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Experimental And Numerical Analysis Of Modelling Of Solar Shading

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Abstract

The use of solar shading in future low energy office buildings is essential for minimizing energy consumption for building services, while maintaining thermal conditions. Implementing solar shading technologies in energy calculations and thermal building simulation programs is essential in order to demonstrate the effect of adaptive solar shading. In order to document the benefits of the shading technology, the description of the shading device in the thermal building simulation software must be described at a reasonably accurate level, related to the specific solar shading device.
This research presents different approaches for modeling solar shading devices, demonstrating the level of accuracy in relation to measurement conducted in a full-scale façade test facility at Aalborg University. The research bridges the gap between increased complexity of solar shading technologies and the use of these technologies in thermal building simulation software.

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Keywords: Glazed façade; solar shading; venetian blind; dynamic modeling

1. Introduction

In order to reach zero-energy buildings for future office buildings, the use of adaptive envelope technologies is a necessity. The use of adaptive solar shading enables the control of irradiance in order to minimize energy demand for cooling, maximize passive solar heating for a reduction in energy demand for heating and optimize light transmittance for minimizing energy demand for artificial lighting while avoiding glare. As the user-pattern of office buildings tends to follow the same pattern as irradiation, presence during daytime hours, and away during night time hours, the cooling demand for office buildings is created as a sum of the internal heat load from people, equipment and lighting and external the heat load. The latter consists primarily of irradiance. The contribution of heat load from high outdoor

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temperatures is a function of the facades heat transfer coefficient. As the building's façade become more airtight and the maximum requirements for the structural parts U-value are tightened, the effect of high outdoor temperatures in relation to the cooling demand is considered a minimum.

Use of solar shading technologies for lowering energy demand for cooling is described in [1] as being part of a solution for lowering the energy transport through the façade, which potentially can reduce the cooling demand to near 0 kWh/m² pr. yr. The use of dynamic solar shading is a necessity for reducing the energy demand for cooling demand whilst maintaining a high level of passive solar heating. Furthermore the use of dynamic solar shading enables a high daylight level within the perimeter of the façade. [2] describes the potential of using static and dynamic solar shading for reducing the energy demand for cooling and artificial lighting.

The product development of solar shading is tested in a great deal when looking across the literature. The performance of individual solar shading technologies is shown, but as described in [3] the need for standardization of the calculation procedure is needed for documentation of solar shading technologies. [3] reviews the different methodologies for describing the optical properties of solar shading. In general there is agreement in the modeling of the direct-direct shading coefficient using the geometric method. The direct diffuse shading coefficient is modeled through the use of view factors between surfaces.

There is a gap in the current knowledge of solar shading technologies when describing these in thermal building simulation programs. The typical description of solar shading technologies are described as a function of incident angle [4]. The understanding of the performance of solar shading technologies from experiments compared with different detailing levels of the solar shading technologies is necessary.

The goal of this paper is thus to test different detailing methodologies for description of solar shading technologies in thermal building simulation software comparing the calculations with full scale experiments. The solar shading combined as a total shading factor or split into diffuse and direct shading factors and furthermore described as a fixed factor, as a function of incident angle, or absolute solar position will be analyzed. The description of the shading coefficient using different methodologies for description of the radiation from the different cloud covers will be investigated.

2. Method

The total shading factor is calculated as shown in Eq. (1), calculated as and irradiance weighted fraction of the irradiance reaching the façade including and excluding shading.

$$Fs = \frac{Fs_b I_b + Fs_d I_d + I_r}{I_b + I_d + I_r} \tag{1}$$

where F_s is solar shading factor, F_{sb} is direct solar shading factor, F_{sd} is diffuse solar shading factor, I_b is direct incident irradiance, I_d is diffuse incident irradiance, I_r is reflected incident irradiance.

The shading factor for direct radiation is calculated by geometric calculation of sunlit area versus total area as shown in Eq. (2). The calculation of the sunlit area is a sum of the direct-direct radiation and direct-diffuse radiation transmitted through the solar shading.

$$Fs_b = \frac{A_{w,s}}{A_w} \tag{2}$$

Where $A_{w,s}$ is shaded window area A_w is total window area.

