Integrated Tensile Fabric Curved-Ceiling with Lightshelf for Daylight Performance in Office

Abstract

This research presented the optimization of lightshelf performance with curved ceiling geometries. An innovative design of Polyester - PVC Fabric curved ceiling using tensile structure for the purpose of applying to existing rooms are designed, developed and tested using simulation models in DIALux. The Illuminance level, the reach of daylight admission, the distribution uniformity and the visual quality using luminance ratio were assessed on a working plane of commonly found open-plan office spaces with the depth of 8 meters or more. The Polyester – PVC fabric optical properties are as followed; visible reflectance (e) 0.88, and visible transmittance 0.07 (t). The study compared the results of a room installed with lightshelf (internal 0.5 m., and external 1.00 m.) and the regular ceiling to the room with tensile fabric curved ceiling of 4 types, 1) concave curve facing openings 2) concave curve facing away from openings 3) convex curve facing openings and 4) convex curve facing away from openings. The radius of the curvature and the installation dimension affecting the daylight performance are also studied. The application of the ceiling’s tensile structure with the benefit of its lightweight is presented. The simulation results shown that the ceiling form of concave curve facing into the room are the best geometries to increase the reach of daylight deeper into the space for 1 meter more with more uniformity.
บทคัดย่อ

งานวิจัยนี้นำเสนอการออกแบบเพื่อเพิ่มประสิทธิภาพหิ้งสะท้อนแสงด้วยฝ้าเพดานรูปทรงโค้ง โดยใช้นวัตกรรมฝ้าเพดานในโพลีเอสเตอร์ – พีวีซีรูปทรงโค้งเพื่อเพิ่มแสงธรรมชาติให้กับอาคารสำนักงานผ่านการทดสอบออกแบบและประเมินผลด้วยโปรแกรมจำลองสภาพแสง DIALux โดยการประเมินประสิทธิภาพแสงเพื่อเหมาะสมใช้งานในด้านค่าความสว่างบนพื้นที่ใช้งาน ค่าความสม่ำาเสมอของแสง และความสบายตาในการมองเห็นในเรื่องค่าอัตราส่วนความสว่างสะท้อนจากมิวัวตูร์ ของอาคารสำนักงานพื้นที่ใช้งานรวมกัน ความสัดส่วน 8.0 เมตรขึ้นไป โดยใช้วัสดุฝ้าเพดานรูปทรงโค้ง – ผ้าใบโพลีเอสเตอร์ ซึ่งมีคุณสมบัติค่าการสะท้อนแสง 0.88 และค่าการส่องผ่านแสง 0.07 การศึกษาเปรียบเทียบดังกล่าวได้ทำาในแบบจำลองห้องสำนักงานพื้นที่ใช้งานรวมกับหิ้งสะท้อนแสง อายุ 0.50 เมตร ระยะทางหิ้งสะท้อนแสง 1.00 เมตร และฝ้าเพดานรูปทรงโค้งแบบ 4 รูปแบบ ได้แก่ รูปทรง 1) โค้งเข้าช่องเปิด 2) โค้งหลุดออกจากช่องเปิด 3) โค้งเข้าช่องเปิด และ 4) โค้งหลุดออกจากช่องเปิด ในการศึกษาครั้งนี้ประกอบด้วยตัวแปร 1) รัศมีความโค้ง และ 2) ระยะการติดตั้ง ที่ส่งผลต่อประสิทธิภาพการกระจายแสงธรรมชาติเข้าสู่พื้นที่ใช้งานภายใน รวมถึงการประเมินค่าความสว่างสะท้อนแสงและการคำนวณเปรียบเทียบในอาคารจริงในลักษณะจะใช้รูปแบบต่อไปนี้: รูปแบบเพดานที่มีศูนย์กลางที่เพดานที่มีรูปทรงผิวเพดานแบบรูปทรงโค้งที่รูปแบบแบบ a) ระยะการติดตั้ง 1.00 เมตร เมื่อเทียบกับหิ้งสะท้อนแสงที่มีฝ้าเพดานแบบเรียบและให้ความสม่ำาเสมอของแสงมากขึ้น

Keywords (คำสำคัญ)

Illuminance Level (ระดับค่าความสว่าง)
Daylight Admission (แสงธรรมชาติที่ได้รับ)
Uniformity (ค่าความสม่ำาเสมอ)
Luminance (ค่าความสว่าง)
1. Introduction

Bringing daylight into building has significant benefits in lighting energy savings and increase workers’ productivity (Heschong Mahone Group, 2003). By providing daylight, designers should consider the consequential cooling loads and also visual quality of building occupants. In hot-humid climate regions like Thailand, the main concern is to limit the direct sunlight and glare. Hence, many buildings are designed with only small openings. With its low ceiling of 2.50 meters or lesser, the daylight level and the reach of daylight admission into room are limited especially those of office buildings with the depth of 8.00 meters or more. The purpose of this research is to explore the performance of a lightshelf with the innovative design of integrated curved ceiling geometries to increase the daylight performance and also providing good visual quality. This study applied software simulation, DIALux to understand the overall impact on daylight performance.

