

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

การออกแบบฝ้าเพดานผ้าใบที่ใช้งานร่วมกับหิ้งสะท้อนแสงเพื่อเพิ่มประสิทธิภาพการใช้ประโยชน์จากแสงธรรมชาติสำหรับอาคารสำนักงาน

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### 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

งานวิจัยนี้นำเสนอการออกแบบเพื่อเพิ่มประสิทธิภาพหึ่งสะท้อนแสงด้วยผ้าเพดานรูปทรงโค้ง โดยใช้นวัตกรรม ผ้าเพดานผ้าใบโพลีเอสเตอร์ – พีวีซีรูปทรงโค้งเพื่อเพิ่มแสงธรรมชาติให้กับอาคารสำนักงาน ผ่านการทดสอบ ออกแบบ และประเมินผลด้วยโปรแกรมจำลองสภาพแสง DIALux โดยการประเมินประสิทธิภาพแสงธรรมชาติบนระนาบใช้งานในด้านค่าความสว่างบนพื้นที่ใช้งาน ค่าความสม่ำเสมอของแสง และความสบายตาในการมองเห็นในเรื่องค่าอัตราส่วนความสว่างสะท้อนจากผิววัสดุ ของอาคารสำนักงานที่มีพื้นที่ใช้สอยร่วมกัน ความลึกตั้งแต่ 8.0 เมตรขึ้นไป โดยวัสดุผ้าใบโพลีเอสเตอร์ – พีวีซีที่เลือกใช้มีคุณสมบัติพื้นฐานค่าการสะท้อนแสง 0.88 และค่าการส่องผ่านแสง 0.07 การศึกษาเปรียบเทียบดังกล่าวได้ทำในแบบจำลองห้องสำนักงานพื้นที่ใช้สอยร่วมกันที่ใช้งานร่วมกับหึ่งสะท้อนแสงยื่นออกไปภายนอก 1.00 เมตร และยื่นเข้ามาภายใน 0.50 เมตร ระหว่างผ้าเพดานทั่วไปแบบเรียบ และผ้าเพดานผ้าใบรูปทรงแบบโค้งวงรี 4 รูปแบบ ได้แก่ รูปทรง 1) โค้งเว้า หันหน้าเข้าช่องเปิด 2) โค้งเว้าหันหน้าออกจากช่องเปิด 3) โค้งนูนหันหน้าเข้าช่องเปิดและ 4) โค้งนูนหันหน้าออกจากช่องเปิด ในการศึกษาครั้งนี้ประกอบด้วยตัวแปร 1) วัสดุมีความโค้ง และ 2) ระยะการติดตั้ง ที่ส่งผลถึงประสิทธิภาพการกระจายแสงธรรมชาติเข้าสู่พื้นที่ใช้งานภายใน รวมถึงการประยุกต์ใช้ร่วมกับหึ่งสะท้อนแสงและการคำนึงถึงการออกแบบในการใช้งานกับอาคารจริงในลักษณะชุดอุปกรณ์สำเร็จรูป ในลักษณะโครงสร้างผ้าใบรับแรงดึง (tensile structure) จากการศึกษาพบว่า รูปแบบผ้าเพดานโค้งเว้าหันหน้าออกจากช่องเปิดเมื่อใช้งานร่วมกับหึ่งสะท้อนแสง ทำให้ค่าความสว่างในห้องในระยะที่ลึกขึ้น 1.00 เมตร เมื่อเทียบกับห้องกรณีพื้นฐานที่มีผ้าเพดานแบบเรียบและให้ความสม่ำเสมอของแสงมากขึ้น

## Keywords (คำสำคัญ)

Illuminance Level (ระดับค่าความสว่าง)

Daylight Admission (แสงธรรมชาติที่ได้รับ)

Uniformity (ค่าความสม่ำเสมอ)

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.