The direct-direct irradiance is calculated based on the fraction of the irradiance being transmitted directly through the solar shading, relating the directly sunlit surface area with the total surface area. The calculation of the direct-diffuse irradiance is calculated based on the shading materials optical properties and view-factor between the shading surfaces and the glazing. The calculation process is shown in Eq. (3) and (4).

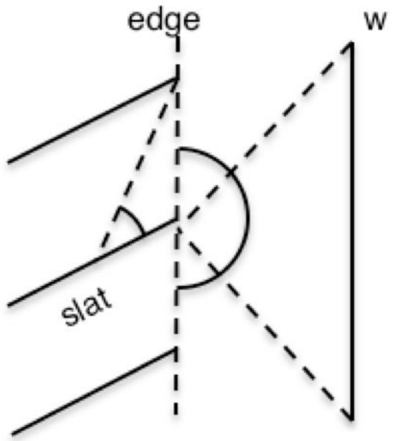

Fig. 1. View-factor from the solar shading technology to the surface w.

$$A_{w,s} = Fs_{b,dir-dir} A_w + Fs_{b,dir-dif} A_w \tag{3}$$

$$Fs_{b,dir-dif} = \frac{A_{slat,s}}{A_{slat}} \left(\rho_{slat,F} \Psi_{slat,F-edge} + \rho_{slat,F} \rho_{slat,B} \Psi_{slat,F-slat} \Psi_{slat,B-edge} \right) \Psi_{edge-w} \tag{4}$$

Where $A_{w,s}$ is shaded window area A_w is total window area. ρ is reflectance of window, Ψ is the viewfactor. Subscript "slat, F" is front side of slat, "slat, B" is back side of slat, "edge" is Edge of solar shading (figure 1).

Using the calculation software ParaSol [5] developed at Lund University enables the calculation of the hourly to yearly performance of standard shading technologies used on vertical surfaces. The calculation procedure is similar to the methodology used in ISO 15099. The program calculates the total solar shading performance of the shading technology taking into account the location of the solar shading technology in relation to the window.

Since the total shading factor calculated using [5] also contains factors of location near the window, the specifications derived from the results from [5] needs to be analyzed for dependent factors in order to determine the shading coefficients of the solar shading technology, independent of location near the window. The energy balance of the window system is therefore of interest with regards to determining the effect of the parameters involved and how they influence the inner surface temperature of the window system.

In order to validate the performance of the calculation methodologies, experiments have been conducted in the test facility "The Cube", at Aalborg University, see figure 2. The test facility has two identical rooms facing south, with the internal dimension of 5.66 × 2.46 × 1.65 m³ (H×W×D). Each of the entire window systems facing south has a size of 1.5×4 m². There are two operable windows, one large window in the middle and a filling at top of the window system. The operable windows facing south has a size of 1.5×0.5 m² including frame area, and the middle window has a size of 1.5×2.2 m². The filling at the top of the window system has a size of 1.5×0.8 m². The period of measurements is conducted in middle of February 2011 with cold outdoor temperatures and low solar irradiation.

