

The performance of natural lighting in classrooms using shading devices

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ARTICLE INFO	ABSTRACT
<p><i>Article history:</i> Received August 28, 2023 Received in revised form Sept. 10, 2023 Accepted September 25, 2023 Available online December 01, 2023</p> <p><i>Keywords:</i> Class room Natural lighting Shading devices</p> <p>*Corresponding author: Sahid Master of Architecture Study Program, Department of Architecture, Faculty of Engineering, Universitas Katolik Parahyangan, Indonesia Email: sahid@unpar.ac.id, nancy@unpar.ac.id ORCID: https://orcid.org/0000-0002-2249-078X</p>	<p><i>One alternative energy source to replace fossil energy is sunlight. The presence of sunlight has an impact on the building in the form of heat radiation and natural lighting. Under certain circumstances, these two effects are contradictory. Buildings need natural lighting to reduce their reliance on artificial lighting, but adding this natural lighting also causes the building to become warmer, which will increase the energy required for air conditioning. One alternative solution to reduce the intensity of heat entering a building is the use of shading devices. The presence of sun shading is believed could be used to prevent heat radiation from entering the building, but the lighting intensity is not at its best. Educational buildings, particularly classrooms, are one type of building that utilizes natural lighting extensively. One of the educational buildings that has attempted to use shading devices. This research aims to determine the performance of natural lighting, especially uniformity in classrooms that used shading devices. The research administers quantitative methods with Dialux Evo software simulation to determine the uniformity ratio of natural lighting in classrooms that use various forms of shading devices. The research results reveal that the performance of classrooms with the four types of shading devices still does not meet standards. There is still a need for adjustments to the four types of shading devices so that their performance can meet standards.</i></p>

Introduction

Architects design comfortable built environments by understanding the needs of users and at the same time understanding the surrounding natural environment (Dinapradipta et al. 2020; Widodo 2019). Lighting is one of the user needs. The availability of lighting, especially optimal natural lighting, is essential for residents because at the same time it can fulfill visual or physical needs (to see the work area or space) as well as fulfill psychological needs to get environmental stimulation (Milaningrum 2015). Visual and thermal comfort can be achieved by utilizing passive strategies (Sahid, Sumiyati, and Purisari

2020). Passive strategies that can be employed to obtain thermal and visual comfort are to consider orientation, building shape, envelope, interior arrangement and greening (Sahid, Sumiyati, and Purisari 2020).

One of Indonesia's numerous abundant sources of renewable energy and a source of natural lighting is the sun. Because sunlight is the light with the spectrum that best suits human visual responses, using natural lighting sources has the advantage of optimizing visual lighting. However, since weather and time conditions are constantly changing, natural light sources can result in lighting disturbances (glare) and uneven light distribution (Nuha and Ary 2018).

The campus as a place for the teaching and learning process contributes to electricity consumption of 32.44% of the total industrial consumption implemented for lighting and air conditioning. The use of electrical energy on campus requires appropriate efforts to save electrical energy (Panghargiyo and Wirasmoyo 2022).

The classroom, which serves as the focal point of the campus, is a space where theory- and practice-related teaching and learning activities are performed using straightforward special tools. Internal users, room amenities, physical room conditions, and non-physical room conditions all contribute to a classroom's comfort level (Lina 2021). The freedom of view, ease of access, flexibility, comfort, and beauty are the five key components of a comfortable classroom. Aside from that, a number of other factors also come into play, such as interior design factors like user needs, user movement, lighting, ventilation, and sound (Lina 2021).

The architectural form will influence the quantity and quality of natural lighting in the building (Pangestu 2019). The spread or distribution of natural lighting during the day is influenced by the differences and dimensions of space (Kartika and Elsiiana 2021). If the building's width is small or flat so that it can collect light, lessen contrast, and provide views, natural light will enter the building effectively. In a rectangular plan, 41% of the central area still receives some natural light, compared to 16% of a square plan's central area that receives no natural light at all (Lechner 2015).

The position of the side opening (side lighting) is in the form of a window on the building wall to let light in horizontally into the work area. Most of the natural light coming in from the side is sky light. The position of the opening in the middle of the wall allows light to be distributed to surface areas that are only close to the opening so that the light intensity is higher. The position of the opening only on one side of the wall (unilateral/single side lighting) provides strong unidirectional lighting and the further away from the opening, the weaker the light will be (Lechner 2015).

