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EVALUATION OF DAYLIGHT ILLUMINANCE ON THE PERFORMANCE OF LIGHT SHELVES OF AN OFFICE ROOM

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Abstract

Influence of light shelves and its performance on illuminance level can make good improvement on daylight factor. Admission of daylight into the core of a building, light shelf plays an influential factor, also it improves the visual comfort environment. One of the best natural lighting system, which directs sunlight deeper with glare reduction and becomes an important sustainable architecture. Three contributions of natural daylight are - visual comfort to the eyes, reduction of energy consumption and low installation cost make it unique among innovative daylighting systems. This study consists of light shelf performance based on simulations and prototype measurements were carried out for verification of performance.

Keywords: Average daylight factor, Daylighting, Light shelf, Lightstanza, Sketchup model.

1. Introduction

In recent years, for sustainability and for achieving high energy efficiency in building design, many studies have focused on innovative light penetration systems like light shelves. Because of the impact on energy reduction due to light shelves, some studies also focus on dynamic daylighting systems. Benefits of daylighting can be achieved by effective utilization of (DLS) [1].

The basic concept behind the light shelf is that natural light comes into a building by reflecting from light shelf material and from indoor ceiling reflectance. Natural light gives a positive impact on health and electric billing cost. Today significant numbers still do not properly analyse during the operational phase.

Light shelf performance depends on position, shape (width, tilted or curved), the material used, the climate condition, obstruction of the sky as well as window size affect the performance of light shelf.

According to Lee et al. [2], for minimizing the effect from wind pressure, the perforated light shelf is used. Most efficient performance occurs in the southern orientation of the light shelf [3]. For reduced glare complaints, light shelves provide better indoor light [4]. Width-adjustable reflector light shelf gives more lighting energy [5]. Light shelf eliminates glare by providing shading near room window [6]. The movable light shelf will be helpful when users will use it in changing weather conditions [7]. Diffusion sheet can improve Uniformity in light shelf performance [8].

2. Prediction of Illuminance

For illuminance, prediction on an idea of a building one has to create a sketch up file. That sketch up file has to be imported to the simulation for the calculation of output based on the location and climatic condition. After the desired result is obtained, architects should start the decision on design building model. The complete decision-making process for prediction of illuminance is shown in Fig. 1.

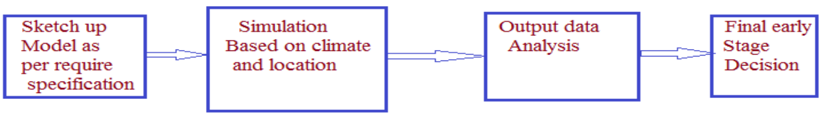


Fig. 1. Decision-making process for early prediction on illuminance.

In this study, an office room situated in Bhubaneswar was considered for evaluating the performance of illuminance value. The sketch up file for an office is shown in Fig. 2. Mohapatra et al. [9] explained that VELUX is useful for daylighting design as well as for simulation of building models to get information on daylight factor. Figure 3 shows the simulation output (consideration as per Table 1) for finding DF for the complete sketch up model. The simulation results for sketch up model indicate that no light as (DF almost equal to 0) will be there in the middle room. The south and north facing office rooms having daylight factor nearly about 8 near to the window, as in simulation contours image is shown and it is in red colour and it starts decreasing as we move away from the window of the room whether it's south or north facing of the room. Similarly, the results of illuminance value without a light shelf for the complete year for a fixed date is shown in Fig. 4.

Figure 4 indicates ISO-contour images for illuminance values of north, middle and south office rooms. The variation in result can be observed easily due to fixed date (21st) and time (11 a.m.), for all months of the year 2018.

Table 1. Simulation and prototype test model specifications and conditions.