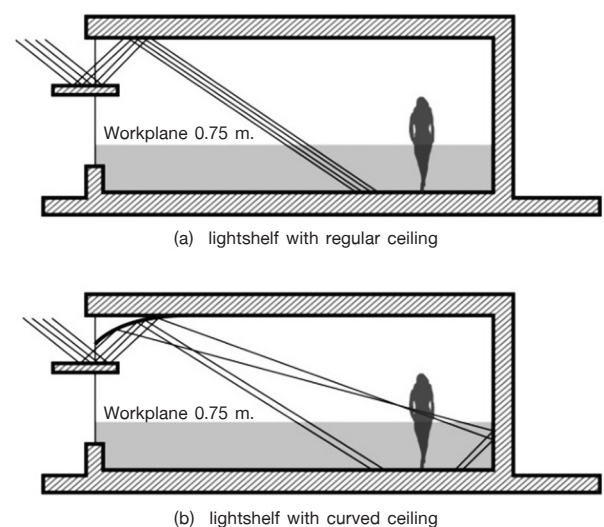
## 2. Related work

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

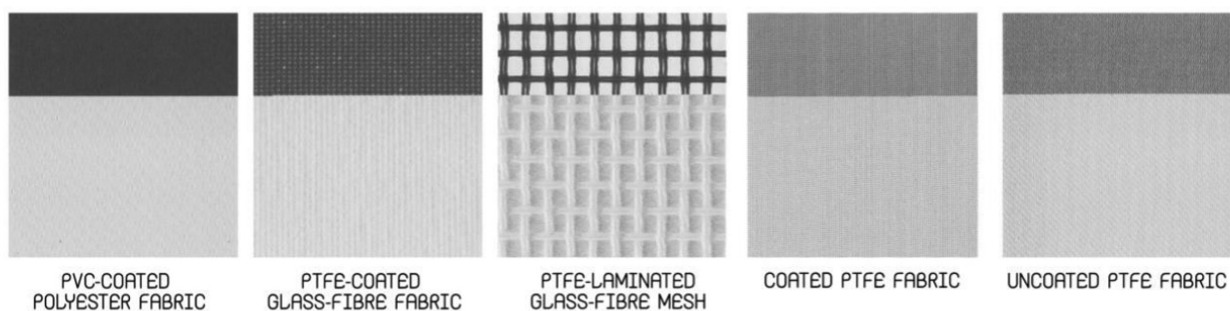
Many materials are investigated to see their appropriate optical and thermal properties to apply as a curved ceiling to improve the daylight performance of the lightshelf and also not to increase the cooling loads.

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

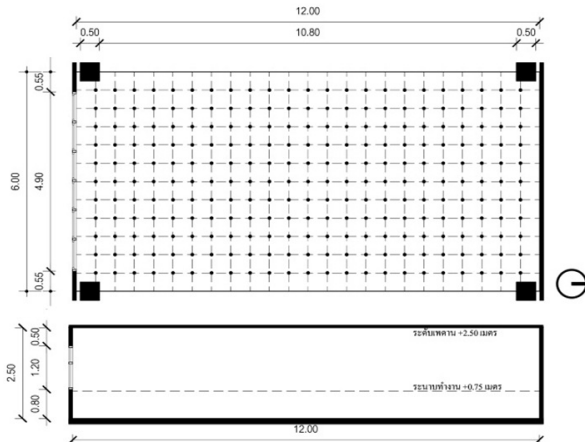
The simulations were done in the lighting simulation program, DIALux 4.11, to assess the different curve geometries daylight performance with lightshelf. The study was performed on a theoretical open-plan office space, 6.0 x 12.0 m (20 ft x 40 ft) with a ceiling height of 2.5 m (8.2 ft) as seen in Figure 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 x16 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.



