JOURNAL OF ARCHITECTURAL RESEARCH AND DESIGN STUDIES
DOI: 10.20885/jars.vol7.iss1.art5

Daylight And Artificial Lighting Integration In Achieving Lighting Uniformity In Educational Building

Hazimah Ulfah Az Zaky[1], Ova Candra Dewi[2], Widyarko[2], Coriesta Dian Sulistiani[2]

[1] Master Student, Department of Architecture, Universitas Indonesia, Indonesia
[2] Department of Architecture, Universitas Indonesia, Indonesia

Article History
Received : 17 January 2023
Accepted : 15 May 2023
Published : 17 May 2023

Abstract

Educational buildings in Depok City typically have deep classroom plans, which pose a challenge in achieving good uniformity of lighting distribution throughout the room. Therefore, this study aims to investigate the integration of daylight and artificial lighting to achieve lighting uniformity, especially in classrooms of educational buildings in Depok City. This paper simulated the combinations of Light Shelves (LS), horizontal blind curtains, and artificial lighting dimming systems through Dialux software to explore and discuss the illumination distribution of daylight in the classroom. The combinations were arranged in 7 different strategies and were carried out in average sky conditions. The strategy simulation results show that lighting uniformity is optimally achieved in strategy 3 with 0.74 lux and strategy 7 with 0.72 lux. These results prove an increase in the uniformity of daylight in the classroom by 0.49 lux with LS and 0.58 lux with horizontal blinds but still requires artificial lighting with 50% dimming.

Keywords: *Dimming; Horizontal blind curtain; Light shelves; Lighting uniformity.*

Introduction

Artificial lighting in buildings is accountable for a significant portion of overall energy consumption. (Shankar et al., 2021). While other sources mention that school buildings consume 20%-45% of energy consumption for lighting (Martinopoulos et al., 2018) and consume 17% of the non-residential building total consumption (Lautsen et al., 2009). Depok City, Indonesia, which is located in a tropical country, still has this issue. As part of the tropical area, Depok City has daylight intensity that can be assumed to be more constant throughout the year compared to other regions (Fitriany et al., 2019). By this condition, Depok City is supposed to have something other than an energy overconsumption issue (Fitriany et al., 2019).

Correspondence: Hazimah Ulfah Az Zaky
Master Student, Department of Architecture, Universitas Indonesia, Indonesia
E-mail: hazimah.ulfah@ui.ac.id

According to Lechner (2015), the space planning or floor plan of the building with open space is very profitable for bringing natural light into the space. While in general, educational buildings in Depok City have a typical wide floor plan to maximize classroom size. Consequently, daylight is difficult to reach the entire classroom area due to the deep depth of the classroom. Only the perimeter area near the window can be benefited from daylight (Bernardo, 2017), even when it uses a fully glazed facade. This situation shows an uneven distribution of daylight in the classroom area (Kim et al., 1999). For such cases, artificial lighting is usually used to support the interior areas because sunlight cannot reach spaces far from the facade (Ganslandt, 1992).

In the design stage, average horizontal illuminance or uniformity is one of the lighting parameters that need to be considered (Rea, 1991; Skarżyński, 2020). It can be verified by utilizing appropriate measurements recommended by lighting standards (Skarżyński, 2020). In rooms that are unevenly illuminated, there are possibility that the immediate task area is much brighter than the surrounding area which may elevate the discomfort effects (Osterhaus, 2005).

Luminaire's strategy to produce lighting uniformity must precisely concern the condition of the walls and the ceiling (Samani, 2012). The simplest procedure to achieve good lighting performance is by combining daylight and artificial lighting (Slater et al., 1990). The light shelves strategy and the blind curtain can increase the range of natural lighting that enters the room with accurate light shelves element factors (Abimaje et al., 2018). Therefore, this study aims to investigate and discuss how integrating light shelves, internal blinds, and a dimming system achieves uniformity of lighting in the classroom, especially in an educational building in Depok City.

Literature Review

Due to the issue of this paper, the immediate solution is to expose daylight in the deeper classroom area to increase uniformity. Therefore, this paper investigates the basic lighting design principle and the standards used to evaluate solutions of several sustainable lighting control strategies that increase uniformity.