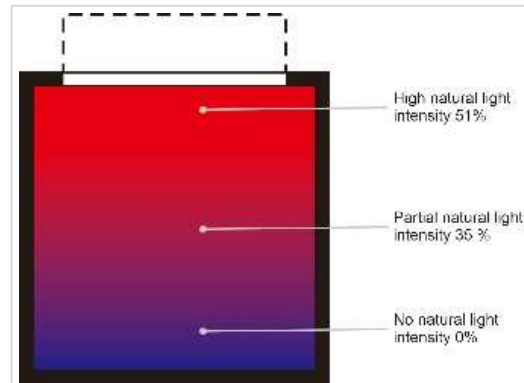


Figure 1. Distribution of natural light with unilateral openings
Source: (Lechner 2015)



Figure 2. Unilateral side opening position using horizontal shading device
Source: (Lechner 2015)

For buildings with openings on one side (single side lighting), the further the distance from the window, the weaker the light intensity (Nurhaiza and Lisa 2019). The area near the window will have a tendency to meet the minimum standards for natural lighting and the further away from the window the tendency decreases (Dewi 2013). The entry of natural lighting into the room not only has an impact on the brightness of the room but also has an impact on increasing the building's energy consumption to cool the building (Kurniawan 2020). Proper envelope design can optimize the thermal and visual performance of a building (Adi, Afiq, and Pamungkas 2022). The building envelope can play a direct role in preventing heat from entering the building (Budhyowati 2021). Selecting the right type of envelope (design and material) will be able to reduce heat transfer into the building (Octarino and Feriadi 2021).

Sunlight Protection Fins or shading device are a component that architects frequently employ in an effort to manage heat and enhance the effectiveness of natural lighting entering a space. Direct sunlight and incoming heat are blocked by shading device. Lechner claims that in order to achieve thermal comfort and visual comfort,

buildings in tropical climates need to pay attention to the idea of solar-responsive design, specifically how to avoid heat (heat avoidance) and reject heat (heat rejection). Achieving even natural lighting that complies with standards will be directly impacted by selecting the best type of shading device and window openings (Chandra and Purwanto 2021). Shading Device will have a direct effect on the value of light intensity (daylight factor) and the level of light uniformity (uniformity ratio) in a room (Sabtalistia 2017). Horizontal shading device, for example, will play an effective role when used in openings that are oriented towards the north (Sari and Rauzi 2021). In this way, shading device provides shade in building openings and on building walls, thereby reducing the effect of direct solar radiation entering the building or preventing direct sunlight from heating the room.

This research was conducted to determine the effectiveness of using shading device on the uniformity of natural lighting in classrooms. The results of this research can be used as recommendations for designers and building owners in determining optimal shading device design strategies to meet the performance of natural lighting in classrooms. The performance of natural lighting in classrooms is measured by the parameters of natural light intensity (lux), uniformity ratio and daylight factor (%DF). The hypothesis of this research is that the use of shading device in classroom at Parahyangan Catholic University results in inadequate natural lighting performance.

Method

This research aims to determine the quality of natural lighting, especially the uniformity ratio of natural lighting in classrooms that use Sunlight Protection Fins (shading device). In general, this research employs quantitative methods. Initial data regarding light intensity in classrooms was obtained by direct measurements in the field using Light Meter Distance. The data is then simulated using Dialux Evo software to obtain lighting performance and energy consumption according to the specified conditions (“Energy Efficiency in DIALux,” n.d.). Dialux Evo has been widely used to research issues related to natural lighting and/or artificial lighting (Adi 2019). The simulation

results are then analyzed using the following standards:

1. Illumination standards (light intensity) use the SNI 03-2396-2001 standard. For classrooms it is set at 250 lux. (SNI 03-2396-2001 2001; Mangkuto 2016).
2. The Daylight Factor (DF) standard uses the BREEAM 2018 standard which is set at 2% (Phillips and Gardner 2012; BRE Group 2012; Mardaljevic 2011).
3. The Uniformity Ratio (UR) standard uses the EN 12464 standard which specifies Emin/Eavg between 0,4 – 0,6. (Iversen et al. 2013; European committee for standardization 2011).