	Simulation model	Prototype model
Sky condition year location	Clear sky 2018 latitude 20.25 and longitude 85.83	Clear sky 2018 latitude 20.25 and longitude 85.83
Working plane level	0.85 m	0.056 m
Lintel level	2.1 m	0.14 m
Window height	1.25 m	0.083 m
Window width	1.8 m	0.12 m
First room dimension	(3×5×2.8)	(0.2×0.33×0.186)
Facing	*N - S*	*N - S*
Light shelf	1.8 m × 0.5 m	0.12) × 0.06 m

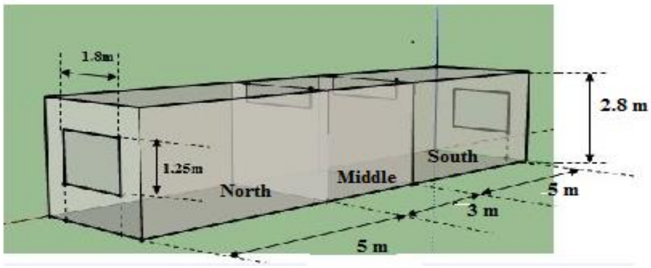


Fig. 2. Sketch up model of investigated shape of room (geometry and dimensions).

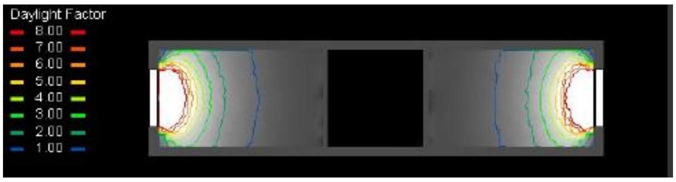


Fig. 3. VELUX simulation for finding daylight factor for complete sketch-up model of investigated office room.

(a) Whole office illuminance output for January 2018 at 11 a.m.

(b) Whole office illuminance output for February 2018 at 11 a.m.

(c) Whole office illuminance output for March 2018 at 11 a.m.

(d) Whole office illuminance output for April 2018 at 11 a.m.

(e) Whole office illuminance output for May 2018 at 11 a.m.

(f) Whole office illuminance output for June 2018 at 11 a.m.

(g) Whole office illuminance output for July 2018 at 11 a.m.

(h) Whole office illuminance output for August 2018 at 11 a.m.

(i) Whole office illuminance output for September 2018 at 11 a.m.

(j) Whole office illuminance output for October 2018 at 11 a.m.

(k) Whole office illuminance output for November 2018 at 11 a.m.

(l) Whole office illuminance output for December 2018 at 11 a.m.

Fig. 4. VELUX simulation for finding illuminance value for twenty-first of every month for complete year 2018 without light shelf.

The climatic temperature throughout the year is shown in Fig. 5. From Fig. 5, one can assure the temperature value to be between 15 to 38 degrees. Further, for clear understanding, more investigation was carried out only on one north office room instead of all other rooms, by investigating luminance values without light shelf and influence of light shelf was considered. The design consideration for the prototype is (15:1) scale of that simulation model. Table 1 describes the dimension of both simulations as well as the prototype model. The sketch up models are in Figs. 6(a), (c) and (e) and the prototype models are just right of the sketch up model, i.e., in Figs. 6(b), (d) and (f). A light shelf is always kept at a position above eye height, so it should be 1.6 meters, otherwise, light falling on the eyes of the occupants would be inconvenient. Angled light shelf solid work model, prototype and with reflecting mirrors are shown in Figs. 6(g) to (i).

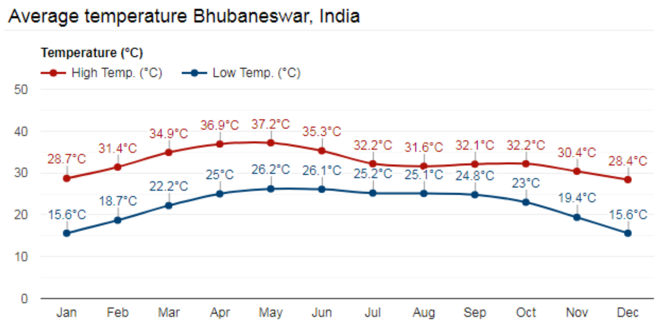
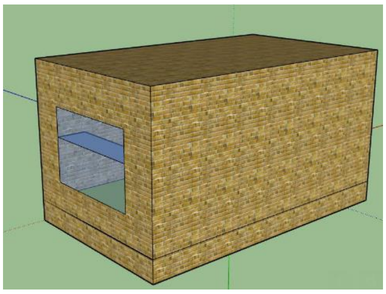
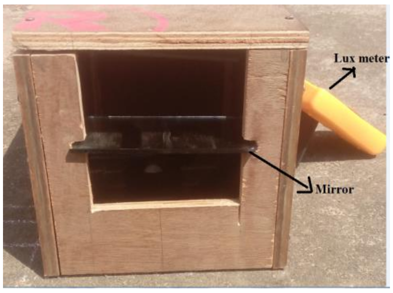


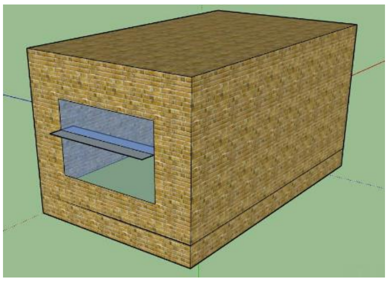
Fig. 5. Climatic condition throughout the year in Bhubaneswar [10].



