

Visual Quality Analysis: Annual Luminance Ratios in Daylighted Spaces with Automatic-Control Translucent Fabric Shade Using DAYSIM

การวิเคราะห์คุณภาพการมองเห็น: อัตราส่วนความสว่างที่สะท้อนจากผิววัสดุรายปี ภายในพื้นที่ที่ใช้ม่านกันแดดโปร่งแสงอัตโนมัติด้วย DAYSIM

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Abstract

Luminance ratios are one of the available metrics to evaluate daylight quality within a space. This paper presents a simple method for evaluating task-to-surround luminance ratios in daylighted space with automatic-control translucent fabric shades using DAYSIM and simulation models with a full-year analysis and site-specific weather data. An example study is presented using TMY2 data for Minneapolis, MN, and considered a private perimeter office with a 40% window to wall area ratio facing both west and south. The window glazing is fitted with both light and dark translucent shades for comparison purpose. The luminance ratios for several measurement points, including an average window luminance, were analyzed to determine the effects of the shades under different control strategies. The simulations also include the contribution from electric lighting with a photosensor controlled dimming system. The results illustrate how shades can improve daylight quality in the space. This type of study should be helpful to designers in evaluating different daylight delivery systems and shade control strategies.

บทคัดย่อ

อัตราส่วนความสว่างที่สะท้อนจากผิววัสดุเป็นหนึ่งในระบบการวิเคราะห์คุณภาพการมองเห็นแสงธรรมชาติในอาคาร บทความวิจัยนี้นำเสนอวิธีการเบื้องต้นในการวิเคราะห์อัตราส่วนความสว่างที่สะท้อนจากผิววัสดุภายในพื้นที่ที่ติดตั้งระบบม่านกันแดดโปร่งแสงอัตโนมัติ จากการวัดค่าความสว่างสะท้อนที่พื้นผิวใช้งานต่อพื้นที่ผิวโดยรอบโดยใช้แบบจำลองและโปรแกรมคอมพิวเตอร์ DAYSIM พร้อมกับการวิเคราะห์แบบรายปีและการใช้ฐานข้อมูลสภาพอากาศจริง การศึกษานี้ใช้ข้อมูลสภาพอากาศ TMY2 ของเมือง Minneapolis มลรัฐ Minnesota ประเทศสหรัฐอเมริกา เป็นกรณีศึกษา การวิเคราะห์ใช้พื้นที่ห้องทำงานขนาดเล็กที่ติดกับกรอบอาคาร มีสัดส่วนพื้นที่หน้าต่างต่อพื้นที่ผนัง

40% และศึกษาเฉพาะหน้าต่างที่หันทางทิศตะวันตกและทิศใต้ หน้าต่างดังกล่าวติดตั้งมานานกันแดดโปร่งแสงทั้งแบบสีอ่อนและสีเข้มที่มีค่าการส่องผ่านแสงต่างกันเพื่อการเปรียบเทียบ การวัดอัตราส่วนความสว่างสะท้อนจากผิววัสดุ การวัดแบบจุดวัดหลายจุด รวมไปถึงการวิเคราะห์และหาค่าอัตราส่วนความสว่างสะท้อนเฉลี่ยจากกระจกหน้าต่าง ซึ่งจำเป็นต่อการวิเคราะห์ผลกระทบจากการติดตั้งมานานกันแดดโปร่งแสง ในการศึกษาที่มานานกันแดดโปร่งแสงจะถูกควบคุมอัตโนมัติที่แตกต่างกัน การจำลองด้วยโปรแกรมคอมพิวเตอร์ดังกล่าวคำนึงถึงผลกระทบของการใช้แสงประดิษฐ์และระบบการควบคุมแสงประดิษฐ์อัตโนมัติด้วยเซนเซอร์วัดแสงธรรมชาติด้วย จากผลการศึกษาคคุณภาพของแสงธรรมชาติภายในพื้นที่ใช้งานเมื่อมีการติดตั้งมานานกันแดดโปร่งแสงแบบปิดทั้งวัน และแบบควบคุมด้วยระบบอัตโนมัติพบว่ามีคุณภาพและความสบายตามากกว่าเมื่อไม่มีการติดตั้งมานานกันแดดโปร่งแสง ส่วนวิธีการวิเคราะห์ในการศึกษาสามารถใช้ให้เกิดประโยชน์กับผู้ออกแบบในการประเมินคุณภาพของแสงจากระบบการนำแสงธรรมชาติเข้าสู่อาคาร รวมถึงคุณภาพแสงจากการติดตั้งมานานกันแดดโปร่งแสงภายใต้ระบบควบคุมอัตโนมัติ และระบบควบคุมแสงประดิษฐ์อัตโนมัติได้ด้วย

