ASSESSMENT OF MODELING APPROACHES FOR LOUVER SHADING DEVICES IN OFFICE BUILDINGS

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ABSTRACT

The presented paper focuses on the performance of exterior shading devices made of louvers. 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 tools. A ray tracing method has been developed to describe the global solar transmittance of louver shading devices. Consecutively, this method is integrated in the dynamic building energy simulation program TRNSYS to assess the cooling demand and required cooling power in a south oriented office cell. The proposed integrated approach allows calculating the solar transmittance for each time step. The method however is also quite complex and requires an important computational effort. Therefore this research contrasts the results of this ray tracing method against the performance of other modelling approaches to assess the performance of louver shading devices in dynamic building energy simulation programs. It is shown that representing the shading device as a fixed reduction factor, independent of orientation, is an important simplification and is insufficient to incorporate the complexity of the performance and control of exterior louver systems. Deviations up to 102% were found for the cooling demand and up to 72% for the cooling power. The use of view factor models typically underestimate the cooling demand by up to 36% and the cooling power by up to 26%. The use of a simplified implementation of shading factors, however, is possible within acceptable margins if the results of a ray tracing calculation are implemented in a building energy simulation tool. Implementing the results of a ray tracing calculation of one representative average or sunny day reduces the deviations to 14% for the cooling demand and 18% for the cooling power. Performing additional ray tracing calculations for typical heating or cooling conditions or for every month further reduce the deviations to the order of 10% to 5% for the cooling demand and power respectively.

INTRODUCTION

Exterior shading devices are very well suited to provide good protection against excessive solar radiation. The need for this protection, however, depends on the actual energy demand of the building. When heating is required, the shading device should be retracted or allow a maximum of transmitted solar radiation. If cooling prevails, an efficient protection is required while allowing daylight inside the building. In order to capture this complexity, models predicting the solar transmittance of louver shading devices have to be integrated into building energy simulation tools (BES). Typically only simplified approaches are available for integrating shading devices in BES-tools. For all shading devices, solar properties depend
amongst others on the position of the sun. While most BES-tools can include angle dependent solar properties for glazings and solar screens, this is often not the case for shading devices with fixed elements such as louvers. Here, more advanced modelling techniques are required.

In this work a ray tracing (RT) method has been developed to calculate the instantaneous solar transmittance of louver shading devices. This RT-method was integrated in the dynamic building energy simulation program TRNSYS to assess the cooling demand and required cooling power in an office cell. 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 modelling approaches to assess the performance of fixed louver shading devices. The results are compared with simple implementations as can be 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) [1].

**METHODOLOGY**

**Shading device models**

The solar radiation transmitted through vertical louver systems consists of two parts: direct solar transmittance (direct and reflected short-wave radiation) and secondary heat transfer (long-wave radiation, convection and conduction). In this work we will focus on the first part as it dominates the solar transmission of shading devices in buildings that have insulating glazing units. Two models are used to calculate this solar transmittance: (1) The first model uses a forward ray tracing method based on the work of Rooftoof [2]. This model calculates the net transmitted direct and diffuse fraction accounting for specular and diffuse reflection on the louvers. (2) The second model uses a view factor method (VF) similar as used in Safer [3] where the transmitted fraction of the direct solar radiation is calculated as the glazing area that is not shaded multiplied by the impinging direct solar radiation. The shaded fraction is determined by a geometrical calculation of the shading pattern on the window based on the position of the sun. The diffuse solar fraction is calculated as the amount of the sky that can be seen by the window multiplied by the incoming diffuse solar radiation. As this method does not take into account multiple diffuse or specular reflections it generally underestimates the transmitted solar radiation. The results are expressed as a Shading Factor (SF) which is defined as one minus the ratio of the net transmitted solar radiation on the receiver over the total incident solar radiation. Although the ratios for direct and diffuse radiation are calculated separately, it is chosen to express SF as a combination of both ratios as this suffices for the used BES-tool (see further).

In this paper an elliptic curved louver shading device is calculated (diffuse reflectance = 0.643, direct reflectance = 0.689). The louver width is 0.2 m, thickness is 0.04 m, louvers are separated 0.2 m from each other. The distance between the shading device and the outer glazing surface is 0.09 m. The results are calculated for two louver positions: one horizontal position (0 deg) and a louver inclination of 30 degrees compared against the horizontal position (30 deg).