(a) Sketch up design of office room for internal light shelf.

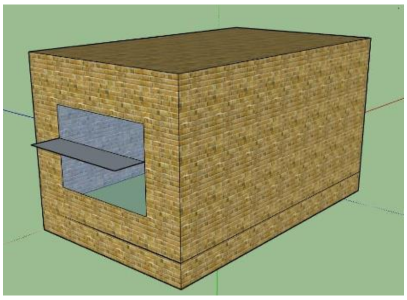


(b) Prototype model for internal light shelf.



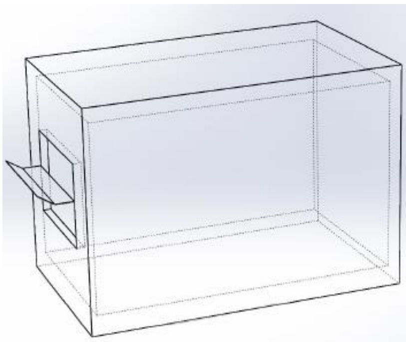
(c) Sketch-up design of office room for middle position of light shelf.

(d) Prototype model for middle position of light shelf.



(e) Sketch-up design of office room for external light shelf.

(f) Prototype model for external position of light shelf.



(g) Solid work design of office room for external flat and angled light shelf.

(h) Prototype model for external flat and angled light shelf.

(i) External angled light shelf with reflecting mirrors.

Fig. 6. Investigated shapes of simulation and prototype (geometry and dimensions).

For light shelf simulation, Lightstanza a web-based simulation tool was used to find illuminance levels. As one can design with any of the following formats - Rhino, Sketch-Up, IFC, Revit, the designs can be directly imported to Lightstanza. Learning is easy and organized results are produced by Lightstanza. Natural lighting simulation in homes can be performed by some advanced software nowadays [11].

Illuminance is defined by HyperPhysics [12]:

$$E = \frac{I \cos\theta}{r^2} \tag{1}$$

where θ is the angle between the plane perpendicular to the incident light and illuminated surface as shown in Fig. 7.

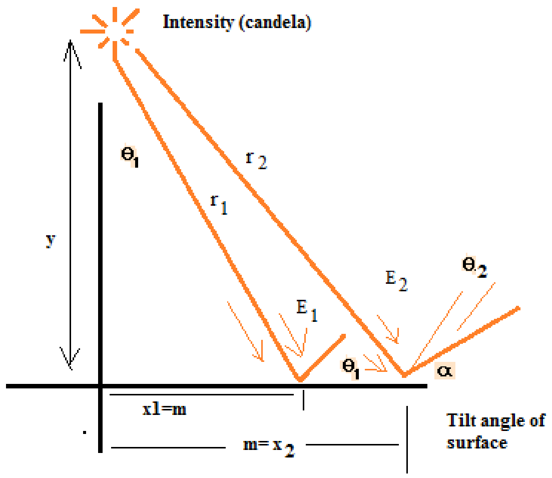


Fig. 7. Surface illuminance calculation.

3. Material Specification

Efficient utilization of solar energy inside a room requires a good light shelf. The material used for the light shelf surface should have properties like high absorption over the solar spectrum.

Many non-selective coatings are available for surface coating of a light shelf. Most of these coatings absorptance exceeds 0.95 and emittance is in between 0.85 to 0.90 as shown in Table 2.

As proposed by Ching et al. [13], organic coatings such as flat black paints have problems of moisture permeation and ultraviolet stability, which may be important in long-term degradation. Sheet aluminium can be made into a good reflective and is good for environmental stability [14, 15].

Table 2. Test model specifications and test conditions.

