Performance Fabric Research

Effect of shading fabric properties on glare, daylight, and view

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Introduction

Window shades can protect occupants from glare and direct sunlight, influence the indoor daylight performance, and impact occupants' view clarity to the outside, depending on their optical properties. The following three criteria are defined to quantify glare, daylight, and view clarity performance in a space.

Daylight Glare Probability (DGP): The likelihood that an occupant will begin to experience daylight glare in a space. Generally, DGP values of 35% or less result in "imperceptible" glare and are considered a good design.

Spatial Daylight Autonomy (sDA): The percentage of the work area where daylight contributes at least 30 FC for 50% of work hours or more. This is the area of a building where even daylight switching of the light fixtures will give significant energy savings.

View Clarity Index (VCI): Clarity of view when looking through a fabric to the outdoors. A value of 1 is as clear as with no shade at all, and a value of 0 indicates that a typical occupant cannot see through at all.

Manufacturers provide specifications with basic fabric properties, listing the Openness Factor (OF) and normal Visible Light Transmittance (Tv).

Openness Factor (OF): The percentage of light that transmits directly through a solar screen without being redirected or diffused.

Visible Light Transmittance (Tv): The percentage of light that transmits through a solar screen, including both direct and diffuse light.

Fabrics with higher OF and Tv will transmit more daylight into the space, therefore improving space daylight autonomy and increasing energy savings. They will also provide occupants better view clarity to the outside. However, the fabrics with higher OF and Tv could also result in glare problems. Therefore a balance is needed between daylight provision and visual comfort (reduction of glare and increase of outside view clarity). Until now, this balance was unknown since the impact of fabric properties and control on daylight glare could not be quantified.

To solve this problem, Lutron Electronics and Purdue University completed a comprehensive research study in 2014. The objective of this study is to investigate the impact of shading fabric properties and control operations on space glare, daylight, and view clarity performance, and to develop a reliable tool – the Lutron Fabric Wizard (www.performanceshadingadvisor.com) - a web-based tool that can help designers choose shading fabrics based on their project requirements in order to achieve the optimized glare, daylight, and view clarity performance.

The principal investigator from Purdue University was Dr. Thanos Tzempelikos (Associate Professor of Civil Engineering and Herrick Labs Faculty) assisted by two PhD candidates (Y. Chan and I. Konstantzos), all experts in this field.

Effect of fabric properties on daylight and glare

Develop a simulation tool

Manufacturers provide listed Openness Factor (OF) and normal Visible Light Transmittance (Tv) values for every shading fabric. However, the Tv of a fabric is not constant, but instead depends on the solar incidence angle, for both the direct and the diffuse light portions. Assuming constant values will result in significant errors in daylight performance and glare evaluation[1],[2]. The OF and normal Tv can be used to model the angular variation of light transmittance through fabrics[3].

To evaluate the impact of shading properties and controls, an advanced integrated daylight-thermal simulation tool was used. The tool was developed at Purdue University and has been used in several scientific studies in the last few years[4],[5]. This tool is unique in that it can model the dynamic performance of any fenestration and shading system, using its detailed properties and customized controls, for any room geometry, occupant location, space orientation and climate. It combines the benefits of increased accuracy and computational efficiency, plus the added value of modeling flexibility for various types of façade/shading controls and evaluating glare through calculation of transient vertical illuminance and luminance in the field of view. In addition, it performs a dynamic thermal analysis of the space utilizing the advanced EnergyPlus[6] simulation engine.

Direct sunlight, diffuse sky light and ground-reflected radiation are calculated separately including their transmission through the windows and shading devices, for every hour in the year. Direct light and specular reflections are treated with the ray-tracing module, while diffuse light and reflections are computed using the radiosity method[7], which separates each room surface into 1600 sub-surfaces (grid nodes) for maximum accuracy. Detailed glazing properties are imported directly from WINDOW 7 software[8].

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[1] Y.C. Chan, A. Tzempelikos, B. Protzman, *"Solar Optical Properties of Roller Shades: Modeling Approaches, Measured Results and Impact on Daylighting and Visual Comfort"*, Proceedings of 3rd International High Performance Buildings Conference at Purdue, July 2014.

[2] Y.C. Chan, A. Tzempelikos, B. Protzman, *"Impact of Optical Properties of Roller Shades on Energy, Daylighting and Comfort"*, ASHRAE Annual conference, Atlanta, June 2015.