Keywords (คำสำคัญ)

Luminance Ratios (อัตราส่วนความสว่างที่สะท้อนจากผิววัสดุ)

Translucent Shade (มานานกันแดดโปร่งแสง)

DAYSIM (โปรแกรม DAYSIM)

Visual Quality (คุณภาพการมองเห็น)

Lighting Control (ระบบการควบคุมแสงประดิษฐ์)

Daylighting (แสงธรรมชาติ)

1. Introduction

Daylight provides an opportunity for energy savings, and helps improve visual quality, occupant health and well being. For visual quality, luminance ratios are one of the metrics available to evaluate the interior environment. Luminance ratios refer to relative luminance of two surfaces within the field of view, generally between the task and both adjacent and distant surfaces. The Illuminating Engineering Society of North America, IESNA (IESNA, 2000) states that luminance ratios generally should not exceed the following recommended ratios for critical work tasks as Table 1.

Table 1. IESNA recommended luminance ratios for critical work tasks

Critical Work Tasks		Luminance Ratios ($\text{cd/m}^2 : \text{cd/m}^2$)	
		Hi:Lo	Lo:Hi
Paper Task	Adjacent VDT screen	3:1	1:3
Task	Adjacent surroundings	3:1	1:3
Task	Remote surfaces (non-adjacent)	10:1	1:10

This paper presents a simple method for evaluating task to surround luminance ratios using the daylight simulation program DAYSIM, which offers the ability to analyze the luminance at a series of points in daylighted space specifying by the user. The case studies are selected to show the impact of the use of automatic-control translucent fabric shades (Wankanapon, 2009) on visual quality. DAYSIM provides a full-year analysis using the daylight coefficient approach and site-specific weather data, TMY2 (NREL, 1995).

2. Simulation Parameters

The test space is a perimeter private office of 3.0 m x 4.6 m (10 ft x 15 ft) with a ceiling height of 3.2 m (10.5 ft). The window-to-wall area ratio in this space was fixed at 40% (Figure 1), with two orientations studied, west and south.

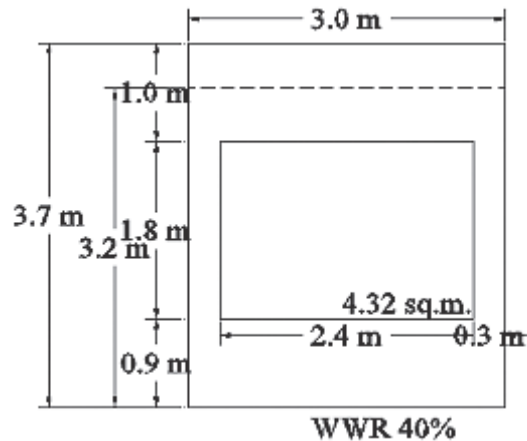


Figure 1. Window areas for the test spaces.

The insulated double-pane low emissivity window (Low-E) and shade properties are shown in Table 2. An example study is presented using the Typical Meteorological Year 2 data, TMY2, (NREL, 1995) for Minneapolis, Minnesota, USA.



The test space was equipped with electric lights that provide a minimum illuminance level of 500 lux (50 fc) at a reference point on the workplane. Electric lights are dimmed to maintain 500 lux and turned off after reaching a minimum dimming level of 2%. Shades are controlled to be opened all day (NO SHADE) as a base case. Comparisons are made to a condition with the shades closed all day (WITH SHADE) and to shades that are automatically controlled.

The automatic shade control strategies are:
Control strategy 1– shades are closed when direct sunlight would penetrate beyond a 0.6m (2 ft) distance in the space for the profile angle (A_p) between 0 to 72 degrees and the building elevation azimuth angle (A_z) beyond 72 degrees regardless of cloud cover condition.

Control strategy 2—shades are controlled as in control strategy 1, but left open during overcast conditions which assumed as when direct normal illuminance is less than 2500 lux (250 fc).

Control strategy 3—shades are closed when the workplane illuminance at the reference point on the workplane exceeds 2000 lux (250 fc).

