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An hourly based performance comparison of an integrated micro-structural perforated shading screen with standard shading systems

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ABSTRACT

This article evaluates the performance of an integrated micro structural perforated shading screen (MSPSS). Such a system maintains a visual connection with the outdoors while imitating the shading functionality of a venetian blind. Building energy consumption is strongly influenced by the solar gains and heat transfer through the transparent parts of the fenestration systems. MSPSS is angular-dependent shading device that provides an effective strategy in the control of daylight, solar gains and overheating through windows. The study focuses on using direct experimental methods to determine bi-directional transmittance properties of shading systems that are not included as standard shading options in readily available building performance simulation tools. The impact on the indoor environment, particularly temperature and daylight were investigated and compared to three other static complex fenestration systems. The bi-directional description of the systems was used throughout the article. The simulations were validated against outdoor measurements of solar and light transmittance.

1. Introduction

Buildings are responsible for usage of significant amount of the energy and account for 40% energy consumption in Europe and the USA. Energy reduction by buildings has become an important part of energy policy and is reflected in building regulations, which require decreased total building energy demand [1,2]. The largest energy usage is attributed to heating, cooling and electrical lighting.

Optimization of window elements can reduce energy consumed for heating, cooling and electric lighting. Optimization strategies consider heating by increasing solar gains, cooling by providing solar protection and lighting by utilizing daylight [3]. All the functions cannot be addressed by a standard window and the traditional windows have to be combined with shading systems, which then can be described as complex fenestration system (CFS). The challenge is to evaluate those parameters in an interconnected context for CFS performance, since some of the functions are contradicting for static systems, e.g. increasing solar gains in winter while providing shading in the summer [4].

In recent decades, new and renovated buildings have become increasingly insulated and air tight. These steps lower building heating loads but they also increase risk of overheating by capturing excess solar gains, especially in office buildings. Removing overheating by mechanically cooling is expensive and can negate the savings from solar gains in the winter, and thus cooling loads are growing in importance. Contemporary commercial and institutional buildings typically have a low heating and high cooling loads as they have high internally generated loads by people/lights/equipment and have well-insulated envelopes. Residential buildings have relatively low internal loads vs. their envelope loads [4]. Solar shading is an effective strategy to reduce overheating and diffuse direct sunlight thus reducing energy consumption [3]. There are many options available for shading systems and it is difficult to precisely describe the energy performance impact of a non-standardized solution [5,6]. Many of the CFSs have angularly dependent solar and light energy properties but use normal-incidence glazing values of the performance indicators, e.g. total solar energy transmittance. The normal-incidence value description is not an accurate indicator for angularly dependant systems, which need to be described with bi-directional data [7]. The limitations of the available simulation tools and testing methods can be overcome by performing state-of-the-art simulation and its validation with measurements [8].

The main motivation for this research is to establish a procedure for generating information, which can be used during product development of CFSs or an initial phase of building design. This paper focuses on the performance modelling of CFSs and comparison between types. The results of the simulations were compared against measurements taken outdoors and in a laboratory. The

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aim is to determine the performance criteria of the tested CFSs to indicate impact on the energy and indoor climate in the occupied spaces.

2. Method

Performance is simulated for several shading systems and a comparison is based on the evaluation of various aspects. The bi-directional transmittance simulation results compared to measurements. The performance evaluation is performed with several steps, starting with the shading layer and ending with shading system impact onto a reference room. The design criteria for widows and CFS in modern buildings are:

- Energy use – heating, cooling, electrical lighting
- Thermal comfort – overheating
- Visual comfort – daylight, glare, view to outside

These criteria are interdependent, in this study they are addressed in the context of the following aspects: facade orientation, building location, time of day and year, window size, window position on facade, shading strategy, and human factors (view, comfort and temperature).

The building location determines the climate, including the sun position and sky luminance distribution, which is further dependent on the actual time/date. The central criteria for this article is angular dependant light transmittance (T_{vis}) and solar transmittance (T_{sol}) of the CFS. With these parameters the solar heat gain coefficient (SHGC) could be described, which is also referred as the total solar transmittance (*g*-value) and is central in determining cooling loads of buildings. The thermal transmittance of windows (U_W-value) is one of the major energy performance characteristics controlling heat loss. Transmittance refers to both T_{vis} and T_{sol} further in the paper if not specified otherwise.

In this paper, the interconnections of the above parameters are illustrated in case examples presented throughout the paper. Annual performance simulations are carried out when possible.

2.1. Complex fenestration systems

This study focused on a micro structural perforated shading screen (MSPSS) which is made of an insulated double glazed unit with low-e coating on surface 3 and the MSPSS on surface 2. The MSPSS is made from a stainless steel sheet with elliptical holes smaller than 1 mm. The holes are cut in a downward direction (when viewed from the inside) to reduce transmission from sources above the horizon and increase transmission from below the horizon. MSPSS was selected because the angular dependence is not symmetrical about the normal making it difficult or impossible to evaluate with standard simulation tools. The MSPSS combines solar and glare protection, provides direct view out and is not included in any standard testing software. Fig. 1 shows a side-by-side view through the MSPSS with an unobstructed view. From observations the view appears less obstructed when viewed at a greater distance. The picture is slightly blurry as it was necessary to focus on the shading layer and the background was in the distance.

In order to have a complete understanding of performance, the tested CFS is compared to references systems. MSPSS was compared to clear double glazed windows, without shading, with horizontal venetian blinds, and with a semi-transparent roller shade. The clear glazing reference case was studied to demonstrate the effect of the shading and glazing separately. Venetian blinds were used as a comparison because they are a conventional system that also provides shade and permits view. A roller shade was also used as a reference because it blocks solar gains and glare more efficiently then the semi-opened system, however, unlike MSPS and Venetian blind, it blocks the view to outside.

Fig. 1. View through MSPSS (left), unobstructed view (right).

All the shading systems were simulated with the same glazing. In all cases, the shading was located between the glass panes to limit the variations in the energy performance of the individual systems.

2.2. Determining bi-directional transmission characteristics

T_{sol} and T_{vis} are the fundamental performance indicators for CFS and all the following calculations were based on them. The calculations are carried out in several sequential steps with increasing level of information.

2.2.1. BSDF generation via simulation

Radiance was used to generate a bi-directional scattering distribution function (BSDF). Radiance is an accurate backward ray-tracing Unix-based programme that has been validated for such purposes [9]. The new software development allows generating a BSDF, which describes transmittance dependent on incident angle (IA). A model of the MSPSS was created using detailed geometric drawings from the manufacturer and reflectance measurements of an un-perforated sample also provided by the manufacturer. Radiance's programme genBSDF was used to generate a BSDF matrix [10]. The genBSDF programme generates blocks of values which describe 145 Klem's incidence angles for one of 145 oppositely placed outgoing directions [11]. This data was validated against goniophotometer measurements for a few incident angles [12]. The validated BSDF was used to calculate T_{sol} and T_{vis} of the glazing unit with the shading screen.

2.2.2. Comparing measurement with simulations

Measurements were taken of the MSPSS taken to ensure that daylight simulations using BSDFs would reliably reproduce real-world results. Measurements were taken outdoors in order to include direct light from the sun and diffuse light from the sky reproducing the type of environments experienced by a real building. Both components of daylight are important because together they determine indoor daylight conditions, unlike cooling loads which are highly dependent on the direct sunlight [3]. Measurements were taken on clear days in June and July because clear skies are the most reliably reproduced of the CIE sky types (and clear skies are commonly occur in the summer in Denmark, where the measurements were taken) [9]. The sample was rotated to imitate different incident azimuth and altitude angles so that many