**Building simulation model**

A thermal model of a typical office cell (H x W x L = 2.8 m x 2.7 m x 4.0 m) with south-facing façade (glazed area is 2.43 m²) has been implemented in the dynamical simulation program TRNSYS 16.1 [4]. The opaque parts of the façade have a U-value of 0.56 W/(m²K). The window consists of an insulating glazing (85%, U-value equals 1.21 W/(m²K), g-value equals 0.625) and a frame (15%, U-value equals 2.00 W/(m²K)). The “multi-zone building”,
TYPE 56 of TRNSYS is used to model the energy demand of the office zone. Simulations are done for a typical moderate Belgian climate. The hygienic ventilation rate equals 22 m³/h per occupant (IDA 3 according to EN 13779) and is provided by a balanced mechanical ventilation system. The air supply temperature is 16°C throughout the year. The ventilation system as well as the heating and cooling system operate during office hours from 08:00 a.m. till 06:00 p.m. on workdays (from Monday till Friday). Set points for heating and cooling are 21 °C and 23 °C respectively. The internal heat gains for appliances and lighting are estimated at 260 W per occupant. The cooling demand and power are expressed as the net sensible cooling demand calculated for the considered office. It does not include the energy needed to condition the ventilation air.

In order to implement the solar properties of the shading device into the building simulation model, the previously defined SF is used. The SF reduces the solar radiation impinging on the window. In such a way, only the reduction due to a lower transmitted solar radiation is considered and indirect solar gains by the heating of the shading device are not accounted for. However, the effect is estimated to be small for current highly insulating glazings. Different methods were used to implement the SF in the simulations.

(1) A first method uses the hourly values that are calculated with the above described RT-model and VF-model. This method takes into account the full variation of the transmission of solar radiation due to the changing solar position. The RT-model combined with the use of hourly SFs will be further referred to as reference results. (2) A second method uses a fixed SF for the entire simulation. Distinction is made between different approaches to obtain this fixed value. A first approach is to use a default value. In this paper the results are compared against a fixed SF of 0.50 as proposed by the Flemish EPR [1]. The following approaches use a yearly average of the SF as calculated with the RT-model. Both a simple arithmetic average (second approach) and a weighted average (third approach) are implemented. Weighting factor for the latter is the incoming solar radiation. Using a fixed value treats the heating and cooling season in the same way. As a result some important physical phenomena are disregarded: during heating season solar positions are low resulting in lower than average SFs. Using an average SF hence overestimates both the heating demand and the cooling demand. (3) Therefore, the third method makes distinction between the heating and cooling season. For both seasons an average and weighted average value is calculated. (4) The fourth method calculates an average and weighted average for each month. As most simplified energy calculation methods, such as the Flemish EPR, use a month as time-step, this represents the most accurate approach available for such methods.

In the above, the SF is determined for each hour of the year. As the hourly calculations and especially the RT-calculations require quite some computation time, it is further examined what the influence is of simulating only a limited number of days to determine the SF. The following approaches were used to specify these days: (1) an overcast day in midseason in an attempt to simulate the most average situation, (2) the sunniest day in winter and summer in an attempt to have the right characteristics when it matters most, and (3) the sunniest day of each month.

**DISCUSSION**

Figure 1 compares the results of the different methods and approaches to calculate the SFs based on the full set of calculations. It is shown that on average the louver inclination of 30 degrees offers 12% (VF-method) or 21% (RT-model) more protection than the horizontal position. Also the method used to calculate the SF shows similar ranges of variation: the VF-method predicts a 23% better protection than the RF method for horizontal louvers. For an inclination of 30 degrees this is 14%. The evaluated method to calculate the SF hence
introduces errors of the same magnitude as the influence of the inclination angle. As a logical result of the lower solar position during winter, the SFs are higher than average for the cooling season and lower than average for the heating season. The results however depend on the inclination angle: the deviations are more pronounced for the horizontal louvers than for the louvers with a 30 degree inclination. Focussing on the differences between the averages calculated as arithmetic mean versus the solar radiation weighted averages reveals that the differences are smaller than 4%. Focussing on the influence of simulating only a limited number of days to determine the SF, Figure 2 shows for all three approaches the average (arithmetic mean) and solar radiation weighted average SF. Compared against the averages based on the full hourly values (see Figure 1), the difference are typically smaller than 5% if the corresponding values are compared. This suggests that the full hourly calculations of the SF may be replaced by calculations of a set of typical days.