**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)

Fabric	Solar/Visible Transmittance	Solar/Visible Reflectance	UV Transmittance	UV Reflectance	Weight (kg/m <sup>2</sup> ) / Pre-stress force (kN/m <sup>2</sup> )
Polyester-PVC	0.09/0.07	0.78/0.88	0.00	0.10	0.8-1.45/2.0-6.0
Glass-Fiber-PTFE	0.15/0.15	0.78/0.82	0.03	0.63	0.8-1.45/3.0-9.0
Glass-Fiber Mesh-PTFE	0.47/0.47	0.40/0.45	0.30	0.42	0.8-1.45/3.0-9.0
PTFE-Coated	0.41/0.38	0.51/0.59	0.12	0.09	0.8-1.45/3.0-9.0
PTFE-Uncoated	0.41/0.38	0.51/0.59	0.12	0.09	0.8-1.45/3.0-9.0



**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;

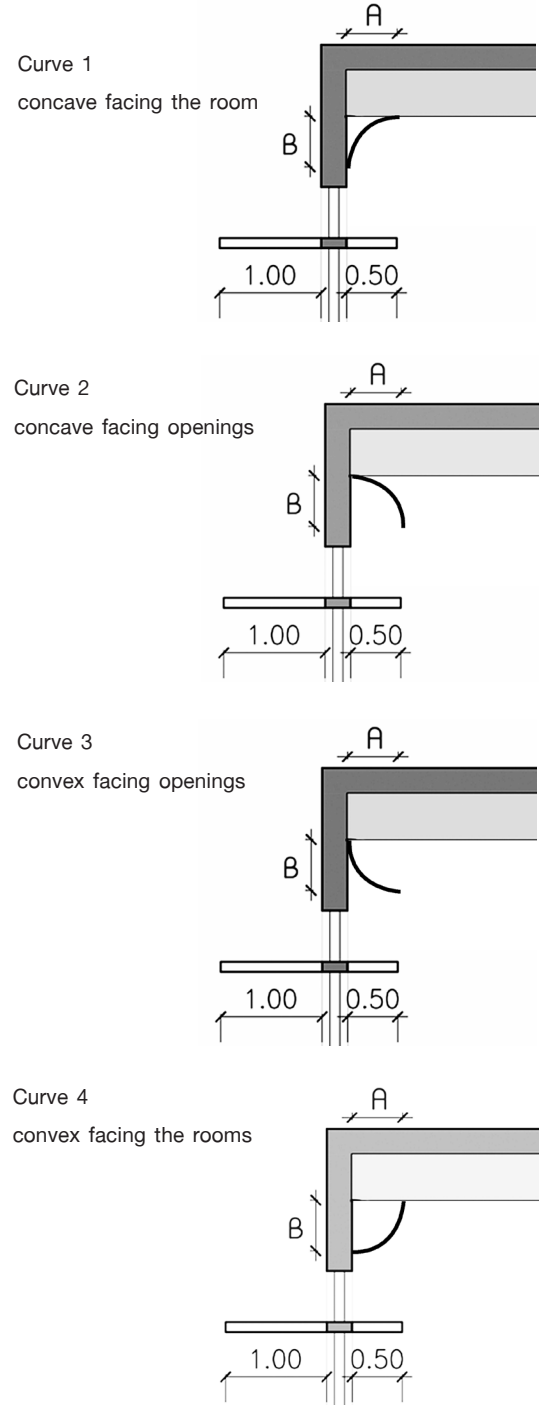
$$\frac{x^2}{A^2} + \frac{y^2}{B^2} = 1, \text{ when } A \geq B, A^2 + C^2 = B^2 \text{ and } B = 0.5$$

----- [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 with in 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.



**Figure 4.** Four types of ceiling curvatures.

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).