1. Illumination and Lighting Uniformity in Educational Buildings

The Indonesian National Standard (SNI 6197: 2020) states that the illuminance standard for educational buildings is 350 - 750 lux depending on classroom activities. Another recommendation stated by The Chartered Institution of Building Services Engineers (CIBSE) in 2022 is that the illumination uniformity range is 300 lux to 500 lux depending on the type of classroom; those values help restrict glare to reasonable levels. Those recommendations are the minimum illumination and the range level, which may produce comfort. On the opposite, the high level of illumination may lead to glare. Therefore, Heerwagen et al. (2004) said there is some evidence of increased discomfort at illuminance above 1000 lux in uniform light. Freewan (1990) investigated the illuminance uniformity and the ratio was found to be between 0.5-0.7 for different variation of tasks on a desk. Another recommended uniformity levels for classroom by CIBSE (2022) are within a range of 0.6.

The uniformity can also be calculated according to European Standard Specifies Lighting Requirements for Humans in Indoor Workplaces (DIN EN 12464–1) using the formula:

$$U_0 = E_{\min} / \bar{E} \tag{1}$$

Where Emin denotes the minimum and E denotes the average measured illuminance values.

2. Daylight and Artificial Light Integration

Some of the best lighting details combine the effects of daylight and electric light sources (Slater et al., 1990).

Light Shelves and Blind Curtain

Light shelves are either internally or externally horizontal or inclined surface that is built on a window and placed above eye level (Ganslandt et al., 1992). It is the simplest light distribution system among daylighting systems, which is capable of controlling and redistributing incoming daylight through reflection on its upper surface (Ganslandt et al., 1992; Haq et al., 2014). Due to the opening, the LS position divides the window into two parts; the top (clerestory) which serves to pass sunlight, and the bottom of the window for outdoor views (Abimaje et al., 2018).

According to William (1986), the types of light shelves can be applied to buildings by placing horizontal elements such as a continuous canopy into the building on the window so that light reflection can occur and can still see the view outside the window (figure 1). This type of light shelf is usually used in buildings facing north-south and is usually used for buildings that are difficult to get light from outside the building (Kontadakis, 2017).

Figure 1. cross-section of an opening with an extended light shelf.
Source : Kontadakis (2017)

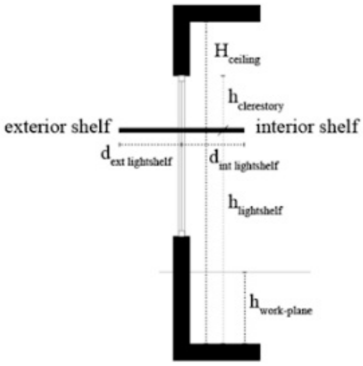
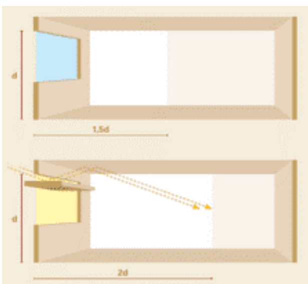


Figure 1 shows the static horizontal light shelves which is the simplest form of a light shelf. It usually provides the best compromise between daylight distribution and shading requirements compared to other LS forms. Tilting up will increase the penetration of reflected sunlight and reduce the shading effect while tilting the LS down will reduce the amount of light reflected onto the ceiling. (Leccese et al., 2020). During its development, there were many forms of light shelves, namely curved, chamfered, sloped up and sloped down ceiling, and can be tilted with mirrored or diffuse upper reflecting surfaces (Bean, 2004). The movable systems provide more flexibility on controlling the operation and on the application, however, it is more expensive.

Figure 2. natural light range with and without light shelves
Source: Green Building User Guide Jakarta (2012)



As stated by Green Building User Guide Jakarta (2012), interior shading: blinds and roller shades are very efficient at preventing glare. Nevertheless, with similar material, blinds may perform similarly to light shelves which distribute the daylight to the deeper area through material reflection. Figure 2 explains that the use of light shelves can increase the range of natural lighting that enters the room by twice the height of the floor to the window through the material reflection. Light shelves are most effective when placed on the south position of the building rather than the West/ East part, especially when the sun is low in the sky (Li et al., 2019).

Dimming System on Artificial Lighting

The dimming system has a more remarkable presentation for energy saving (Xu et al., 2016). Although this can be done manually, greater size energy saving is possible by strategically placing a light sensor in the room (Escuyer et al., (2001). This sensor dims or turns off the lights to maintain the desired light level. Continuous dimming results in more significant savings than dimming stepped on-off, but also more expensive to implement (Xu et al., 2016).