The following are several variables used in this research to simulate the uniformity ratio of natural lighting:

1. Controlled variables: location of Bandung city (6°LS, 107 BT), overcast sky conditions, height of work area 0.80 m.
2. Independent variable: shading device shape (horizontal and eggcrate), opening orientation facing north - south and east - west, time in March, June and December at 08.00, 10.00, 12.00, 14.00, 16.00
3. Dependent variable: uniformity intensity of natural light (illumination), daylight factor (DF) and uniformity ratio (UR).

The object of this research is a classroom which has dimensions of 7.20 m × 7.20 m × 2.77 m and has an opening orientation facing north. In this classroom model, there are four forms of shading device which will be tested to find out the most optimal shading device criteria in terms of uniformity ratio of sunlight.

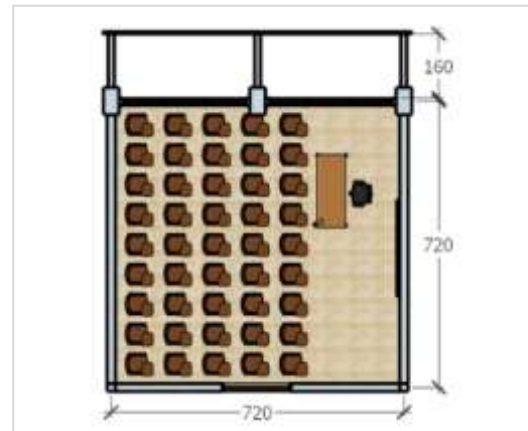


Figure 3. Classroom plan

In the existing condition of this classroom, the room's enclosure materials used are gypsum ceilings, ceramic floors, walls with light gray white paint and 6 windows made of glass and wooden frames. The transmittance value on window glass is 87%. The distance from the window wall to the shading device is 1.60 m. This classroom uses shading device with a horizontal, massive shape with an angle of 90°.



Figure 4. View of the classroom

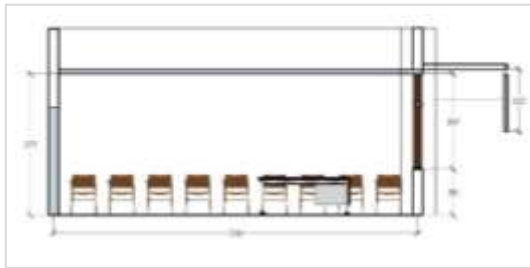


Figure 5. Classroom opening wall piece

In this measurement, there are 16 measuring points to determine the distribution of light entering the classroom. The distance from the wall to the measuring point is 1 meter. The following is the arrangement of measuring points in the classroom.

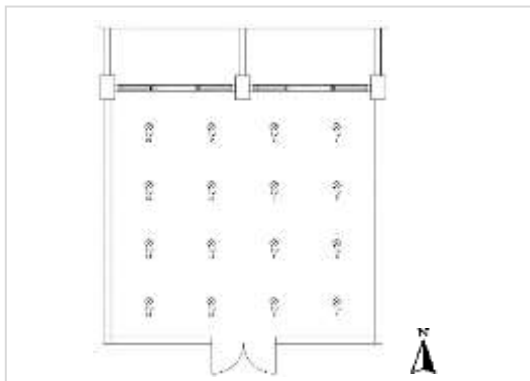


Figure 6. Measuring points in the classroom

Result and Discussion

Based on measurement data carried out at 08.00, 12.00 and 16.00. This measurement is used to determine the light intensity in lux units. The following are the results of measurements using the light meter distance measuring instrument.

Table 1. Results of measurement of light intensity in the classroom (lux)

Measuring Point	Time		
	08.00	12.00	16.00
1	79	165	78
2	24	93	13
3	17	13	5
4	17	11	3
4	13	11	3
5	16	13	3
6	13	162	6
7	24	116	11
8	66	204	77
9	77	24	127
10	20	24	12
11	17	18	5
12	12	14	3
13	11	10	3
14	16	16	6
15	22	26	11
16	82	107	47
Min	11	10	3
Max	82	204	127
Average	31,81	50,5	25,62
Uniformity Ratio (UR)	0,34	0,19	0,11

From table 1, it can be seen that the measurement results do not meet natural lighting standards. The average light intensity at 08.00 is 31.81 lux, 12.00 is 50.5 lux and 16.00 is 25.62 lux. Looking at this data means that the average value of light intensity is still very far from the minimum standard for natural lighting or has not yet reached the lighting standard in classrooms of 250 lux.