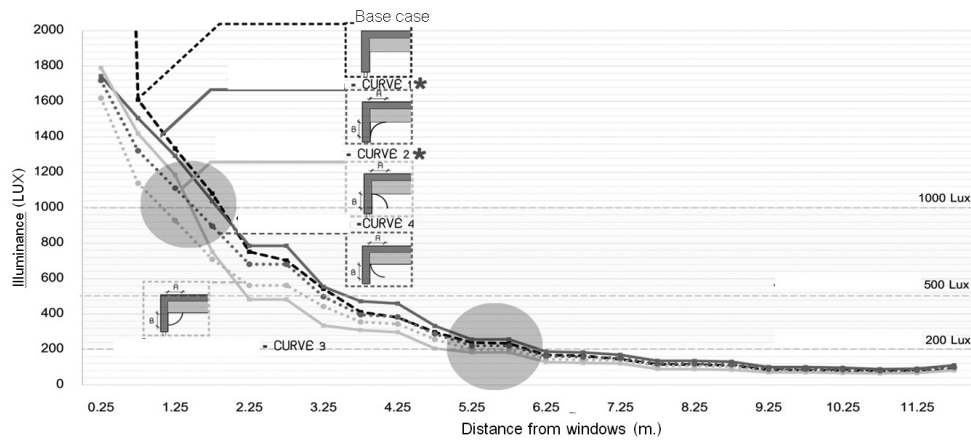


Figure 5. Comparison results of different curvatures.

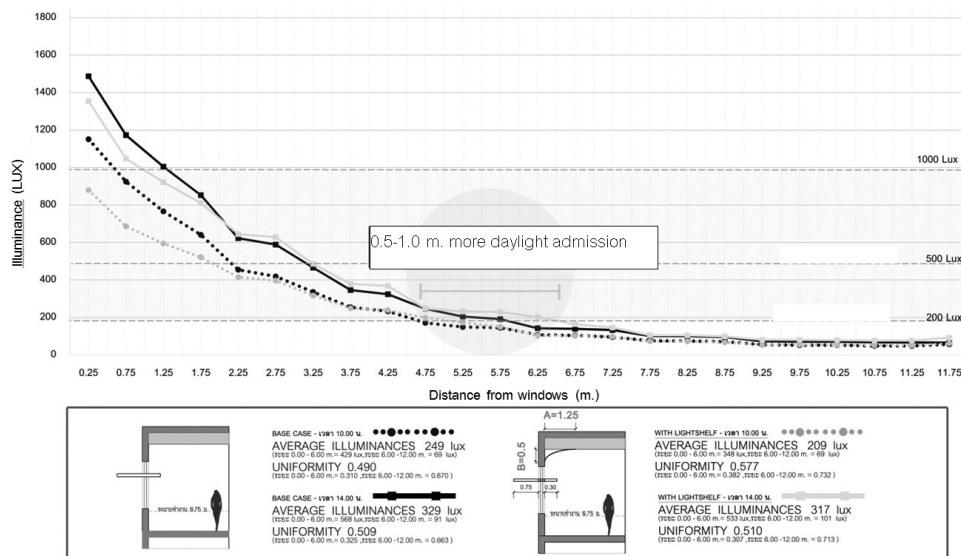


Figure 6. Daylight distributions of a Base case, windows with lightshelf only (black, dotted black line) and a curved ceiling case with light shelf (color, dotted color line) at 10:00 and 14:00 hrs on March 21, clear sky condition.

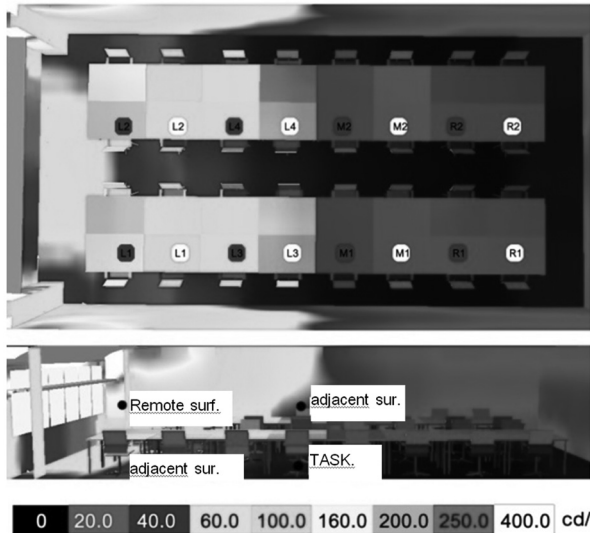
## 6. Luminance Ratios

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 3. Recommended luminance ratios by IESNA. (IESNA, 2010)

Between paper task and adjacent VDT screen	3:1 or 1:3
Between task and adjacent dark surroundings	3:1 or 1:3
Between task and remote (non-adjacent) surfaces	10:1 or 1:10