Dimming system can be designed in daylighting schemes as an on–off control by switching electrical lighting automatically through a predetermined level of the lighting levels fall and rise (Danny et al., 2010). A unique problem that may occur with this control type is the rapid and frequent switching of lights, particularly during unstable weather conditions when daylight levels change around the switching illuminance, moreover, these conditions can be unbenefited for occupants and unsustain for the lamp life (Danny et al., 2010). On the other hand, the dimmer can be set on the electric light component, so a photo-sensor can be implemented to control the exact quantity of electric light being contributed and to detect variation in daylight levels (William, 1986). Such systems ensure that the electric light is not wasted. Therefore, changes in lighting levels occur slowly and are usually not perceived by the user (Green Building User Guide Jakarta ,2012). With opposite dimming controls, further energy conservation can be achieved when the total light output from the light fittings exceeds the target values (Xu et al., 2016).

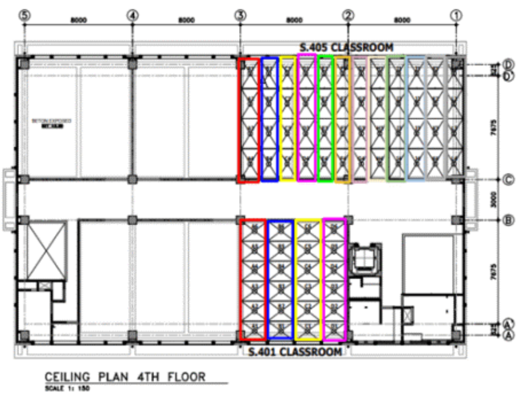
The simplest control can be a double switch which can turn off some lights in one lamp housing or several lighthouses in one room. This manual control system is simple with low installation costs (Green Building User Guide Jakarta,2012). However, the effectiveness of this manual system is highly dependent on user behavior (Escuyer et al., (2001). If the user does not turn off the lights when it is not needed, saving energy will not occur. This strategy is to place some light switches in several locations, so users cannot turn on all the lights simultaneously (Galasiu et al., 2004). In situations where the pattern of room use occurs consistently, automatic time control may be used to turn off the light at a particular time.

Methodology

This paper uses a quantitative approach with field measurements under existing conditions to investigate the uniformity of lighting in a case study. Furthermore, strategy simulations were carried out to investigate the effect of uniform lighting performance of each strategy compared to the existing results.

As stated on the Standard of SNI 7062:2019, the south classroom was measured by 36 points (room area is more than 100 m2), and the north classroom was measured by 25 points (room area between 50 m2 to 100 m2). Measurements were set at the tool sensor's height of 0.8 m from the floor. Figure 3 shows the position when measuring the classrooms of the case study.

Figure 3. Position when measuring with a lux meter in the classroom of case study
Source: Author



In addition to manual measurements, DIAlux© software was used to simulate alternative research strategies. The simulation requires case study material and climate data at the site simultaneously as manual measurements. Table 1 shows the finishing materials in the classroom with the reflectance values of these materials to be applied in the DIAlux simulation. This paper simulated seven strategies, combining LS, horizontal blind curtain, and dimming system.

Table 1. The material used in the classroom

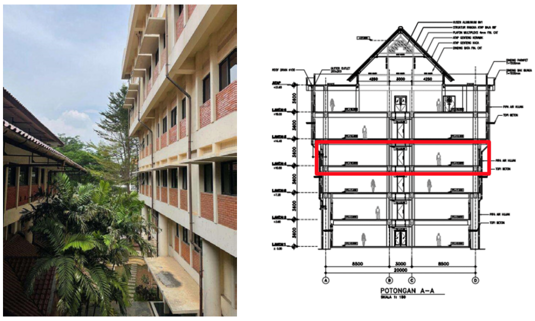
Room Element	Materials	Reflectance (%)
Floor	Light Brown Granite	50 %
Wall	White painted	65 %
	Red painted	0.5 %
Ceiling	White Gypsum	85 %
Window Glass	Clear Glass 8mm	8 %
Whiteboard, desk,	White Melamic	45 %
Door, Window frames, Chair		30%

Source: Author

Data collection of manual measurement and Dialux simulation was carried out in the S building on Mei 28th, 2022. Measurements are made to determine the intensity of lighting on objects, work objects, equipment or machines and production processes, and specific work areas where activities require different lighting intensities (SNI 7062:2019). This paper measures the incoming lighting on the classroom's fourth floor facing north and south. The consideration for choosing the 4th floor, apart from the floor in the middle of the building floor, is because the view from the window was not obstructed by trees and roofs of the surrounding buildings, so natural lighting is maximally entered into the classroom on the 4th floor. (as shown in figure 4 a-b). It may not give a different result from the simulation, which is not inputting the trees around the building model. In this study, the data obtained was sourced from the measurement results from direct observation of the object study.