Table 2. Window unit and shade properties

Window/shades	Transmittance (T_{vis})	Reflectance (ρ)
Window unit	0.64	0.12
White shade (WS) 	0.14	0.71
Dark shade (DS) 	0.04	0.05

3. Simulation Tool: DAYSIM

DAYSIM (Reinhart & Walkenhorst, 2001) is a daylight simulation program that employs the daylight coefficient (Tregenza & Waters, 1983) method and the Perez all-weather sky model (Perez, Seals, & Michalsky, 1993) in daylighting calculations. The program applies the RADIANCE raytracing engine with all surfaces assumed to be Lambertian (perfectly diffuse). The illuminance values are measured at the measurement points. Luminance values are obtained from the following Equation 1.

$$L = (E * \rho) / \pi \quad (1)$$

Where,

L = Luminance at the reference point [cd/m^2]

E = Illuminance at the reference point [Lux]

ρ = Surface reflectance

π = pi value [3.412]

DAYSIM offers the ability to analyze illuminance at points that are specified by the user, the example case study considered measurement points as shown in Figure 2;

- 1) VDT screen (VDT),
- 2) Paper Task (PAPER),
- 3) Adjacent wall (ADJ),
- 4) Remote wall (REMOTE)

and Figure 3 with

5) Window (WINDOW) using a shielded illuminance sensor position for average window luminance measurement.

The room reflectances are 0.80/0.60/0.30 for ceiling/ wall/ floor with furniture reflectance of 0.50.

4. Luminance Analysis

Luminances at the points of interest and the average window luminance are obtained as follows. Annual hourly illuminances are computed at the measurement points (Figure 2). Then, the luminance at each point is obtained through the surface reflectance. Two primary tasks were analyzed, a paper task (PAPER) and a Video Display Terminal unit (VDT). For the VDT, an average luminance of $200 \text{ cd}/\text{m}^2$ is applied for the self-luminous monitor.

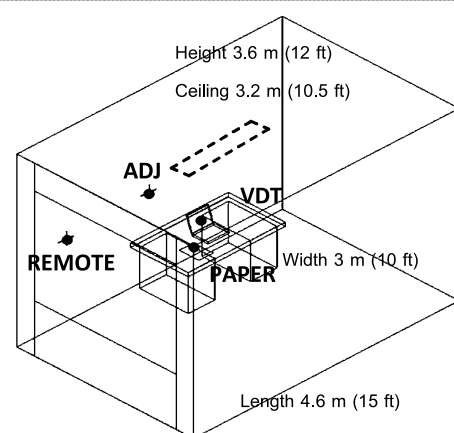


Figure 2. Location of illuminance sensors used in order to measure the luminance.

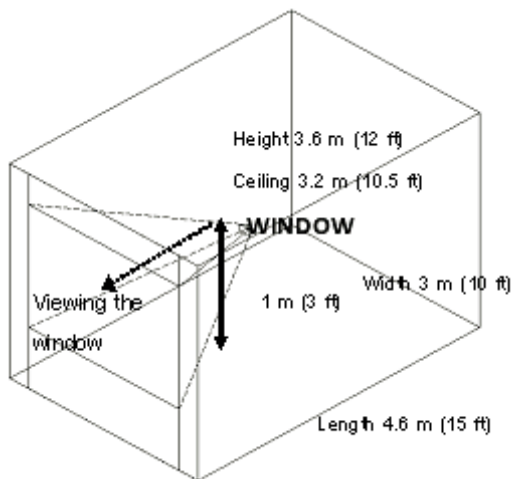


Figure 3. Location of a shielded illuminance sensor that are used to compute room surface luminances.

Average window Luminance (cd/m^2) is adapted from the methodology described by Littlefair, Aizlewood and Birtles (1994). The methodology suggests the use of a shielded cone with a matte black surface ($\rho = 0$) on an illuminance sensor to limit the sensor's view to the window (WINDOW sensor in Figure 3).

The average window luminance is then calculated from the following Equation 2.

$$L_s = \frac{E_{shielded}}{\pi * \phi} \quad (2)$$

Where,

L_s = the average window luminance (cd/m^2)

$E_{shielded}$ = the average vertical illuminance from the shielded illuminance sensor (lux)

ϕ = the configuration factor from the window to the shielded sensor

Luminance ratios throughout the year are analyzed by calculating the number of daylight hours (Hrs) at the points of interest where the luminance ratio exceeds the recommended value, with separate accounting of ratios that are too low (hi:lo) versus too high (lo:hi). The higher the number of hours, the greater the potential that luminance will negatively impact an occupant's visual quality.