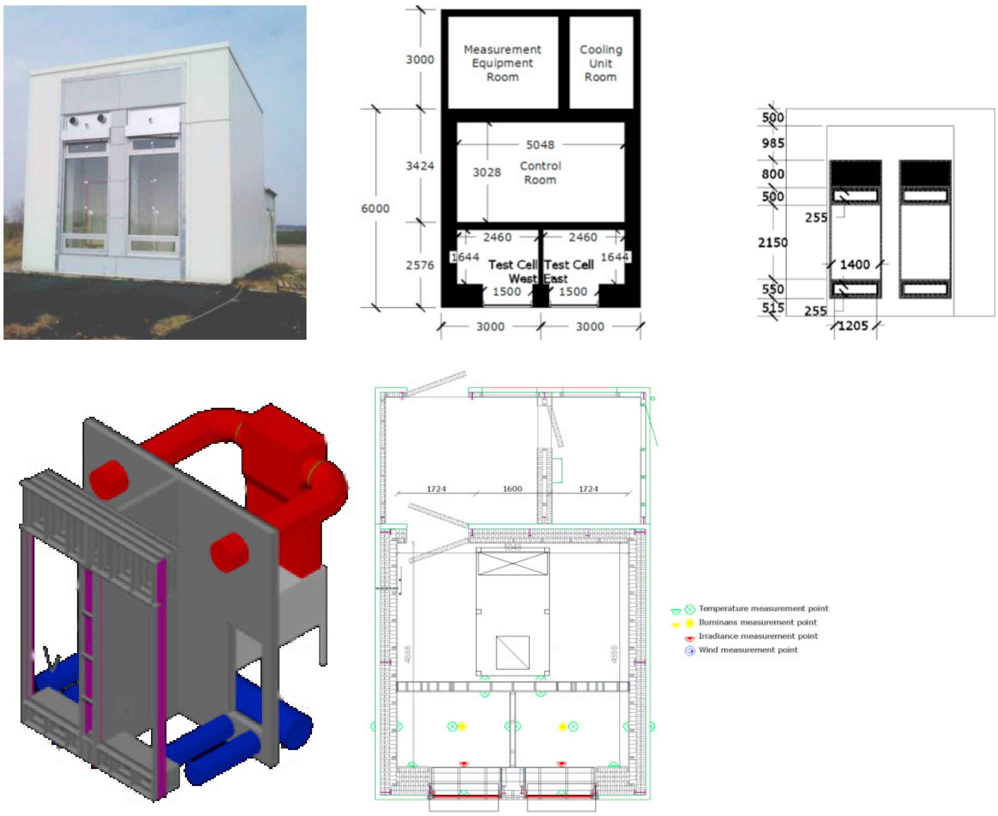

Fig. 2. Picture (left), plan drawing (center) and façade view (right) of the test facility in Aalborg.

The solar shading technology used in the experiments consists of external venetian blinds, which can be adjusted to a given angle for different strategies. In this study, the angles of the blinds have been adjusted to 0°, 45° and 80° (only the result of 0° will be shown later due to the page limitation).

3. Result

The results from the simulations presented here are the calculation of the surface temperature of the glazing system, and the total solar transmittance through the glazing system. The results presented here are for cases with different slat angles of the solar shading technology. The different methodologies for interpreting the solar shading factor have been applied to test their influence on the calculation of the surface temperature of the glazing system.

The final case with a slat angle of 0° show a good pattern concerning surface temperature and transmitted irradiance for all methodologies, see figure 3 and 4. It is interesting to see that the methodologies which follow the pattern of the measured irradiance, such as the solar shading coefficient split into direct and diffuse as function of incident angle, tend to give higher surface temperatures in the simulation results, whereas the more conservative transmitted irradiance from methodologies describing the shading coefficient as function of solar position and split into diffuse and direct shading coefficients give surface temperatures matching the measured surface temperature.

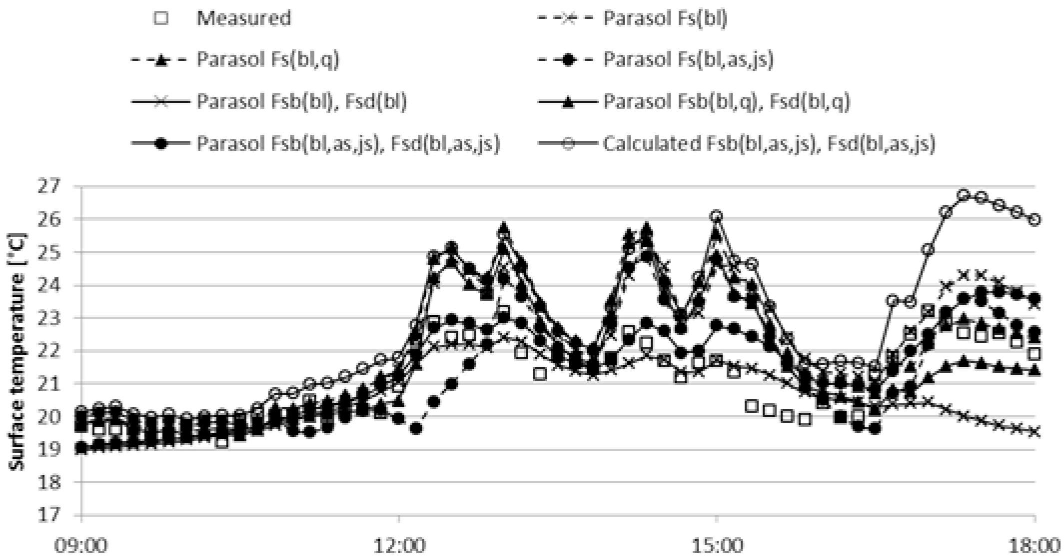

Fig. 3. Calculated and measured surface temperature of glazing system for a slat angle of 0° 29/3-11.