[3] N.A.Kotey, J.L. Wright, M.R. Collins, *"Determining off-normal solar optical properties of roller blinds"*, ASHRAE Transactions 115(1), 145-154, 2009.

[4] H. Shen, A. Tzempelikos, *"Daylighting and energy analysis of private offices with automated interior roller shades"*, Solar Energy, Vol. 86 (2), pp. 681-704, 2012.

[5] H. Shen, A. Tzempelikos, *"Sensitivity analysis on daylighting and energy performance of perimeter offices with automated shading"*, Building and Environment, Vol. 59, pp. 303-314, 2012.

[6] US Department of Energy. EnergyPlus. http://apps1.eere.energy.gov/buildings/energyplus/, 2015.

[7] A.K. Athienitis, A. Tzempelikos, "A methodology for calculating room illuminance distribution and light dimming for a room with a controlled shading device", Solar Energy, Vol. 72 (4), pp. 271-281, 2002.

[8] Lawrence Berkeley National Laboratory. WINDOW 7. http://windows.lbl.gov/software/window/7/, 2014.

The tool uses TMY3[9] hourly weather data (or any other type of climatic data) as inputs, together with a basic space description (space geometry, orientation, window size and properties, surface reflectance) and occupant information (location and view direction). Fig. 1 presents the basic logic. Complex fenestration systems and controls are in the core of the model, since their impact is critical. The model runs for the entire year or for any selected time period. Output data includes: hourly work plane illuminance distributions, vertical illuminance (on the eye), luminance in the field of view, hourly shading position, and annual daylight metrics (e.g., Daylight Autonomy, Spatial Daylight Autonomy, Useful Daylight Illuminances) as well as Daylight Glare Probability.

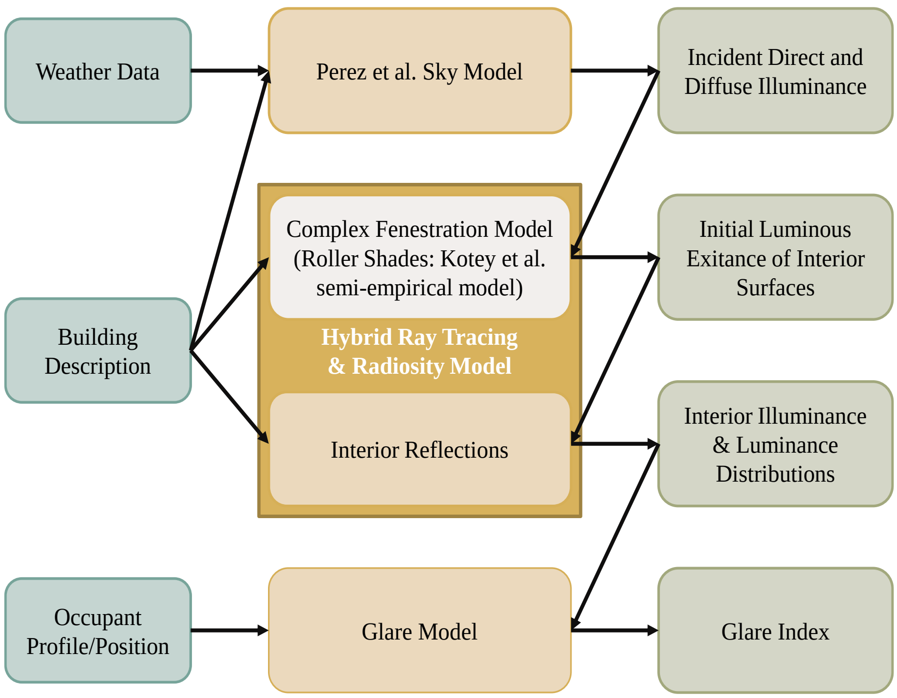

Fig. 1. Basic flowchart of integrated simulation tool.