Measurements were performed when sky conditions had an average light intensity of 40,000 lux at 08.00, 73,000 lux at 12.00 and 16,000 lux at 16.00. From the results of these measurements, the daylight factor results can be

determined using a formula $\frac{E_{inside}}{E_{outside}} \times 100\%$ in the following table:

Table 2. Daylight factor measurement results in the classroom (%DF)

Measuring Point	Time		
	08.00	12.00	16.00
1	0,199	0,218	0,479
2	0,060	0,039	0,078
3	0,043	0,017	0,030
4	0,033	0,015	0,018
5	0,040	0,017	0,018
6	0,033	0,022	0,034
7	0,060	0,036	0,063
8	0,164	0,158	0,487
9	0,190	0,278	0,789
10	0,049	0,033	0,073
11	0,041	0,026	0,030
12	0,029	0,019	0,018
13	0,027	0,013	0,018
14	0,038	0,022	0,035
15	0,053	0,036	0,061
16	0,195	0,145	0,267
Min	0,027	0,013	0,018
Max	0,199	0,278	0,789
Average	0,078	0,068	0,156

From table 2, it can be identified that the average daylight factor calculation results are still below the BREEAM standard of 2%. At 08.00 the average DF was only 0.078%, at 12.00 the average DF was 0.068% and at 16.00 the average DF was 0.156%. This result is still very far from the BREEAM standard.

From table 1, it can also be acknowledged that the Uniformity Ratio results have not reached the EN standard of 0.4. Only at 08.00 is it almost close to the standard of 0.34. Thus, looking at the results of measuring the intensity of natural light, calculating the daylight factor and calculating the uniformity ratio, it does not reach the standard for the quality of natural lighting in classrooms.

As a comparison with direct measurements, a simulation needs to be conducted with Dialux Evo

simulation. The following are the simulation results of natural lighting intensity in classrooms using 90o shading device with the software:

Table 3. Simulation results of light intensity (lux) and uniformity ratio

	Time				
	08.00	10.00	12.00	14.00	16.00
Min	8,94	15,5	17,8	15,2	8,34
Max	104	181	208	177	97,1
Avg	27,5	47,7	54,8	46,7	25,6
Uniformity (UR)	0,33	0,32	0,32	0,33	0,33

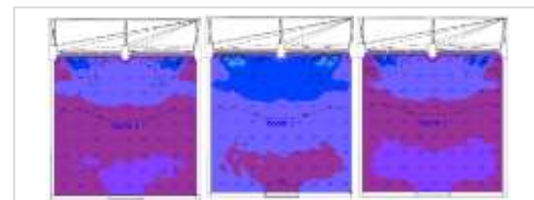


Figure 7. (left to right) Natural lighting intensity distribution, 08.00, 12.00, 16.00

Table 3 demonstrates that the average light intensity has not reached the lighting standards in classrooms. Table 2 also displays the results of an increase in light intensity entering the room from 08.00 to 12.00 then a decrease in light intensity from 12.00 to 16.00. Looking at figure 7, it can be identified that the intensity of light entering is only around the window/opening. The intensity of incoming light is not evenly distributed throughout the classroom. At 12.00 the light distribution almost fills 50% or half of the classroom but at 08.00 and 16.00 the light distribution is only one third of the length of the classroom.

From table 3, the Uniformity Ratio calculation results demonstrate that UR still has not reached the EN standard of 0.4 – 0.6. The UR simulation results are around 0.32 – 0.33. This UR value is almost close to the EN standard.

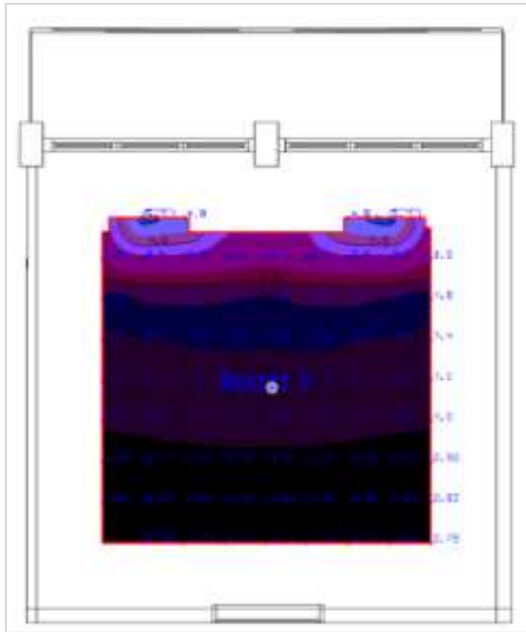


Figure 8. Daylight factor simulation results

The results of the daylight factor simulation with overcast sky conditions are a min value of 0.15%, a max value of 0.561% and an average value of 0.27%. When referring to the BREEAM standard, a DF value $\geq 2\%$ has not reached the standard for DF results in the classroom. This is possibly the effect of the openings only being on one side of the wall opening and the sunlight entering the room being blocked by the shading device.