**Figure 7.** Measurement points for luminance ratio analysis.

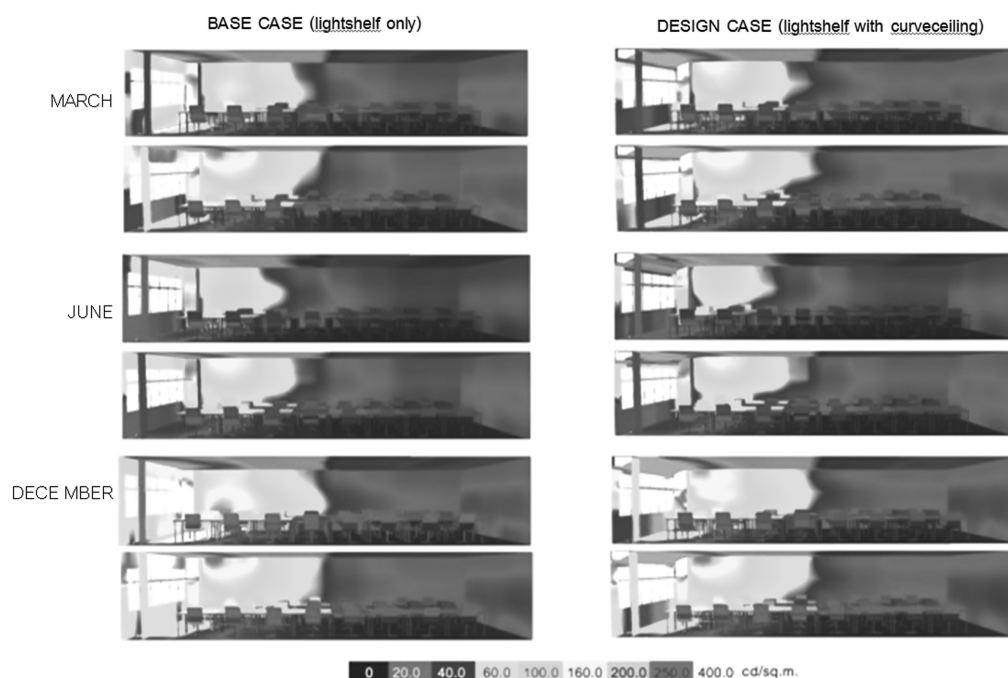
It was found that with the present of curved ceiling and lightshelf clearly help the area near the window (0.00 – 6.00 m from the window) to pass the luminance ratio recommendation.

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.

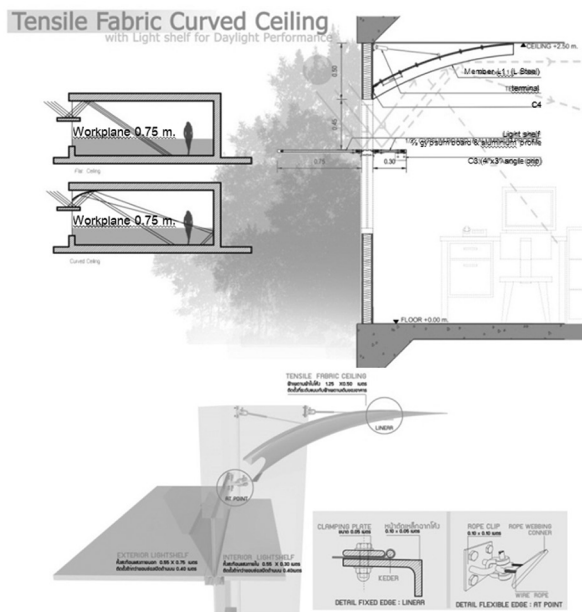
## 7. Building Application

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)



**Figure 8.** Luminance results of a Base case, windows only (Left) and a curved ceiling with lightshelf (Right) on Dec, Mar, Jun 21<sup>st</sup> at 10:00 and 14:00 hrs.



**Figure 9.** Drawings of the prototype of the Integrated Tensile Fabric Curved Ceiling with Lightshelf (Patent Pending).

## 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).



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