Validate the simulation tool

The simulation tool has been extensively validated with full-scale experimental measurements in test offices (for a variety of different fabrics and advanced controls) as well as with Radiance[10] and Daysim[11] software programs (for cases with simple shading controls). A set of twin identical rooms (20' x 20') with a large south-facing façade (Fig. 2) and reconfigurable curtain wall, glazing and shading systems, exposed to real weather conditions, have been used to measure the daylight distributions with several fabrics and controls (Fig. 3). A sample of measured vs model results is presented in Fig. 4. Work plane illuminance at the desk level and vertical illuminance on the occupant eye were measured over four days with different sky conditions (red lines). For the same conditions, these quantities were calculated using the model described above (blue lines). The results are in very good agreement, proving the validity of the simulation model. More detailed validation information can be found in

[9] TMY3" http://apps1.eere.energy.gov/buildings/energyplus/weatherdata_sources.cfm#TMY3, 2015.
[10] Lawrence Berkeley National Laboratory. Radiance. http://radsite.lbl.gov/radiance/.
[11] Christoph Reinhart. Daysim. http://daysim.ning.com/, 2015.

published studies[12],[13]. The only model assumption is that it cannot consider the impact of interior furniture when calculating annual daylight distributions.

Fig. 2. Exterior view of test offices; interior view; HDR camera for luminance measurements.

Fig. 3. Testing the daylight performance of light-colored and dark-colored fabrics.

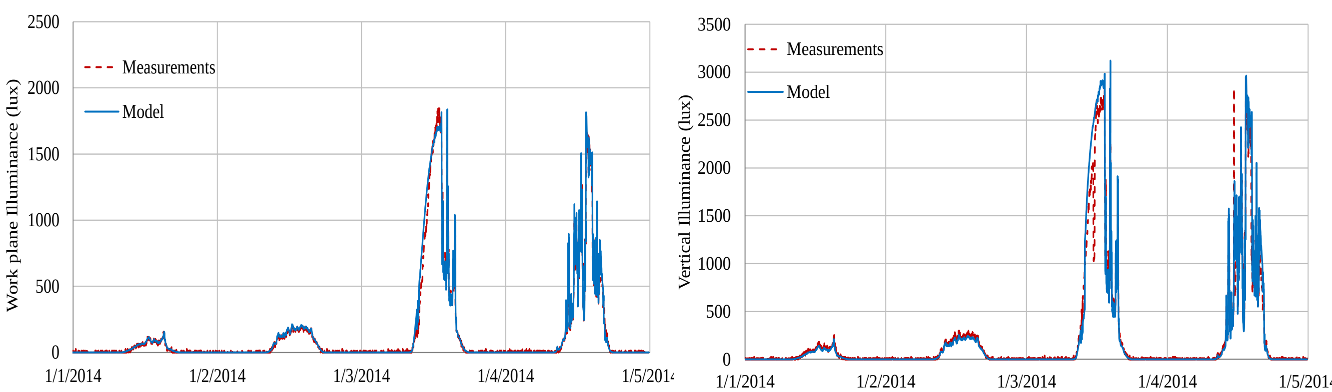

Fig. 4. Comparison of measured and modeled work plane illuminance on desk (left) and vertical illuminance on eye (right) in the test offices over 4 successive days.

A case study

First, the simulation tool was used to identify the most important parameters affecting the glare and daylight performance of spaces with roller shades. It was found that fabrics of the same openness but different colors (and vice versa) have totally different Tv values and would result in completely different interior illuminances and Daylight Glare Probability (DGP). Indeed, it is possible that fabrics with smaller openness factors may result in higher DGP values. Table 1 shows representative results for an office in Phoenix (70% Window-to-Wall Ratio,

[12] I. Konstantzos, A. Tzempelikos, Y-C. Chan, "*Experimental and simulation analysis of daylight glare probability in offices with dynamic window shades*", Building and Environment, Vol. 87, 244-254, 2015.

[13] Y-C. Chan, I. Konstantzos, A. Tzempelikos, "*Annual Daylight Glare Evaluation for Typical Perimeter Offices: Simulation Models versus Full-Scale Experiments Including Shading Controls*", ASHRAE Annual conference, Seattle, June 2014.

glazing transmittance=65%) with closed shades. Fabric 9 provides better glare protection than fabrics 6, 7 or 8, although it has a higher OF (but a lower Tv, affecting diffuse light transmission). Therefore, the OF and Tv, including angular properties, all play a role in the total amount of transmitted light; glare evaluation and simple conclusions cannot be drawn without a detailed analysis.