2. Related work

The lightshelf is a horizontal plane component with a reflective upper surface that projects over a view window. It could be an internal, external or both. As a daylighting system, it is designed to block the direct sunlight for view windows while bouncing more daylight through upper windows towards the ceiling, which potentially reflects daylight deeper into the room. It also helps reduce high illuminance level occurred near windows, provides more uniformity across the workplane and decrease the use of lighting energy. The properties of lightshelf depend on dimensions, orientations, locations, reflectance of lightshelf and ceiling, and the weather conditions which yield significant factors influencing lightshelf performance.

Many literatures have shown that using lightshelf can reduces cooling load when acts as a shading devices. It also helps reflecting light deeper into the room providing more uniformity and improving visual quality. Edmonds and Greenup (Edmonds & Greenup, 2002) studied various innovative daylighting systems that provide shading and daylighting. They demonstrated that a lightshelf is a good shading device and daylighting system. Although lighshelves are supposed to improve daylight levels and save energy use, these advantages are not happened all the time. Kim, G. (Kim, 2009) studied the performance of lightshelf and provides different guidelines on utilizing different size of internal and external lightshelves. Freewan, A.A. (Ahmed A. Freewan, 2010; A. A. Freewan, Shao & Riffat, 2008) studied the use of lightshelf with different geometries of ceiling and lightshelf itself. It was found that by using the curved ceiling in the front and the rear of the room, higher reach of daylight admission at 52% at the back of the room and more uniformity are achieved. However, to apply this curve ceiling geometry on existing space without altering architectural form is somewhat difficult.

Hence, this research intended to optimize the lightshelf performance using integrated curved ceiling with the design concept as shown on Figure 1.

Figure 1. Daylight redirection concept of (a) regular ceiling and (b) curved ceiling.
3. Design criteria

Many materials are investigated to see their appropriate optical and thermal properties to apply as a curved ceiling to improve the daylight performance of the lightshelf and also not to increase the cooling loads.

The objectives of this innovative design component are; 1) lightweight, easy to install indoor, 2) can be curved 3) high light reflectance and 4) low UV transmittance.

The study yielded the selection properties as seen in Figure 2 and Table 1. The selection is due to its highest reflectance, its ability to curve as a tensile structure, its lightweight, and its ability to retain form when curved and including the ease of incorporation with existing ceiling.

4. Simulation

The simulations were done in the lighting simulation program, Dialux 4.11, to assess the different curve geometries daylight performance with lightshelf. The study was performed on a theoretical open-plan office space, 6.0 x 12.0 m (20 ft x 40 ft) with a ceiling height of 2.5 m (8.2 ft) as seen in Figure 3 with windows facing south orientation. The room reflectance is at 0.80/0.50/0.20 (ceiling/walls/floor). The window-to-wall area ratio was 0.4 with the workplane height of 0.75 m (2.5 ft) and a window size of 1.2 m high and 4.9 m wide (3.9 ft x 16 ft) with the lower sill height of 0.8 m (2.6 ft) and the glazing transmittance of 0.60. The clear sky, partly cloudy and overcast sky of June, September and December 21st at 10:00 and 14:00 are studied in test cases because it is time building applications.

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**Figure 2.** Color and physical appearance of different fabric materials (Construction Manual for Polymers + Membranes: Materials, Semi-finished Products, Form-Finding, Design, 2011)

**Table 1.** Different fabric materials’ optical and physical properties (Knippers, Cremers, Gabler & Lienhard, 2011)

<table>
<thead>
<tr>
<th>Fabric</th>
<th>Solar/Visible Transmittance</th>
<th>Solar/Visible Reflectance</th>
<th>UV Transmittance</th>
<th>UV Reflectance</th>
<th>Weight (kg/m²) / Pre-stress force (kN/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyester-PVC</td>
<td>0.09/0.07</td>
<td>0.78/0.88</td>
<td>0.00</td>
<td>0.10</td>
<td>0.8-1.45/2.0-6.0</td>
</tr>
<tr>
<td>Glass-Fiber-PTFE</td>
<td>0.15/0.15</td>
<td>0.78/0.82</td>
<td>0.03</td>
<td>0.63</td>
<td>0.8-1.45/3.0-9.0</td>
</tr>
<tr>
<td>Glass-Fiber Mesh-PTFE</td>
<td>0.47/0.47</td>
<td>0.40/0.45</td>
<td>0.30</td>
<td>0.42</td>
<td>0.8-1.45/3.0-9.0</td>
</tr>
<tr>
<td>PTFE-Coated</td>
<td>0.41/0.38</td>
<td>0.51/0.59</td>
<td>0.12</td>
<td>0.09</td>
<td>0.8-1.45/3.0-9.0</td>
</tr>
<tr>
<td>PTFE-Uncoated</td>
<td>0.41/0.38</td>
<td>0.51/0.59</td>
<td>0.12</td>
<td>0.09</td>
<td>0.8-1.45/3.0-9.0</td>
</tr>
</tbody>
</table>
Figure 3. (top) plan of the study space showing the measurement grid of 0.5 x 0.5 m (bottom) the section of study space showing the workplane level of 0.75 m.

