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Angular selective window systems: Assessment of technical potential for energy savings

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ABSTRACT

Static angular selective shading systems block direct sunlight and admit daylight within a specific range of incident solar angles. The objective of this study is to quantify their potential to reduce energy use and peak demand in commercial buildings using state-of-the art whole-building computer simulation software that allows accurate modeling of the behavior of optically-complex fenestration systems such as angular selective systems. Three commercial systems were evaluated: a micro-perforated screen, a tubular shading structure, and an expanded metal mesh. This evaluation was performed through computer simulation for multiple climates (Chicago, Illinois and Houston, Texas), window-to-wall ratios (0.15–0.60), building codes (ASHRAE 90.1-2004 and 2010) and lighting control configurations (with and without). The modeling of the optical complexity of the systems took advantage of the development of state-of-the-art versions of the EnergyPlus, Radiance and Window simulation tools. Results show significant reductions in perimeter zone energy use; the best system reached 28% and 47% savings, respectively, without and with daylighting controls (ASHRAE 90.1-2004, south facade, Chicago, WWR = 0.45). Angular selectivity and thermal conductance of the angle-selective layer, as well as spectral selectivity of low-emissivity coatings, were identified as factors with significant impact on performance.

1. Introduction

1.1. Angular selective shading systems

Static angular selective shading systems block or filter direct sunlight and admit reflected sunlight, diffuse skylight, or ground-reflected daylight within a specific range of incident solar angles [1,2]. They can be as broadly applicable as non-angular-selective filters, such as diffusing glass, but can deliver potentially more optimal energy efficient performance within the typical 4.6 m (15 ft) deep perimeter zone when tailored to a specific façade orientation and latitude [3].

Angular selective shading systems can be made out of a wide variety of materials, produced in a broad array of shapes, sizes, and colors and are typically located either on the outdoor face of windows or as a between-pane layer in an insulating glass unit (IGU). Commercial products range from woven metal insect screens or punched metal scrims to more engineered systems such as between-pane micro-louvered metal screens, high-reflectance sculpted meshes or mirrored louver systems. Angular selective coatings on glass [2] are yet another option but are at present not included in this category of technologies.

Arguably, the advantage of such systems is the ability to selectively block direct beam solar radiation, reducing the need for interior shading systems and increasing access to outdoor views. If engineered well, the systems could significantly reduce cooling energy use due to solar heat gains, peak cooling loads, transmission of direct beam irradiation which can cause thermal and visual discomfort, and reduction of window luminance which can cause glare. Exterior punched metal scrims have been used to reduce solar loads [4], enabling all-glass facades to meet energy-efficiency code requirements. Some manufacturers have devised manual and mechanized systems to retract structured panels of these systems when no longer needed. If sufficiently porous to permit wind-induced air flow, exterior shading has also been used with natural ventilation schemes to achieve very low energy use goals [4]. Between-pane systems have the advantage of broader application with potentially longer lifetime durability but cannot be retracted for unobstructed views. These systems must also be designed to avoid damaging low-e coatings

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during transport or changing optical clarity if off-gassing should occur.

Alternatively, windows with advanced spectrally selective, low emissivity (low-e) coatings are now able to attain very low solar heat gain coefficient (SHGC) levels with high visible transmittance (Tv) (e.g., SHGC = 0.26, Tv = 0.62, Ke = Tv/SHGC = 2.38), but occupants' use of interior shades to block direct sun can significantly reduce useful daylight [5]. Patterned fritted or etched glass has also been used to reduce solar loads, particularly on large-area windows [6]: this has been an architectural trend for at least a decade. This solution also has the disadvantage of not blocking direct beam sunlight, necessitating the need for interior shades in long-term occupied zones.

For most systems, enhancing the distribution of daylight is not intentionally addressed by angular selective shading systems. Most designs diffuse daylight rather than redirect beam sunlight to the building core, but the combination of controlled daylight and reduced need for interior shading can improve daylight availability to building interiors. Reduction in discomfort glare from either direct views of the bright sky or sun orb is possible depending on the optical properties of the shading system; if the system has specular surfaces, localized reflections could increase glare. Unlike attached exterior overhangs or fins where unobstructed views are possible, angular selective shading systems can obscure views out since they are typically designed to cover the entire area of the window. If the shading elements are small, details of the outdoors can still be discerned.