The educational building used as a study case in this paper is the S Building at the Faculty of Engineering, Universitas Indonesia (FTUI). The University of Indonesia is a campus in Depok City that is trying to implement the concept of green campus design. The building complex consists of a mass of buildings that are integrated with the natural environment and apply the concept of natural lighting.

Figure 4. (a) The trees around the building. (b) Section of the S building from the east.
Source: Author



Currently, there are windows in the classrooms along the north and south sides of the building facade, which can maximize the sunlight entering the room. However, the deeper side of the classroom requires additional lighting, which still uses artificial lighting. On the other hand, the existing artificial lighting is a single switch system, causing different lighting intensities between the area near the window and the area far from the window during the day due to the room's depth. When the light is on, the area near the glass will be dazzled, whereas if the light is off, the area inside will be dark. Therefore, the classroom in S Building is fitted to the problem of this paper, and it is essential to observe the building's sunlight potential, support the performance of artificial lighting, and what strategies to achieve uniform lighting in the classroom.

Result and Discussion

1. Existing Measurement

Table 2 shows the result from manual measurement using a lux meter in clear sky conditions at 12 am. The result of lighting uniformity in the classroom with natural daylight only is 0.149 and 0.173. The condition of minimum illumination is under 350 lux, which verifies the dark side of the classroom, which drives the students to switch the lamps on. When the artificial light is on, the minimum illumination passes 350 lux, which passes the standard for studying activity. Meanwhile, the lighting uniformity is at 0.23 and 0.324. It is due to the high maximum illumination in the area near the window that receives both direct daylighting and artificial lighting.

Table 2. Result of manual measurement

	E_{min}	E_{max}	E_{Av}	U_o
Classroom Facing South				
Natural Daylight	255	5863	1704	0.149
Natural and Artificial Light	502	6399	2186	0.23
Classroom Facing North				
Natural Daylight	183	4911	1057	0.173
Natural and Artificial Light	503	5271	1553	0.324

Source: Author

From the condition of the study case, the simulation strategies require minimizing illumination in the area near the window while still giving enough illumination in the deeper area. Therefore, as stated at the beginning of this paper, integration strategies are needed to increase the lighting uniformity of severe classroom cases. Those strategies are obtained in seven different strategies as shown in table 3.

Table 3. The Strategies

	Lighting Strategies	Analysis Condition
Strategy 1	Grouping and Dimming 50%	Artificial Lamp with Dimming 50%
Strategy 2	Statis Horizontal Light Shelves	Daylight only
Strategy 3		Daylight and Dimming 50%
Strategy 4	Inclined Light Shelves	Daylight only
Strategy 5		Daylight and Dimming 50%
Strategy 6	Blind	Daylight only
Strategy 7		Daylight and Dimming 50%

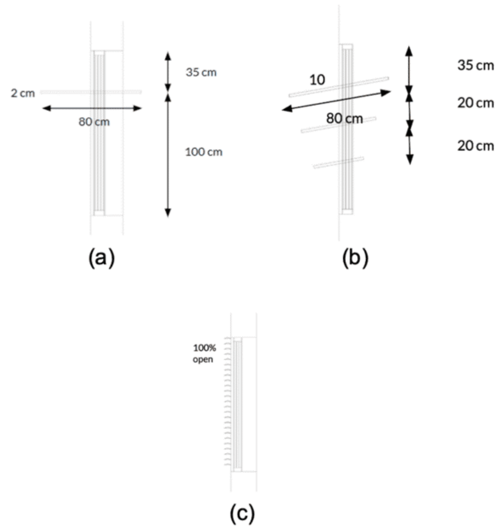
Source: Author

2. Dialux simulation

The first lighting control strategy is to intervene in the window to minimize the contrast of high illumination in areas near the window. The static horizontal light shelves (strategy 2) used were 2 cm in thickness, 80 cm long, and positioned 180 cm above the floor (figure 5a). The material used is Translucent Polycarbonate of diffused type, and the reflection level is 82. The second light shelves strategies simulated have different forms, which have 2 cm of thickness with three layers and are rotated 10 degrees (figure 5b). The first layer is 80 cm long and positioned 180 cm above the floor, the second layer is 60 cm and placed 150 cm above the floor, and the third layer is 40 cm long and 130 cm above the floor.