Coating	Type	Absorptance	Emittance
XS-111	Porcelain enamel	0.935	0.85
Nextel	Paint	0.98	0.89
Enersorb	Urethane paint	0.97	0.90

4. Results: Validation and Verification

The simulations are performed for the date 21st March in clear sky condition where the results are for the day hour, i.e., in between 9 a.m. to 5 p.m. as regular office hours.

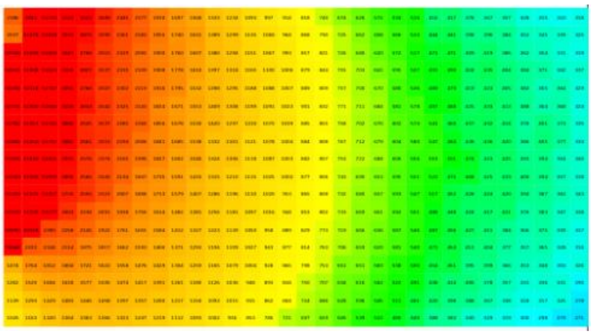
We choose March 21 as fixed date as well as only north office room so that it will be easier to understand the influence of light shelf. Based on studies by Zomorodian and Tahsildoost [16] and Jakica [17], the average lux value can be calculated easily by Lightstanza software for each hour of simulation.

The values are shown in Table 3. From Table 3, we can conclude that the use of external light shelf causes glare reduction and it is useful during the internal and middle light shelf position.

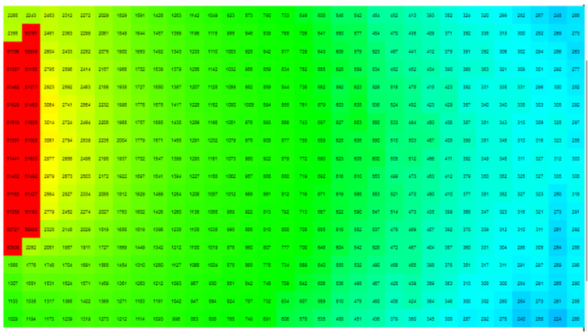
Simulation results at 11 a.m. of the day are shown in Figs. 8(a) (without), (b) (internal), (c) (middle), (d) (external) light shelves, where one can visualize better performance of illuminance value in external light shelf performance.

Table 3. Simulation output for average lux of room (3×5×2.8) performance by light shelf (*LS*).

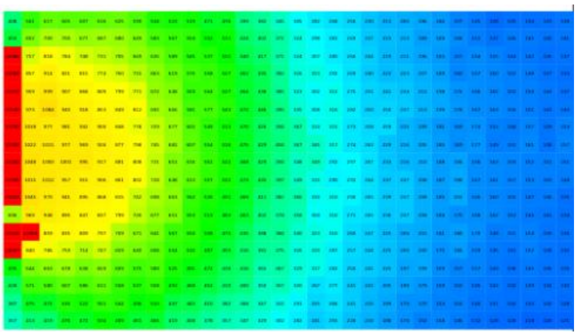
Time	Internal *LS* (average lux)	Middle *LS* (average lux)	External *LS* (average lux)	Without *LS* (average lux)
9 a.m.	1491.83	517.51	1214.93	**1804.35**
10 a.m.	2443.36	829.28	1853.49	3175.46
11 a.m.	3031.56	881.81	2229.87	4187.72
12 p.m.	3267.42	902.00	2101.90	4443.57
1 p.m.	3019.47	862.76	2109.40	4221.79
2 p.m.	2578.25	821.24	1915.17	3418.63
3 p.m.	1741.88	622.62	1398.31	2171.93
4 p.m.	837.45	373.26	867.34	954.06
5 p.m.	263.91	135.60	304.94	311.65



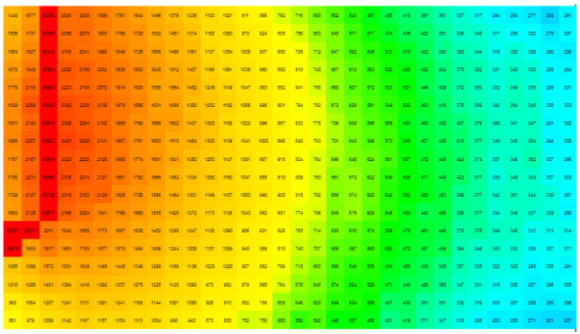
(a) Investigation of simulation at 11 a.m. for without light shelf.