Four ceiling curvatures with the reflectance of Polyester-PVC fabric are modeled as; Curve 1-concave facing the room, Curve 2-concave facing openings, Curve 3-convex facing openings and Curve 4-convex facing the rooms. The curved ceiling geometries are tested together with high reflectance ($\rho=0.8$) of external and internal lightshelf of 1.0 m (3.2 ft) and 0.50 m (1.6 ft) respectively as shown in Figure 4.

The curvatures are optically formed using the elliptical shape with the formula as followed;

$$\frac{x^2}{A^2} + \frac{y^2}{B^2} = 1, \text{ when } A \geq B, \ A^2+C^2 = B^2 \text{ and } B = 0.5$$  \[1\]

The required illuminance at a selected work plane measurement point on a desk height of 0.75 m (2.5 ft) was in the range of 200 – 1000 lux (20-100 fc).

5. Results

The simulation results showed that the best curvature to provide illuminance level within the acceptable range of 200–1000 lux and reach deeper into the room is Curve 1, concave shape facing the room, with A dimension of 1.25 m (4 ft) and B dimension of 0.5 m (1.6 ft) as seen on Figure 5.

The reach of daylight admission is at 6.25 m (20.5 ft) which more than 5.75 m (18.8 ft) of the case with only lightshelf (Base case) shown on Figure 6. The Curve 1 also improved uniformity a little in all simulated time when compare with the standard windows with light shelf (Base case).
Figure 5. Comparison results of different curvatures.

Figure 6. Daylight distributions of a Base case, windows with lightshelf only (black, dotted black line) and a curved ceiling case with light shelf (color, dotted color line) at 10:00 and 14:00 hrs on March 21, clear sky condition.

6. Luminance Ratios

The luminance ratio between the task and surround luminance is an additional measure of lighting quality. The IESNA (IESNA, 2010) states that luminance ratios generally should not exceed the following recommendation in Table 3 for critical work task environments. To analyze the visual quality of the room with the present of curved ceiling and lightshelf, the luminances are obtained from 8 views of occupants seating as shown in Figure 7 while facing the wall with windows on their left hand side. The desk luminance are considered “Task” and the adjacent desk and front wall are considered “Adjacent surroundings” while the wall near windows considered “Remote surfaces”

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Recommended Ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between paper task and adjacent VDT screen</td>
<td>3:1 or 1:3</td>
</tr>
<tr>
<td>Between task and adjacent dark surroundings</td>
<td>3:1 or 1:3</td>
</tr>
<tr>
<td>Between task and remote (non-adjacent) surfaces</td>
<td>10:1 or 1:10</td>
</tr>
</tbody>
</table>

Table 3. Recommended luminance ratios by IESNA. (IESNA, 2010)
It was found that with the present of curved ceiling and lightshelf clearly help the area near the window (0.00 – 6.00 m from the window) to pass the luminance ratio recommendation.

The lightshelf helps redirect light upward and the curved ceiling help redirect and diffuse daylight to the deeper area of the room (6.00 - 12.00 m) as seen in Figure 8.

7. Building Application

The curved ceiling geometry with lightshelf is proven to help increase daylight distribution into the room without compromising the visual quality. The authors aim is to incorporate the use of this finding into building application. Tensile structure is used with detail of components as followed:

1) The tensile structure using the L-profile metal bar

2) Stabilizing cables are used to provide the Polyester-PVC fabric with the form of the curved.

3) The Polyester-PVC fabric are used

4) The lightshelf of gypsum or cement board with high reflectance paint are cut and attached as external and internal light shelf to the existing windows. (Only internal lightshelf will be used in some difficult application)
8. Conclusions

This paper explored the optimization of light-shelf performance with curved ceiling geometries and also aimed for incorporate the findings as an innovative design daylight delivery systems. The simulations are used to understand the overall impact of the curved geometries in terms of illuminance level, reach of daylight admission, uniformity and visual quality regarding luminance ratios. The best curved ceiling shape found was the elliptical concave curve facing the room. The results showed the geometry increase illuminance level deeper in the room for 1 meter more comparing to the Base case and with more uniformity and better visual quality. The selected Polyester-PVC fabric with its high-reflectance and lightweight can be easily applied with the tensile structure to create the curved shape required. Further work needs to be done on the lighting energy saving potential when applied this innovative daylight delivery systems with lighting control systems. In addition the physical experiment should be done to confirm the simulation performance. The prototypes are currently under development and patent pending (Figure 7).
References