The simulation result in table 4 shows that strategy 2 gives maximum illumination on 743 lx and an average illumination value of 343 lx. Nevertheless, there is an area that still gets 110 lx the lowest. It may conclude that illumination is under the recommendation in the deeper classroom area. Meanwhile, the inclined light shelves (strategy 4) simulation results show lower values for minimum, maximum, and average illumination. The minimum illumination value is 99 lx, the maximum illumination is 522 lx, and the average illumination is 210 lx.

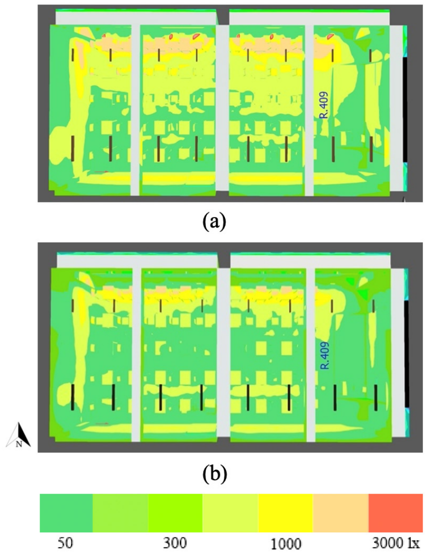
Figure 5. (a) Static Horizontal Light shelves section. (b) Inclined Light shelves section, (c) Blind section.
Source: Author



Moreover, for strategy 2, the light uniformity reaches 0.42. For strategy 4, the light uniformity reaches 0.47, which verifies that the case study's light shelves strategies may increase the uniformity close to the recommendation. Nevertheless, to reach the minimum standard of 0.6 uniformity, the deeper area still needs the support of artificial lighting with dimming control.

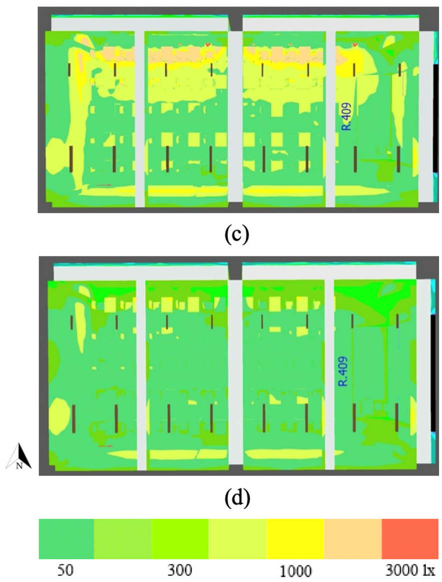
In other consideration, light shelves need extra effort for construction and material when applied to the classroom. Therefore, the blind curtain is easier to install and more common in public buildings as a window intervention. According to Zumtobel (2006), the blind has a similar function to light shelves that can distribute daylight evenly and minimize glare. The simulation strategy uses 100% opened blind (strategy 6), as shown in figure 5(c).

Figure 6. (a) Dialux Simulation of Strategy 1. (b) Dialux Simulation of Strategy 5.
Source: Author



The simulation result shown in table 4 shows that strategy 6 gives the light uniformity that reaches 0.51. It indicates that blind curtains may increase the uniformity of lighting. While the minimum illumination value is 81,5 lx, maximum illumination is 382 lx, and average illumination is 161 lx. It indicates that the illumination is lower than the result of light shelves strategies. It may conclude that a blind curtain has glare prevention that worked well as a function of the blind curtain but could not distribute the daylight into the deeper side of the classroom.

Figure 7. (a) Dialux Simulation of Strategy 3. (b) Dialux Simulation of Strategy 7.
Source: Author



The daylight optimization strategies above give a better result of lighting uniformity than the LS strategy. Nevertheless, there is still an area that gets low illumination when the area near the window gets a good illumination level. Therefore, it needs the support of artificial lighting with dimming control for the different needs of illumination intensity. This case study uses the dimming settings of 0% (the artificial lamp was off) for the area near the window and 50% dimming for the deeper classroom area (strategy 1). The artificial lamps were grouped in two rows. The simulation result is shown in table 4; strategy 1 gives the minimum illumination value of 471 lx, maximum illumination of 1233 lx, and an average of 648 lx. The light uniformity reaches 0.73 when the number under or above 50% gives low uniformity performance (under 0.6), which is caused by high intensity of maximum illumination or low intensity of minimum illumination according to the standard. From the result of the simulation above, the lighting uniformity value can reach the recommendation, but the maximum illumination is above the 1000 lx recommendation. Therefore, it needs consideration to give combination intervention on the window to minimize glare or contrast high illumination with collaborating LS and blind curtain and support them with a dimming system.