(b) Investigation of simulation at 11 a.m. for internal light shelf.



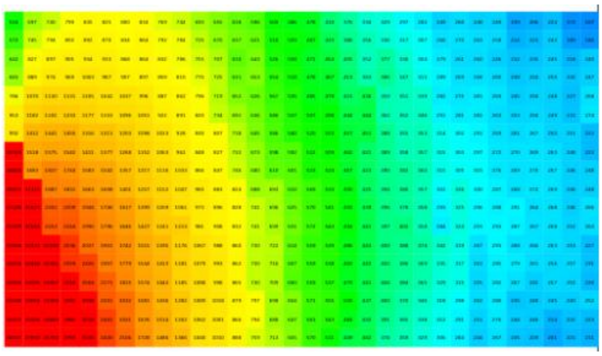
(c) Investigation of simulation at 11 am for middle light shelf.



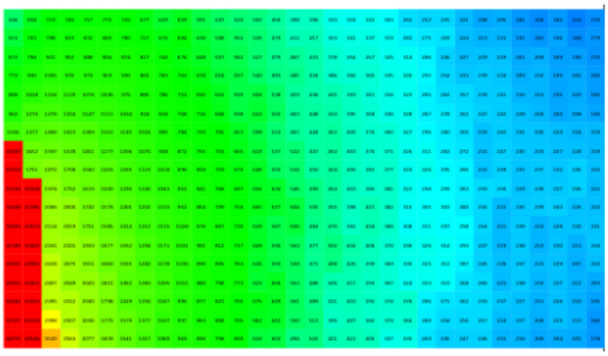
(d) Investigation of simulation at 11 a.m. for external light shelf.

Fig. 8. Simulations results indicating effect of light shelf at 11 a.m.

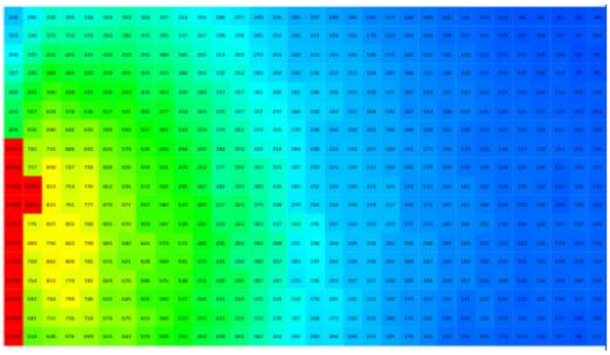
Similarly, the light shelf performance based on simulation results at 3 p.m. on the same day is shown in Figs. 9(a) (without light shelf), (b) (internal light shelf), (c) (middle light shelf), and (d) (external light shelf). The different colours in simulation results show varying illuminance values. High illuminance values are shown in red and followed by orange, yellow, green, light blue and dark blue for reducing values of illuminance. This study is about early prediction as well as user awareness technology, to overcome energy shortage and to provide pleasant environments with the use of a light shelf.



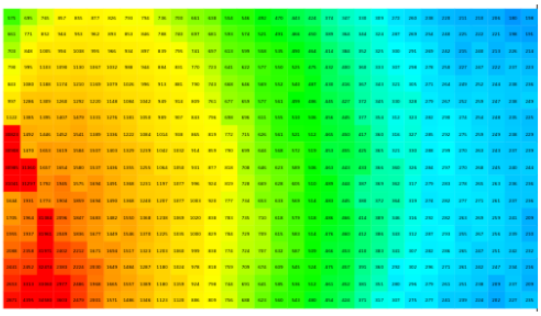
(a) Investigation of simulation at 3 p.m. for without light shelf.



(b) Investigation of simulation at 3 p.m. with internal light shelf.



(c) Investigation of simulation at 3 p.m. with middle light shelf.



(d) Investigation of simulation at 3 p.m. with external light shelf.

Fig. 9. Simulation results indicating effect of light shelf on illuminance at 3 p.m.

Illuminance measurements in the prototype are taken with a lux meter. A reflecting mirror is considered as a light shelf, therefore, it will give better performance. The prototype model was scaled 15:1 as compared to simulation design. A reflecting glass mirror is also used at the ceiling of the prototype model. The grid points considered as *G*1 to *G*7 are spaced 4 cm apart. All the illuminance values are measured along the centre of the window. Comparing at 11 a.m. and 3 p.m., it is clearly shown that external light shelf controls glare as well as penetrates more light along with the depth of the room.