From existing data through direct measurements and simulations, it is necessary to compare with the horizontal shading device type which is horizontal with an angle of 45° , light shelf, and eggcrate.

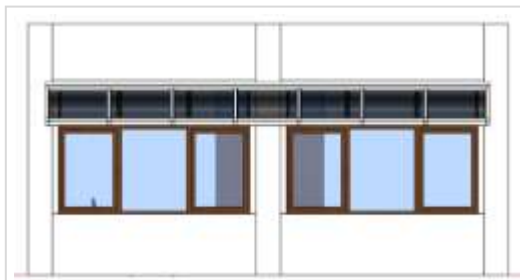


Figure 9. View of classroom with 45° shading device



Figure 10. Section of classroom with 45° shading device



Figure 11. View of classroom with light shelf



Figure 12. Classroom cutout with light shelf

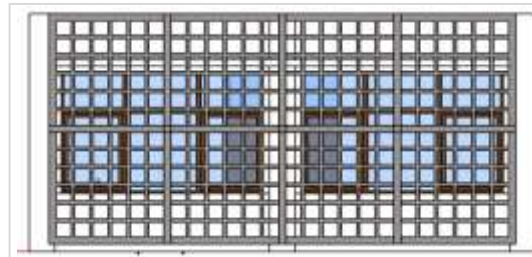


Figure 13. View of classroom with eggcrate shading device

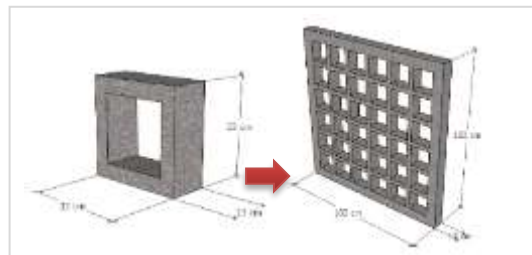


















Figure 14. Eggcrate shading device module. In 1 module there are 36 holes







Figure 15. Section of classroom cutout with shading device eggcrate

The following is a comparison of the results of the average intensity of natural lighting in classrooms using several forms of shading device.

Table 4. Illumination (lux) simulation results on 45° shading device, light shelf and eggcrate

Time	Result	SHADING DEVICE		
		45°	Light Shelf	Eggcrate
08.00	Distribution Plan 			
	Min	23,9	28,2	24,2
	Max	297	391	345
	Avg	85,9	125	85,0
	UR	0,27	0,23	0,28
10.00	Distribution Plan 			
	Min	40,8	48,3	41,4
	Max	509	669	591
	Avg	147	214	145
	UR	0,27	0,23	0,28
12.00	Distribution Plan 			
	Min	46,4	54,8	47,0
	Max	578	760	671
	Avg	167	243	165
	UR	0,27	0,23	0,28
14.00	Distribution Plan 			
	Min	39,0	46,1	39,6
	Max	487	639	565
	Avg	140	204	139

Time	Result	SHADING DEVICE		
		45°	Light Shelf	Eggcrate
16.00	UR	0,27	0,23	0,28
	Distribution Plan 			
	Min	20,7	24,5	21,0
	Max	259	340	300
	Avg	74,7	109	73,9
UR	0,27	0,23	0,28	

Based on the simulation results of natural lighting intensity using 3 forms of shading devices, it can be seen from table 4 that the average shading device design that is close to the standard is the light shelf. Of the three forms of shading device design, the results are minimal and on average do not meet natural lighting standards in classrooms or are still below 250 lux.

Table 4 also illustrates that the Uniformity Ratio of these three forms of shading device has not reached the EN standard. The UR value achieved is only 0.2, thus, these three forms of shading device are not able to provide uniform natural lighting in the classroom so that visual comfort in the room has not been achieved. The UR value is also greatly influenced by the illumination value/intensity of light entering the classroom.