Strategy 3 gives minimum illumination on 428 lx, maximum illumination on 1121 lx, and average illumination on 601 lx. At the same time, the light uniformity is 0.71, which meets the standard excellently. Nevertheless, both results are unfit if we see the minimum and maximum illumination. The minimum illumination of daylight simulation is 110 lx under the standard, while the maximum illumination of the artificial simulation is 1121 lx above the standard. While strategy 5 shows that minimum illumination is 420 lx, maximum illumination is 688 lx, average illumination is 564, and uniformity is 0.74, all results fit the standard. Moreover, the simulation of strategy 7 gives minimum illumination on 354 lx, maximum illumination on 648 lx, and average illumination on 467 lx. The result shows that minimum, maximum, and average illumination fits the standard. At the same time, the light uniformity is 0.76, which meets the standard excellently.

Table 4 shows the overall result of all the lighting control strategies. The marked red denotes an unfit result from the recommended standard, and the marked bold denotes the fit result that passes the recommended standard. From the simulation result shown in the table, light uniformity is reached on strategy 1, strategy 3, strategy 5, and strategy 7. Furthermore, the illumination result that fits the standard is shown in strategy 3 and strategy 7. While considering the energy consumption, strategy 6 performed best *(the highest number), but the illumination performance was low. Therefore, the classroom still needs artificial light performance to reach the overall standard. The simulation results can also be seen from the colors that represent the level of illumination in figure 6 and figure 7. These figures depict the floor plan of the study case room.

However, this paper has mentioned the importance of lighting uniformity as a parameter that indicates good design (Skarżyński et al., 2020). It indicates the ratio of the minimum lighting lever to the average lighting level, which is a quality parameter for overall illuminance distribution. If the illumination uniformity is low, we can conclude that there are areas of contrast with low levels of illumination and areas of high illumination. Classroom plans require general learning activities with flexible study layouts, so the screen area is the only specific area that does not require uniform lighting. Otherwise, this area requires a low illumination level for the screen to be visible. Therefore, minimum, maximum, and average illumination results must also be analyzed carefully.

As stated in the study of Lesecce et al. (2020), the Amount of Light consists of the indicators 1) the average illuminance over the task area, 2) the uniformity of the illuminance, and 3) the illuminance distribution ratio is the first luminance criterion of the luminance evaluation indicator. As shown in table 4, the strategies of Static Horizontal Light Shelves, Inclined Light Shelves, and Internal Blind Curtains in daytime conditions almost meet the lighting uniformity. However, it should be noted that the minimum illumination output is well below 350 lux. In addition, the strategy managed to set the maximum exposure not far above 1000 lux [24] as recommended. It also shows that it can manage glare in areas near windows with the highest amount of daylight. With the study of Lesecce et al. (2020), it is also appropriate that glare, the second evaluation factor, has the indicator to avoid Overhead Illuminance.

Table 4. Table Discussion

	Artificial Lighting Control			Illumination Minimum	Illumination Maximum	Illumination Average	Illumination Distribution
	SNI Standard (Office/ Classroom)			350 lx	1000 lx		0.6
Existing	**Manual Measurement**	Daylight		255 lx	5863 lx	1704 lx	0.14
		Artificial Light		502 lx	6399 lx	2186 lx	0.23
Lighting Control Strategies Proposed	**Grouping and Dimming 50%**	Dimming 50%	*Strategy 1*	471 lx	1233 lx	648 lx	**0.73**
	Static Horizontal Light shelves	Daylight	*Strategy 2*	110 lx	734 lx	343 lx	0.42
		With Dimming 50%	*Strategy 3*	428 lx	1121 lx	601 lx	**0.71**
	Inclined Light Shelf	Daylight	*Strategy 4*	99 lx	522 lx	210 lx	0.47
		With Dimming 50%	*Strategy 5*	420 lx	688 lx	564 lx	**0.74**
	Blind	Daylight	*Strategy 6*	81.5 lx	382 lx	161 lx	0.51
		With Dimming 50%	*Strategy 7*	354 lx	648 lx	467 lx	**0.76**

Source: Author
*The marked red denotes an unfit result from the recommended standard, and the marked bold denotes the fit result that passes the recommended standard.