If we compare the illuminance values for an internal and external light shelf in Tables 4 and 5, the actual measured values are very poor in case of an internal light shelf.

Table 4. Measured output for average lux of room (3×5×2.8) prototype performance by light shelf (*LS*).

Time 11 a.m.	Internal *LS* (lux)	Middle *LS* (lux)	External *LS* (lux)	Without *LS* (lux)
G1	6700	800	2500	81000
G2	2300	1900	9800	8000
G3	2200	3400	3700	4300
G4	1900	1800	2500	2700
G5	1500	2100	1800	1400
G6	1300	1200	1200	1000
G7	800	600	800	600

Table 5. Measured output for average lux of room (3×5×2.8) prototype performance by light shelf (*LS*).

Time 3 p.m.	Internal *LS* (lux)	Middle *LS* (lux)	External *LS* (lux)	Without *LS* (lux)
***G*1**	1200	300	1400	3400
***G*2**	1300	800	2200	3800
***G*3**	800	1100	1900	2000
***G*4**	700	1200	1300	1000
***G*5**	600	900	800	600
***G*6**	400	500	400	300
***G*7**	300	200	200	100

Tables 6 to 8 compare external light shelf measured the output with Angled Light shelf (ALS) measured output. Here, we have considered the tilt angles in between 150 to 350. For this, we have fixed one reflecting mirror (at base) of the iron frame, which is fixed, and the other reflecting mirror was placed with different angles as shown in Fig. 6(i).

One mirror is fixed at the ceiling of the prototype model so that light can be properly reflected back to the surface of room plane. Beyond this 350 angle, the illuminance values are very poor. Even at tilt angles greater than 250 the illuminance values reduce.

Angled light shelf only gives high lux values to a depth of a room at 3 pm but it gives poor illuminance values at morning 9 and 11 a.m. Therefore, a simple external light shelf is better than an angled light shelf.

Table 6. Measured output for average lux of room (3×5×2.8) prototype performance by angled light shelf (*ALS*).

Time 9 a.m.	External *LS* (lux)	15^0 *ALS* (lux)	20^0 *ALS* (lux)	25^0 *ALS* (lux)	30^0 *ALS* (lux)	35^0 *ALS* (lux)
***G*1**	1200	1600	1600	1800	1600	1600
***G*2**	1700	1800	1300	1500	1300	1300
***G*3**	1500	1400	1200	1200	1000	900
***G*4**	1000	900	800	900	600	500
***G*5**	700	600	600	700	500	300
***G*6**	500	300	400	400	400	200
***G*7**	300	200	200	200	200	100

Table 7. Measured output for average lux of room (3×5×2.8) prototype performance by angled light shelf (*ALS*) at 11 a.m.

Time 11 a.m.	External *LS* (lux)	15^0 *ALS* (lux)	20^0 *ALS* (lux)	25^0 *ALS* (lux)	30^0 *ALS* (lux)	35^0 *ALS* (lux)
***G*1**	2500	3400	3400	3500	3500	3500
***G*2**	9800	47500	47000	48000	47700	42000
***G*3**	3700	4650	4600	4700	4500	4800
***G*4**	2500	2900	2800	3000	2800	3100
***G*5**	1800	2100	2100	2300	2100	2100
***G*6**	1200	1000	1000	1100	1000	1100
***G*7**	800	600	600	600	600	600

Table 8. Measured output for average lux of room (3×5×2.8) prototype performance by angled light shelf (*ALS*) at 3 p.m.

Time 3 p.m	External *LS* (lux)	15^0 *ALS* (lux)	20^0 *ALS* (lux)	25^0 *ALS* (lux)	30^0 *ALS* (lux)	35^0 *ALS* (lux)
***G*1**	1400	1800	1700	1800	1800	1800
***G*2**	2200	2300	2600	2600	2600	2500
***G*3**	1900	2200	2500	2800	2500	2400
***G*4**	1300	1900	1900	2000	1900	1600
***G*5**	800	1300	1200	1500	1200	900
***G*6**	400	900	900	1000	800	500
***G*7**	200	500	500	500	500	400

Too much illuminance causes discomfort to the occupants near the windows, so the light shelf can reduce glare near the window area. External light shelf increases the illuminance values towards the deeper end of the room. This also concludes that DF increases in case of an external light shelf with making visual comfort with reducing the use of artificial light.