Figure 3a shows the results for the annual cooling demand of the office. It is clear that using a fixed value (SF = 0.5) overestimates the cooling demand regardless of the louver inclination. Compared against the reference results, the annual cooling demand is overestimated with 53% (0 degrees) and 102% (30 degrees). Also the effect of the inclination angle is clearly visible. For the reference results, the louver shading with an inclination of 0 degrees yields a cooling demand that is 32% higher than that with an inclination of 30 degrees. Comparing the VF-model results against these of the RT-model shows that the former underestimates the cooling demand. As a result of not taking into account reflections, the cooling demand is underestimated by 33% (0 degrees) and 28% (30 degrees) compared against the RT-model.

![Figure 1](image1.png)  
*Figure 1: Yearly averages of the shading factor as a function of the calculation method and slat angle position, based on the full hourly set of SF calculations.*

![Figure 2](image2.png)  
*Figure 2: Yearly averages of the shading factor as a function of the calculation method and slat angle position based on specific days.*
Focussing on the different methods to implement the SF into the BES-tool shows that, apart from the cooling demand calculated with the fixed EPR value, all results have a relative small deviation from the reference results for a given inclination. The deviation is smaller than 12% for an inclination of 0 degrees and smaller than 8% for the inclination of 30 degrees. Implementing the yearly average SF factor gives the highest deviations: an overestimation of the cooling demand with 12% (0 degrees) and 8% (30 degrees), indicating that the SF is underestimated during cooling season. Using a different average for heating and cooling season partly corrects this problem: the overestimation of the cooling demand is reduced to 9% (0 degrees) and 7% (30 degrees). Further refining the averaging period to one month reduces the deviations to 8% (0 degrees) and 6% (30 degrees).

Using the arithmetic mean as the average has the disadvantage that all hourly SFs have the same weight. By calculating the solar radiation weighted average, SFs that are more relevant receive more weight. Implementing a weighted average SF factor results in an overestimation of the cooling demand with 5% (0 degrees) and an underestimation of 8% in case of an inclination of 30 degrees. Further refinement of the averaging period to heating and cooling season or months reduces the deviations to less than 3%.

Figure 3b shows comparable results for the maximum cooling power. The fixed EPR value (SF = 0.5) largely overestimates the cooling power with respectively 49% and 72% for an inclination of 0 and 30 degrees. The different methods to implement the SF into the BES-tool show a somewhat higher maximum deviation (16%) from the reference results in case of an inclination of 0 degrees but somewhat lower (5%) in case of an inclination of 30 degrees. As for the cooling demand, the VF-model underestimates the cooling power by up to 26% (0 degrees) and 21% (30 degrees) compared against the reference results of the RT-model.

Figure 4a compares the results for the annual cooling demand of the office in case of SFs determined based on daily sets of the RT-calculations with the full hourly reference results. The SF calculations based on the average day (average or sunny day) show the largest deviations for both cooling power and demand. The weighted averages perform better than the arithmetic averages. It is further shown that the results depend on the inclination angle of the louvers. Although the average SFs only show small differences (Figure 2), especially the cooling power and demand of the horizontal louvers has a more important variation. The cooling power has a deviation up to 18% and the cooling demand 14% compared against the full hourly reference results. For the inclination of 30 degrees this is 4% and 5% respectively.

![Figure 3: Annual cooling demand (a) and cooling power (b) as a function of the SF calculation model and slat inclination. Results based on full set of hourly SF calculations.](image-url)
Figure 4: Annual cooling demand (a) and cooling power (b) as a function of the SF calculation model and slat inclination. Results based on daily set(s) of hourly SF calculations.

CONCLUSIONS
The presented paper assesses the influence of different models and approaches to simulate the performance of exterior louver shading devices on the cooling demand and power of a south oriented office cell. As a reference a full hourly forward ray tracing method is used. It is shown that representing the shading device as a fixed reduction factor, independent of orientation, is an important simplification and is insufficient to incorporate the complexity of the shading performance of exterior louver systems. Deviations up to 102% were found for the cooling demand and up to 72% for the cooling power. Also the use of view factor models cannot be defended as they underestimate the cooling demand by up to 36% and the cooling power by up to 26%. The use of a simplified implementation of SFs, however, is possible within acceptable margins if the results of a ray tracing calculation are implemented in a building energy simulation tool. Implementing the results of a ray tracing calculation of one representative average or sunny day reduces the deviations to 14% for the cooling demand and 18% for the cooling power. Performing additional ray tracing calculations for typical heating or cooling conditions or for every month further reduce the deviations to the order of 10% to 5% for the cooling demand and power respectively.

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REFERENCES