Therefore, this research case study still needs artificial lighting with a dimming system in the classroom. Due to the depth of the class, the Light Shelves and Blind strategies still have not succeeded in distributing sunlight to the most profound areas. The dimming strategy successfully increased the minimum lighting levels in the deeper classroom areas. With the combination of Light Shelves and Blind Curtain Strategies, it achieved the amount of light (minimum illumination, maximum illumination, average illumination, uniformity) and avoided glare.

Conclusion And Recommendation

The simulation results show strategies that can achieve uniform lighting: strategy 1, strategy 3, strategy 5, and strategy 7. These strategies still use artificial light as support of LS and blind curtains to reach areas far from windows. Meanwhile, The Light Shelves and Blind Curtain Strategy effectively distribute daylight to deeper classroom areas and maximizes overhead lighting in areas near windows. This makes it practical to avoid glare in areas with the highest daylight exposure. The dimming strategy effectively increases the minimum illumination in dark areas.

This study does not consider the type of artificial light, which can also affect the uniformity and energy consumption of light in the classroom. The results and analysis from this research strategy may also apply only to this case study or to buildings with similar conditions. Furthermore, further research may consider other better-performing strategies and integrations. Organizing data at different times of the year is also recommended.

Acknowledgment

The authors would like to thank Fifi Deviana and Silvia Sebayang, the magister students of Architecture of Universitas Indonesia, for their insights, discussions, and support in compiling this paper.

References

Abimaje, J., Kandar, Z. B., Dodo, M., Aminu, Y. 2018. Light Shelf as a Daylighting System in a Tropical Climate Office Space. *International Journal of Engineering & Technology*

Bean, R. (2004). *Lighting Interior And Exterior.* Massachusetts. Elsivier: Architectural Press

Bernardo, H., C. Henggeler Antunes, A. Gaspar, L. Dias Pereira, M.G. da Silva. (2017). An approach for energy performance and indoor climate assessment in a Portuguese school building, Sustain. *Cities Soc*, 30, 184–194. http://dx.doi. org/10.1016/j.scs.2016.12.014

Economidou, M., Atanasiu, B., Despret, C., Maio, J., Nolte, I., Rapf, O., Laustsen, J., Ruyssevelt, P., Staniaszek, D., Strong, D., & Zinetti, S. (2011, October 15). *Europe's buildings under the microscope.* A country-by-country review of the energy performance of buildings. Netherlands.

Escuyer, S & Fontoynont, Marc. (2001). Lighting controls: A field study of office workers' reactions. *Lighting Research & Technology - LIGHTING RES TECHNOL*. 33. 77-94. doi: 10.1177/136578280103300202.

European Standard. (2021, November). *Light and lighting - Lighting of work places - Part 1: Indoor work places* [E-Reader Version]. Retrieved from https://www.en-standard.eu/din-en-12464-1-light-and-lighting-lighting-of-work-places-part-1-indoor-work-places/

Fitriaty, Puteri & Shen, Zhenjiang & Achsan, Andi. (2019). Daylighting Strategies in Tropical Coastal Area A Lesson From Vernacular Houses. *International Review for Spatial Planning and Sustainable Development.* 7, 75-91. doi: 10.14246/irspsd.7.2_75.

Freewan, A.A.Y. (2014). *Impact of external shading devices on thermal and daylighting performance of offices in hot climate regions*, 102, 14-30, doi: https://doi.org/10.1016/j.solener.2014.01.009.

Galasiu, Anca & Atif, Meziani & MacDonald, Robert. (2004). Impact of window blinds on daylight-linked dimming and automatic on/off lighting controls. *Solar Energy.* 76. 10.1016/j.solener.2003.12.007.

Ganslandt, R., Hofmann, H. (1992). *Handbook of Lighting Design* [E-Reader Version]. Retrieved from https://ia803202.us.archive.org/13/items/Handbook_Of_Interior_Lighting_Design/Handbook_Of_Interior_Lighting_Design.pdf

Haq, M., Hassan M.Y., Abdullah H., Rahman H.A., Abdullah M.P, Hussin F., Said D.M. (2014). A review on lighting control technologies in commercial buildings, their performance and affecting factors. *Renewable and Sustainable Energy Reviews*. 33, 268-279, doi: 10.1016/j.rser.2014.01.090

Kim, H.J., Ok-Hee An. (1999). A study of yield methods including artificial lighting uniformity ratio in interior space. *Journal of Korean Institute of Illuminating and Electrical Installation Engineers,* 13(2), 7-11.