DF depends on mainly two parameters, i.e., outdoor illuminance and indoor illuminance [18].

$$DF = \frac{\varepsilon_i}{\varepsilon_0} * 100\% \tag{2}$$

where ε_o is simultaneous outdoor illuminance on a horizontal plane from an unobstructed hemisphere of the overcast sky (lux) and ε_i is illuminance due to daylight at a point on the indoor working plane (lux).

Room illuminance values are higher at farther regions from a window in case of the external light shelf as compared to others, therefore, ε_i value increases and DF also increases as per Eq. (2).

From Fig. 10, one can directly say that daylight factor decreases as the illuminance level decreases from grid point $G1$ to $G7$. The above result may vary if one will go for other coating materials on the light shelf.

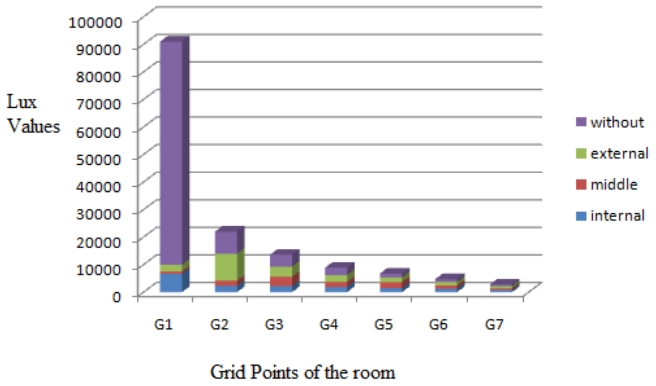


Fig. 10. Investigation of performance measurement at 11 a.m. for different configurations of light shelf.

5. Results and Discussion

The prediction of the illuminance with simulation result will be easier than the real measurement because the values vary with time as well as location, sky condition and in different seasons of the year. All regions of the world and the situation of climate is not the same so the prediction of illuminance will take more time for different regions. Implementation of a light shelf is just like intelligent energy efficient building while minimising the cost of energy. Lighting loads are reduced without compromising users' comfort by the use of a light shelf. The findings reveal that by using an external light shelf, the illuminance level will be better as compared to others, but the concern of winter thermal discomfort affects the selection of key design parameters. Proper utilization of energy would have to incorporate light shelf strategies for more natural and sustainable living.

Limitation of the light shelf is that if there will be any obstruction like (tree or close buildings) to the surrounding of the window area then the designer should go through the early simulation process before planning light shelf design in the actual project. For high-rise buildings, the obstruction will be nearly zero, i.e., from third floor onwards and light shelf design will be very fruitful.

6. Conclusions

This paper supports design assistant for architects or building designers by utilizing the tools in the early stage of building design to make occupants more comfortable with energy saving and also the visual aspect. This suggests a light shelf design idea would have a positive impact in the construction of buildings. For world energy issues, this low-cost installation of light shelf gives excellent performance. Campaigns about light shelf will be effective for wider awareness. A light shelf is important for natural energy utilization and widespread installation to existing and future buildings would benefit maximum occupants worldwide.

However, a prototype room model observation and simulation with the visual appearance for a sample are provided here. The overall advantages of light shelf allowing the design with occupants comfort issue as well as the reduction in heavy artificial light energy consumption during day hours. Further studies are recommended for other climatic conditions throughout the world to get good design strategies to find in terms of climate-responsive light shelf design. By looking at suitable climatic atmosphere, designs from architects or designers will help to get the benefits of the light shelf.

Nomenclatures

E	Illuminance
G_1	Gridpoint value at first middle point near to window in prototype
G_2	Gridpoint value at second middle point near to window in prototype
I	Intensity
N	North facing
r	Distance between source to the desired point
S	South facing

Greek Symbols

ε_0	Outdoor illuminance on a horizontal plane from an an unobstructed hemisphere of overcast sky
ε_t	Illuminance due to daylight at a point on the indoor working plane (lux)
θ	Angle between the plane perpendicular to the incident light and illuminated surface

Abbreviations

ALS	Angled Light Shelf

DLS	Daylighting System
DF	Daylight Factor
LS	Light Shelf

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