1.2. Computer simulation of optically-complex fenestration

Unlike clear glass or some diffusing materials, angular selective shading systems are optically complex, i.e., they scatter light in ways that are not easily describable by theoretically-derived models or by parametric models fitted to experimental data. An approach that addresses this issue hinges on a discretized bi-directional scattering distribution function (BSDF) [7,8] that comprehensively describes the scattering of light from an array of directions of incidence spanning an hemisphere to an array of directions of transmission and reflection spanning two hemispheres, one for transmission and another for reflection. The BSDF for a fenestration system can be derived from physical measurements, using a goniophotometer [9], or using computer simulation [10].

Although lighting simulation software, such as Radiance [11–13] has been able to perform lighting calculations in which the optical properties of materials are determined by BSDF data, the same has not been the case with whole-building simulation software. Programs such as EnergyPlus [14] have used simplified algorithms to determine the transmission of daylight and solar heat gains through fenestration. While these simplified algorithms may be a reasonable approximation for optically-simple fenestration, they most likely fail to capture the complex and highly angle-dependent ways in which optically-complex fenestration systems, and angular selective shading systems in particular, interact with incident radiation.

The approach taken in this paper was to take advantage of experimental, state-of-the-art advances in EnergyPlus that allowed the use of results from highly accurate Radiance simulation instead of EnergyPlus' internal models to more accurately model the optical and near-infrared behavior of angular selective shading systems. This approach was not specific to angular selective shading systems—in fact, its development was intended for any fenestration system that can be modeled by a BSDF. Here, we demonstrate those capabilities in the context of evaluating the technical potential of static angular selective shading systems to reduce energy use and peak demand in commercial buildings.

2. Materials and methods

The objective of this study is to quantify the technical potential of static angular selective shading systems to reduce energy use and peak demand in commercial buildings. This evaluation of the energy performance of angular selective window systems was performed mainly through computer simulation, thus enabling relatively inexpensive evaluation of several different window systems under a multitude of scenarios, including multiple climates, window-to-wall ratios, building codes and lighting control configurations.

2.1. Materials

Three distinctly different commercial shading systems – an expanded metal mesh, a tubular shading structure, and a micro-perforated screen – were selected for evaluation (Fig. 1). Manufacturer center-of-glass specifications of the three systems are shown in Table 1.

2.1.1. Micro-perforated screen

The micro-perforated screen system is marketed as MicroShade by Photosolar A/S. The angular selective micro-perforated screen is applied to the interior surface of the exterior glass pane of an integrated glazing unit (IGU). The two glass panes are clear, the interior pane also having a low emissivity (low-e) coating.

2.1.2. Tubular shading structure

This system consists of a double-glazed IGU filled with plastic tubes, positioned perpendicular to the glass surface. It is marketed as Clearshade IGU by Panelite. When in a two-pane configuration, the interior surface of the exterior glass pane has a pyrolitic low-e coating. This product is available with the plastic tubes in an array of

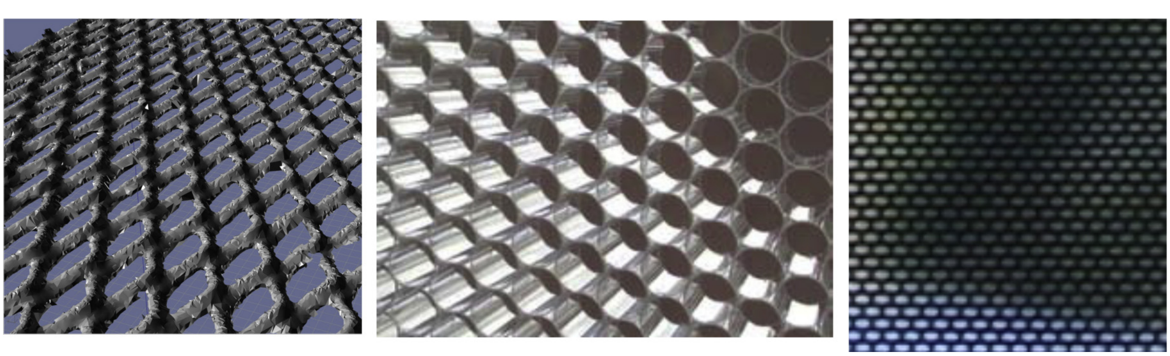

Fig. 1. Angular selective shading systems: (a) expanded metal mesh (left), (b) tubular shading structure (center), and (c) micro-perforated screen (right).