Kontadakis A, Tsangrassoulis A, Doulos L, Zerefos S. (2018). A Review of Light Shelf Designs for Daylit Environments. *Sustainability.* 10(1). 71. doi: https://doi.org/10.3390/su10010071

Laustsen, J., Ruyssevelt, P., Staniaszek, D., Strong, D., Zinett, S. (2011). *Europe's Buildings Under the Microscope Buildings Performance Institute Europe (BPIE),* Brussels. Retrieved from http://www.bpie.eu/publication/europes-buildings-under-the-microscope/

Lechner, N., (2015). *Heating, Cooling, Lighting: 4th Edition*. Ney Jersey, NJ: Wiley

Leccese, F., Salvadori, G., Rocca, M., Buratti, C., Belloni, E. (2020). A method to assess lighting quality in educational rooms using analytic hierarchy process, *Building and Environment.* 168. doi: https://doi.org/10.1016/j.buildenv.2019.106501.

Li, Danny & Mak, Ada & Chan, Wilco & Cheng, Charles. (2009). Predicting Energy Saving and Life-Cycle Cost Analysis for Lighting and Daylighting Schemes. International Journal of Green Energy - *INT J GREEN ENERGY.* 6. 359-370. doi: 10.1080/15435070903107015.

Martinopoulos, G., Papakostas, K. T., Papadopoulos, A. M. (2018). A comparative review of heating systems in EU countries, based on efficiency and fuel cost. *Renewable and Sustainable Energy Reviews*, 90(687), doi: https://doi.org/10.1016/j.rser.2018.03.060.

Module 194: *Evaluating lighting needs for educational facilities*. (2022, March). Retrieved from https://www.cibsejournal.com/cpd/modules/2022-04-lighting/

Osterhaus, Werner. (2005). Discomfort glare assessment and prevention for daylight applications in office environments. *Solar Energy - SOLAR ENERG.* 79, 140-158. doi: 10.1016/j.solener.2004.11.011.

Pemerintah Provinsi DKI Jakarta. (2012). *Jakarta Green Building User Guide Volume 3 Lighting System*. Jakarta: Pemerintah Provinsi DKI Jakarta.

Rea, M.S., Ouellette, M.J. (1991). Relative visual performance: A basis for application.

Lighting Research & Technology. 23(3), 135-144. doi:10.1177/096032719102300301

Samani, S.A. (2012). The Impact of Indoor Lighting on Students' Learning Performance in Learning Environments: A knowledge internalization perspective. *International Journal of Business and Social Science,* 3(24). Special Issue – December 2012.

Slater, A. I. Boyce, P.R. 1990. Illuminance uniformity on desks: Where is the limit? *Lighting Research & Technology.* 22(4), 165-174. doi: 10.1177/096032719002200401

Shankar A., Vijayakumar K., Babu B.C. (2021). Energy saving potential through artificial lighting system in PV integrated smart buildings. *Journal of Building Engineering*. 43. https://doi.org/10.1016/j.jobe.2021.103080.

Skarżyński, K., Rutkowska, A. (2020). *A comparison of the calculations and measurements for a lighting design of the same room.* Przeglad Elektrotechniczny. 96, 11-14. doi:10.15199/48.2020.11.03.

Standar Nasional Indonesia. (2020, December 30). *Konservasi energi pada sistem pencahayaan* [E-Reader Version]. Retrieved from https://pesta.bsn.go.id/produk/detail/13243-sni61972020

William, M.C. (1986). *Sunlighting as Formgiver for Architecture*. New York. NY: Van Nostrand Reinhold

Xu, Lei & Pan, Yiqun & Yao, Yuan & Cai, Dandan & Huang, Zhizhong & Linder, Norbert. (2016). Lighting energy efficiency in offices under different control strategies. *Energy and Buildings.* 138. doi: 10.1016/j.enbuild.2016.12.006.

Zumtobel. (2018). *The Lighting Handbook* [E-Reader Version]. Retrieved from: https://www.zumtobel.com/PDB/Ressource/teaser/en/Lichthandbuch.pdf