Table 1. Frequency of annual working hours with noticeable glare for different fabrics (closed shades)

Fabric	OF	Tv	% of annual hours with noticeable glare (DGP>35%)
1	0.01	0.01	0%
2	0.01	0.05	0%
3	0.01	0.10	9%
4	0.01	0.15	21%
5	0.03	0.03	0%
6	0.03	0.08	3%
7	0.03	0.13	16%
8	0.03	0.18	26%
9	0.05	0.05	0%
10	0.05	0.10	8%
11	0.05	0.15	20%
12	0.05	0.20	29%

The model was then used to run a series of annual simulations to evaluate the impact of significant parameters when selecting different fabric properties and control operations. These are listed in Table 2 and were considered as the main independent variables in the detailed study presented next.

Table 2. Significant parameters in fabric evaluation and range of variables in simulation

Important independent variables	Range
Fabric OF	1% – 10%
Fabric Tv	1% – 30%
Building Location	10 locations in the US (different climatic zones)
Glass Tv	35% – 65%
Window-to-Wall Ratio	30% – 70%
Buffer Zone (occupant distance from window)	3.28 ft – 9.84 ft
Room Surface Colors	Light, medium, dark
Orientation	All orientations
Room size	40ft x 40ft with 10ft ceiling height
Hours of operation	9am – 5pm, sunrise to sunset
Shading control type	Closed shades and controlled shades: Lutron Hyperion® control with dark and bright override

A total of 500 simulations were run with the above variables to provide an extensive database of results, which allowed the study of interactions between the different parameters, and led to the development of the Lutron Fabric Wizard tool for selection of fabric properties for different scenarios.

Another important outcome of this study was that automated shades, when properly controlled (with brightness and darkness set point overrides), may protect from glare equally well to closed shades, while allowing more daylight into the space, leading to energy savings. Fig. 5 presents representative results (Office in Phoenix, 70% WWR, glazing transmittance=65%, south-facing windows, buffer zone =3.28 ft).

The left graph in Fig. 5 compares the frequency of time when glare is noticeable in the office with closed and automated shades, for 12 different fabrics listed in Table 1. The results show that automated shades perform equally well to closed shades for all fabrics (and sometimes better). The right graph of Fig. 5 shows the Spatial Daylight Autonomy in the office with closed and automated shades for the same fabrics. The benefits of shading automation are obvious for every fabric. In addition, automated operation allows at least 20% unobstructed outside view (on average over the entire year).

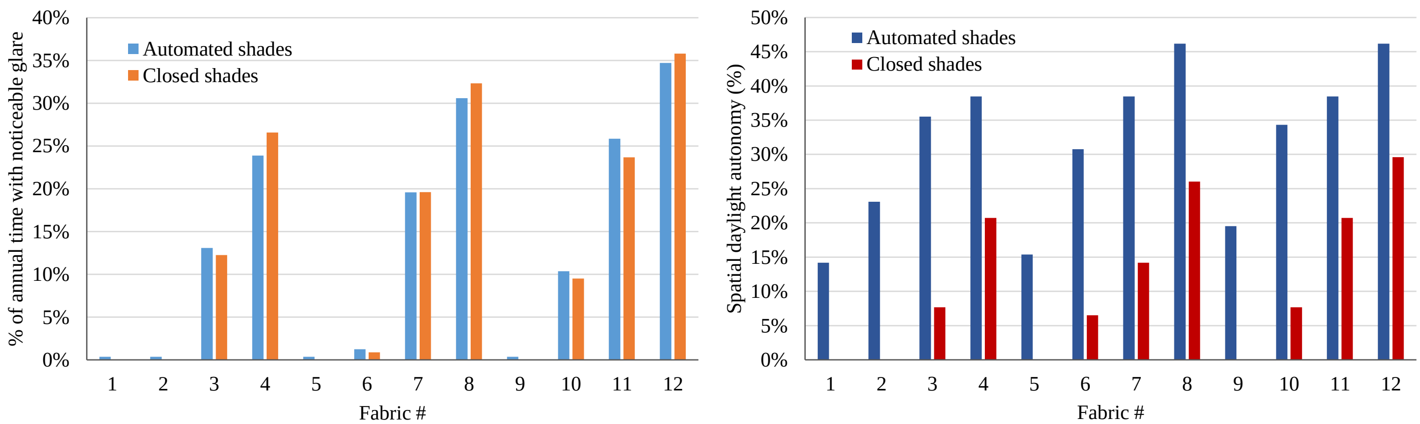

Fig. 5. Annual glare probability and spatial daylight autonomy for the 12 fabrics listed in Table 1, with automated and closed shades.

