gains.

2.2.1. Direct solar gains simplifications

The most common simplification on the calculation models is to consider the TSET as a one-dimensional problem. The shading system is considered infinite and there is no effect of the facade height and length on the solar and long-wave transmittance. In this type of models, each slat is considered to receive the same irradiation regardless of its position and not accounting for possible short cuts along the sides of the shading system. The TSET is mostly calculated for a single cell between two slats located at the centerpoint of the glass.

A commonly used geometrical simplification is considering the slat to be planar and with no thickness. This may cause overprediction of the fraction of the direct solar irradiation, especially when the solar and slat angle are parallel. To overcome this, several models include the slat thickness as a correction factor, increasing the shaded fraction according to the actual shaded thickness formed by the combined slat and solar angle. The model of Parmelee and Aubelee [6] explicitly and implicitly applies the correction factor for the direct and diffuse radiation respectively. In the model of Simmler et al. [20] used in EnergyPlus the correction factor is applied for both direct and diffuse and their respective reflection fractions.

Chantrasrisalai and Fisher [22] used both models to assess the effect of the slat thickness on the TSET. They compared flat, zero thickness slats with flat slats having a slat thickness to slat spacing ratio of 0.1 and found that the error associated with neglecting the slat thickness can be as high as 15% for the peak direct-to-direct transmittance. For typical interior blinds – with slat thickness to spacing ratio of 0.012 – however, Kotey et al. [14] show that slat thickness correction models, as the one developed by Parmelee and Aubele [6], have a minimal effect on the effective optical properties of the blind.

Pfrommer et al. [7] demonstrate that slat curvature on typical interior blind and exterior louver systems should be accounted for when the slat radius curvature is smaller than the slat width. Also Chantrasrisalai and Fisher [22] performed a comparison to assess the influence of the slat curvature parameter on the TSET. By using the model of Pfrommer et al. [7] and Pfrommer [23], flat, zero thickness slats are compared against curved slats having a slat curvature radius to slat width ratio of 1.0. They found that the slat curvature can have a significant effect on both the direct-to-direct and the direct-to-diffuse transmittances depending on the slat and profile angles. The slat curvature has no effect on the direct-to-direct transmittance for +45° slat angle case. However, the curvature correction reduces the peak direct-to-direct transmittance by more than 15% for both 0° and −45° slat angle cases. The model of Simmler and Binder [13] also includes a correction for slat curvature. They compared a model validated against laboratory and outdoor measurements with the planar model of ISO 15099. It was shown that modeling the slat as planar can produce errors as high as 15% for the direct fraction of the TSET when beam direction is parallel to the slat surface. In addition, Kotey et al. [14] improved the model of Yahoda and Wright [10] by accounting for slat curvature for a