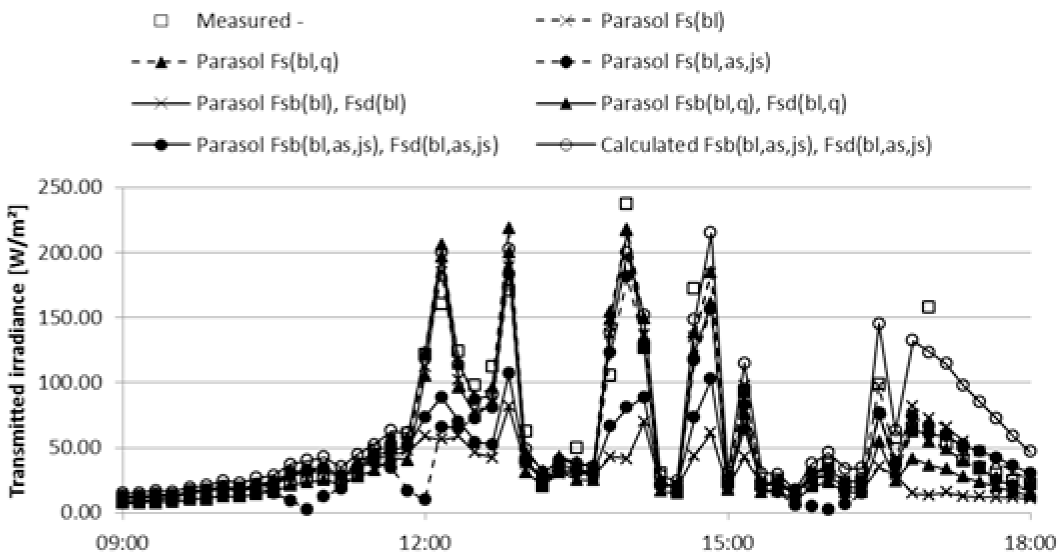

Fig. 4. Calculated and simulated transmitted irradiance for a slat angle of 0° for the 29/3-11.

4. Conclusion

In order to bridge the gap between standards and thermal building simulation, this paper has shown how different modeling techniques perform in relation to measurements of solar shading technologies built in full scale. Modeling solar shading as a function of absolute solar position shows best fit with the experimental data. However the interpretation of a specific solar shading technology with a specific orientation can be averaged over a year, and give reasonable results. This indicates that even though the numerical performance is better with increased accuracy, the accuracy can be equally good with simpler tools. With increased focus on energy transport through the façade and indoor climate, accurate determination of the performance of façade technologies becomes more mandatory. It is therefore inevitable that the description of solar shading technologies within thermal building simulation software become more detailed concerning the description of solar shading technologies.

The geometric method for description of the solar shading technology has shown good potential for describing the solar shading technology. The thermal and optical performance of solar shading technologies can thus be described numerically bridging the gap between numerical description of solar shading technologies and the application in thermal building simulation software giving good but sensitive results concerning the thermal performance of solar shading technologies.

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References

[1] Winther, F. V., Heiselberg, P. & Jensen, R. L. 2010. Intelligent Glazed Facades for Fulfilment of Future Energy Regulations, Towards 2020 - Sustainable Cities and Buildings: 3rd Nordic Passive House Conference 7-8 October 2010.
[2] Nielsen, M. V., Svendsen, S., Jensen, L. B. Quantifying the potential of automated dynamic solar shading in office buildings through integrated simulations of energy and daylight, Solar Energy 2011; 85: 757-768.
[3] Tzempelikos A. A Review of Optical Properties of Shading Devices, Advances in Building Energy Research 2008; 2: 211-239.
[4] Brunger, A.P., Hooper, F.C. Anisotropic Sky Radiance Model Based On Narrow Field Of View Measurements Of Shortwave Radiance, Solar Energy1993; 51: 53-64.
[5] ParaSol, Lund University, http://www.ebd.lth.se/english/software/parasol/