Effect of fabric properties on view performance

In the absence of an existing metric, Lutron and Purdue University collaborated on a research project to develop a new metric for characterizing view clarity through windows with shading fabrics. A full-scale field study with 18 human subjects was conducted to measure view clarity preferences in two offices equipped with 14 shading fabrics of different properties (OF, Tv and color). The tests were conducted in full-scale test offices for different sky conditions and viewing positions. 6912 data points were collected and statistically processed to create a scoring system/fabric rankings and a new metric, the View Clarity Index (VCI)[14].

The results show that: **darker fabrics with higher OF** generally achieve higher clarity scores, followed by **light-colored fabrics with high *OF* and *Tv***, and then dark or colored fabrics with small *OF*; light-colored fabrics with low OF received the lowest view clarity scores.

The ***View Clarity Index (VCI)*** can be predicted for any shading fabric using only the two basic shade properties (OF and Tv). The value of this index can be found from Fig. 6 (listed values in the figure and in the legend) for given fabric OF (x-axis) and Tv (y-axis). Alternatively, the equation below can be used to calculate VCI as a function of OF and Tv:

$$VCI = 1.36 \cdot (OF)^{0.51} + 0.68 \cdot \left(\frac{OF}{T_v}\right)^{1.19} - 0.18$$

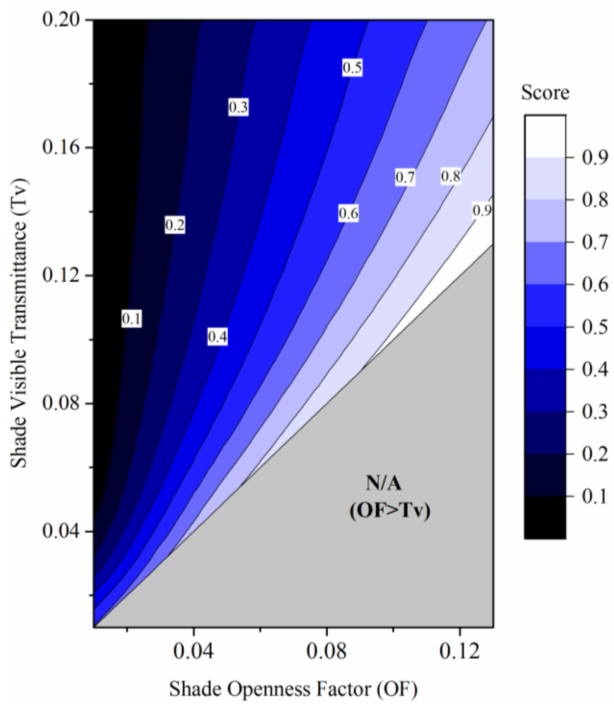

Figure 6: View Clarity Index for various fabric OF and Tv.

[14] I. Konstantzos, Y.-C. Chan, J. Seibold, A. Tzempelikos, R.W. Proctor, B. Protzman, "*View Clarity Index: a new metric to evaluate clarity of view through window shades*", Building and Environment, Available online 15 April 2015, ISSN 0360-1323.

Summary

We have identified key fabric properties that have a strong impact on building glare, daylight, and view clarity performance, which are,

- Openness Factor (OF): The percentage of light that transmits directly through a solar screen without being redirected or diffused.
- Visible Light Transmittance (Tv): The percentage of light that transmits through a solar screen, including both direct and diffuse light.

A simulation tool was developed and validated with full-scale experimental measurements. A case study was conducted using the validated simulation tool to examine the daylight and glare performance with different fabrics for manual and automated shades. Both control methods provided similar glare performance for the same fabric selection, but automated shades provided more daylight and allowed occupants to have at least 20% unobstructed outside view (on average over the entire year).

An experiment was conducted to examine the occupant view clarity through window shades. Based on the experiment results, we introduced a new metric to quantify the occupant view clarity – View Clarity Index (VCI). More information can be found in another Lutron white paper – “Define view clarity through window shades”.

Utilizing the research findings, we developed the Lutron Fabric Wizard (www.performanceshadingadvisor.com), a web-based tool that can help designers choose shading fabrics based on their project requirements in order to achieve the optimized glare, daylight, and view clarity performance.