The results have been used to compare the performance of three different shade control strategies with two different shade colors on two orientations.

5. Results

The results of luminance ratios hours are shown on Figures 4-7. Luminance ratios for the tasks and surfaces in the room show that, without shades (NO SHADE) there are more hours (up to 3,000 daylight hours per year) with excessive luminance ratios both for hi:lo and lo:hi ratios compared to when shades are used all day without control (WITH SHADE) or when shades are automatically controlled (CONTROL 1 through CONTROL 3) for both shade colors.

For the tasks and the proximate surface with white and dark shades always down (WITH SHADE), the VDT: ADJ ratio produces a greater number of problematic high to low (VDT>ADJ) luminance ratio hours (up to 4,000 daylight hours per year for the dark shades) than the case without shades (NO SHADE). This is due to the higher luminance ratio of the VDT to the wall behind it, which exceeded the recommended 3:1 ratio even at a night-time condition. Hence, by providing higher daylight levels with shade control, this ratio is reduced.

White shades with control strategy 1 (CONTROL 1) showed the least hours with high to low ratios (VDT >ADJ) that exceeded the recommendations, while with the dark shades, control strategy 3 (CONTROL 3) showed the least hours with excessive low to high luminance ratios (ADJ > VDT).

For the tasks and distant surfaces, the window luminance (WINDOW) is potentially important, although the window may not be in the occupants' general field of view if the worker faces parallel to the window wall.

Window luminance ratios are improved through the use of darker shades all day (WITH SHADE). Other controls showed similar luminance ratio results on distant surfaces with control strategy 1 (CONTROL 1) showing the least hours outside the range for VDT: WINDOW and PAPER: WINDOW.

The west and south orientations show similar trends with fewer hours outside the range on the south orientation. The results show that white shades improve the luminance ratios in the space more than do the dark shades.

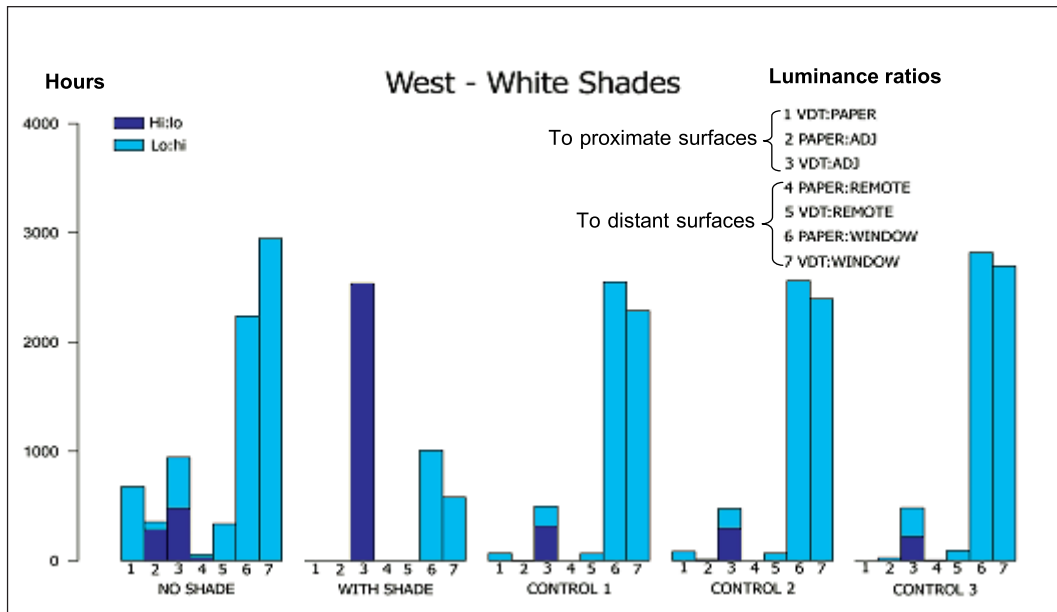


Figure 4. The number of hours where luminance ratios exceed recommended values for a west-facing test space with white shades under different shade control strategies.