Table 5. Daylight factor simulation results on using 45° shading device, light shelf and eggcrate (%DF)




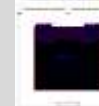
Result	45°	Light Shelf	Eggcrate
Distribution Plan 			
Min	0,399	0,699	0,364
Max	2,438	2,353	2,231
Avg	0,781	1,113	0,795

Table 5 demonstrates a Daylight Factor simulation with overcast sky conditions. From the three shading device trials, it can be identified that the average DF value in classrooms using shading device Light Shelf almost reaches the DF standard although it is still below the 2% DF standard. Even though the minimum and average values are still below the DF standard, for these three forms of shading device, the maximum value has reached the target of 2% DF.

Table 6. Comparison results of average values of natural lighting intensity (lux) in classrooms

Shading device Time	90°	45°	Light Shelf	Eggcrate
08.00	27,5	85,9	125	85
10.00	47,7	147	214	145
12.00	54,8	167	243	165
14.00	46,7	147	204	139
16.00	25,6	74,7	109	73,9

Looking at [table 6](#), it can be seen that the four forms of shading device have not been able to reach the 250-lux standard. If we compare the four forms of shading device, the shading device that is best for distributing natural lighting into a classroom that has one side opening is the shading device light shelf, even though the average value of using the light shelf has not yet reached the standard of 250 lux. However, at 12.00 the average result of using the light shelf almost reached the standard of 250 lux. Based on [table 6](#), it is not recommended for classrooms with unilateral openings or one opening on one side of the wall to use a massive 90° shading device because the natural lighting illumination value is still very far from the standard of 300 lux.

Table 8. Comparison results of Uniformity Ratio (UR) in classrooms

Shading device	90°	45°	Light Shelf	Eggcrate
Uniformity Ratio (UR)	0,33	0,27	0,23	0,28

Based on [table 8](#), it can be identified that the results of the Uniformity Ratio simulation comparison in the classroom by comparing the minimum value with the average value of light intensity show that all of the four forms of shading device have not reached the EN standard of 0.4 – 0.6. These four forms of shading device have only reached a UR value of 0.23 – 0.33. The UR value that is close to the standard is a classroom that uses shading device 90°. UR results are greatly influenced by the value of illumination entering the room, so efforts/strategies are needed to achieve the uniformity ratio.

Of the three performance indicators of natural lighting, encompassing light intensity, daylight factor and uniformity ratio, most of the simulation results with overcast sky conditions at 08.00, 10.00, 12.00, 14.00 and 16.00 have not reached these minimum standards.

Conclusion

After analyzing a sample of classrooms by testing four forms of shading device, it can be identified that the quality of natural lighting in classrooms is not evenly distributed. This demonstrates that using unilateral openings or openings on one side of the wall has not been successful in distributing light evenly throughout the space. The light shelf, however, can be used to achieve an average light intensity value that nearly meets the standard of 250 lux, even though this success was only attained at 12.00.

Furthermore, the DF value in the classroom did not meet the standards or was still below 2% when tested using the four shading devices with overcast sky conditions. Based on the analysis results, the use of shading device becomes less effective because sunlight from outside is blocked from entering due to shading device.

Then, the UR value from using the four shading devices which is almost close to the standard is 90° shading device. The effectiveness of natural lighting to create a comfortable visual environment in the space is also indicated by these UR results. There is the possibility that the lighting distribution is not uniform if the UR value does not meet the standard.

From this research, it was unveiled that the hypothesis was proven, which is that the performance of natural lighting in classrooms using the four existing shading device types did not meet the standards for light intensity, density and uniformity ratio. Each shading device has advantages and disadvantages in achieving the target natural lighting performance indicators. Of the four forms of shading device tested, shading device light shelf is the shading device that has the most potential for achieving lighting performance according to standards. However, further processing is still needed so that the performance obtained is more optimal.

The use of shading device will not necessarily be able to enhance the performance of natural lighting in a room. An appropriate shading device design strategy is needed to obtain optimal lighting performance. The performance of natural lighting includes lighting intensity and uniformity ratio. Visual comfort in the room will be achieved if all three indicators of natural lighting performance are met.

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Author(s) contribution

Christi Maria Saraswati contributed to the research concepts preparation, methodologies, investigations, data analysis, visualization, articles drafting and revisions.

Sahid contribute to the research concepts preparation and literature reviews, data analysis, of article drafts preparation and validation.

Nancy Yusnita Nograho contribute to methodology, supervision, and validation.