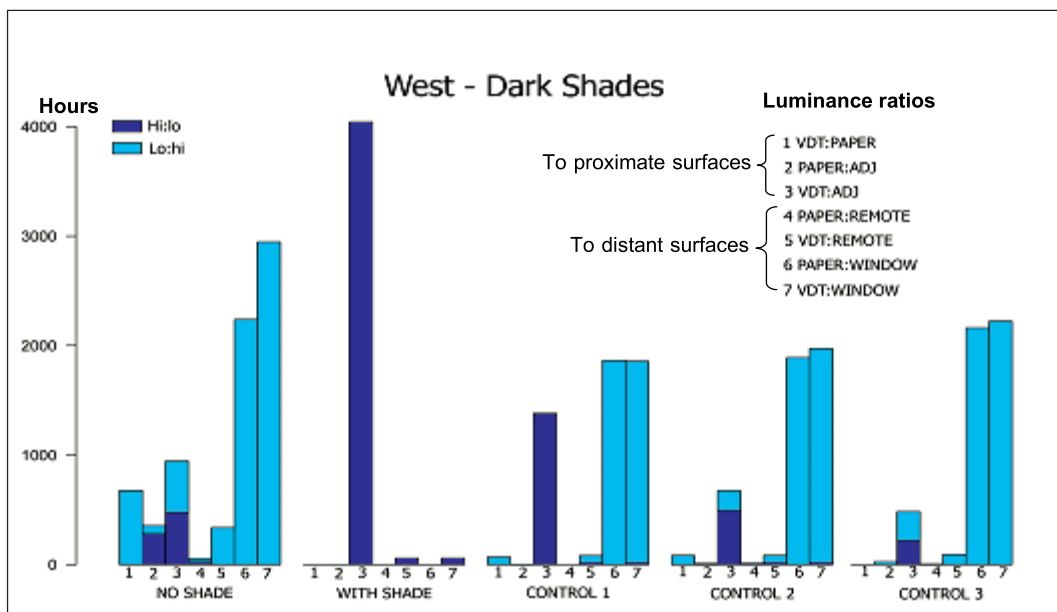


Figure 5. The number of hours where luminance ratios exceed recommended values for a west-facing test space with dark shades under different shade control strategies.

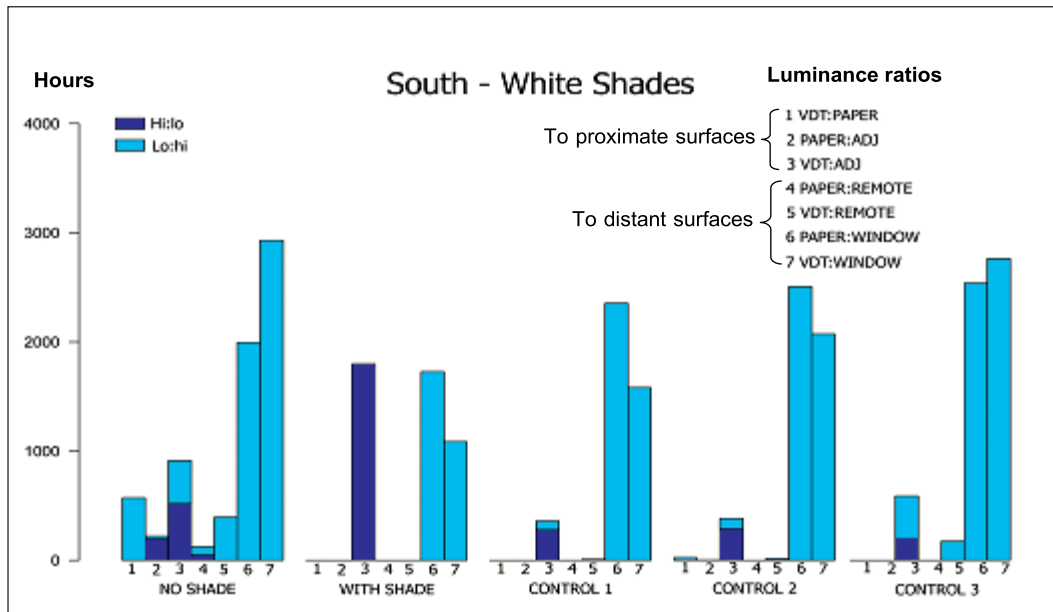


Figure 6. The number of hours where luminance ratios exceed recommended values for a south-facing test space with white shades under different shade control strategies.

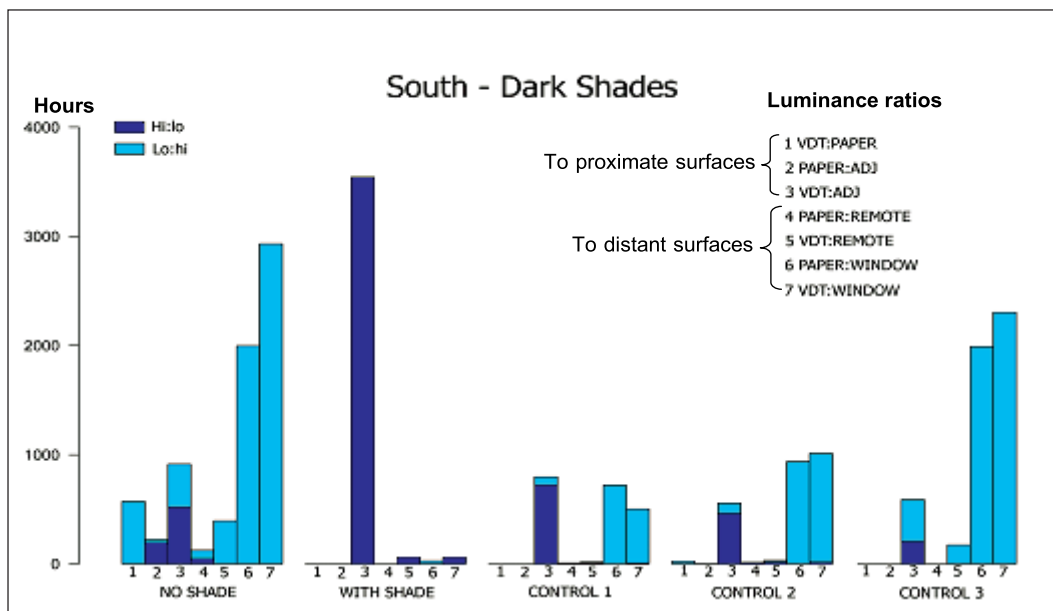


Figure 7. The number of hours where luminance ratios exceed recommended values for a south-facing test space with dark shades under different shade control strategies.

6. Conclusions

The annual luminance ratio analysis in DAYSIM provides detailed results for daylight conditions present over the course of the year. In the example provided, it suggests that the use of shades can help improve visual quality in the space by means of luminance ratios.

White shades help improve the luminance ratios for the tasks and the proximate surfaces while the dark shades help improve the luminance ratios between the task and the distant surfaces when used all day. Three shade control strategies produce somewhat similar results when used with white

shades, while dark shades provide larger differences across these three cases. And the south-facing space tends to have more problematic luminance ratio hours than the west-facing space.

The study also shows that the use of shades with automatic control strategies can improve luminance ratios within the space than when shades are closed all day without altering.

When shades are left open, even with no direct sunlight in the space, task to window luminance ratios will often exceed 1:10. Further studies may be needed to determine if these conditions are acceptable for occupants that do not face the windows.

References

- IESNA. (2000). *The IESNA lighting handbook (9th ed)* New York: IESNA.
- Littlefair, P. J., Aizlewood, M. E., & Birtles, A. B. (1994). Performance of innovative daylighting systems. *Renewable Energy*, 5(5-8), 920-934.
- NREL. (1995). *Typical meteorological years: 1961-1990 National solar radiation data base*. Retrieved August, 2007, from http://rredc.nrel.gov/solar/old_data/nsrdb/tmy2/
- Perez, R., Seals, R., & Michalsky, J. (1993). All-weather model for sky luminance distribution. Preliminary configuration and validation. *Solar Energy*, 50(3), 235-245.
- Reinhart, C. F., & Walkenhorst, O. (2001). Validation of dynamic RADIANCE-based daylight simulations for a test office with external blinds. *Energy and Buildings*, 33(7), 683-697.
- Tregenza, P. R., & Waters, I. M. (1983). Daylight coefficients. *Lighting Research and Technology*, 15(2), 65-71.
- Wankanapon, P. (2009). *The impact of translucent fabric shades and control strategies on energy savings and visual quality*. The Pennsylvania State University, University Park.