ULTIMARCH
International Journal of Sustainable Architecture, Urban, and Multimedia Technology
e-ISSN: xxxx-xxxx, p-ISSN: xxxx-xxxx
Volume 1, Issue I [2024]
https://ejournals.umn.ac.id/index.php/ULTIMARCH

Efficient Opening Design for Daylighting in Educational Facilities: A Case Study of Xaverius 3 Senior High School, Palembang

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Keywords:
OTTV
Lighting
Window-to-Wall Ratio
School Building

Submitted: April 20th, 2024
Revised: June 13rd, 2024
Accepted: July 4th, 2024

Abstract

The school serves as educational facilities to accommodate teaching and learning activities. The efficiency of these activities within the classroom is influenced by the illumination level within that space. Classrooms with more natural lighting allow students to learn 20% more efficiently compared to classrooms with less natural lighting. However, many classrooms still rely on artificial lighting, such as lamps. Apart from reducing -students' learning efficiency, the use of artificial lighting also diminishes energy conservation in school buildings. Therefore, this research aims to analyse the optimization of opening design for natural lighting in classrooms. The case study involves Xaverius 3 Palembang Senior High School as the focus of this research. This school is considered as a case study because it uses artificial lighting in classrooms despite having windows on each side of the room. In the data analysis process, this research employs an experimental research method by modifying the most efficient opening design for natural lighting, targeting an average of 350 lux. The experiment utilizes Dialux Evo software to simulate natural lighting levels in the classrooms. Through this process, it is found that various factors influence natural lighting levels in a room. The buildings' mass shape and orientation are fundamental factors in optimizing natural lighting. The dimensions of openings and the use of shading are other factors affecting natural lighting levels in a room. Therefore, designing the most efficient building opening requires a combination of appropriate opening dimensions and shading usage, maximizing the potential of natural lighting based on the building's mass shape and orientation.

1. INTRODUCTION

Schools are social institutions that play a role in shaping character and honing our skills. Therefore, school buildings need to consider aspects of comfort and flexibility to facilitate teaching and learning activities. These aspects aim to make the activities within a school building more efficient. (Muhaimin et al., 2023).

Lighting is one of the aspects which takes part in determining the quality of health and comfort for the building occupants (Fitria, 2021). Artificial lighting and daylighting are two types of lighting which has been use commonly depending on the building typology and user's need (Ardyanny, 2023). In schools, providing sufficient daylight in classrooms is essential for enhancing students' wellbeing and improving study efficiency (Bian et al, 2023). According to Heschong (1999), classrooms with more natural lighting can enhance learning efficiency by 20% compared to classrooms with less natural lighting. Additionally, utilizing natural lighting as an illumination source within a space can contribute to energy conservation within a building. The significance of natural lighting in improving learning efficiency and saving energy makes daylighting a crucial aspect in the design of a classroom.

Natural lighting in a building enters through opening elements in the building design, such as windows. Considering the three levels in the sustainable architecture approach, several aspects influence natural lighting inside a building, including building mass, building orientation, shading devices, and the dimensions of openings.

2. LITERATURE REVIEW

2.1 BUILDING MASS AND ORIENTATION

The building mass influences the design of openings and the energy usage of the building. According to Lechner (2015), there are several examples of mass forms (Fingure 2.1), along with their several examples of mass forms (Figure 1), along with their advantages and disadvantages:

1) Buildings with a square mass have a compact shape, which can reduce the absorption of heat in the building. However, this mass has a limited potential for natural lighting and has a small potential for maximizing daylight from the north and south.
2) Square-massed buildings with voids have a good natural ventilation system. Additionally, the voids can serve as entry points for daylight into the building. However, similar to mass (I), this mass has a limited potential for maximizing daylight from the north and south.
3) Square-massed buildings with low height (maximum 2 floors) have more variation in utilizing lighting. However, this mass also cannot maximize daylight from the north and south

4) Buildings with a rectangular mass have a significant potential for maximizing daylight from the north and south.
5) Buildings with an L-shaped mass have the same potential as rectangular masses. However, in this mass, there are still some sides of the building that receive daylight from the west and east directions.

When designing openings in a building, it is essential to consider the orientation and geographical location of the structure. This becomes a critical point in designing openings because each direction has a different impact on the efficiency of daylight within the building. Generally, the sides of the openings in a building face east and west, while avoiding placing openings facing north and south.

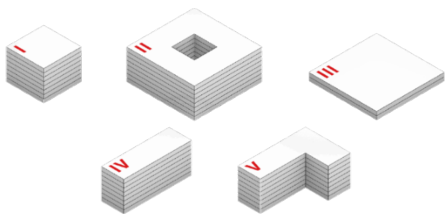

Fig. 1 Types of Building Mass
Source: Lechner, 2015

The east and west sides of a building receive twice as much solar radiation compared to the north and south sides. Therefore, buildings with dominant openings facing east and west are more prevalent than those with dominant openings facing north and south. Naturally, this factor can also influence the energy consumption of the building. (Lechner, 2015).

2.2 SHADING DEVICES

The intensity of daylight entering a building through openings is not always consistent. Excessive daylight entering the building can have a negative impact on the comfort of occupants. Therefore, shading is used to block excessive daylight, allowing the lighting conditions inside the building to be more optimal. The use of shading is prioritized on the sides facing east and west of the building as these are the sides with high levels of daylight (Lechner, 2015).

According to Szokolay (2008), there are three types of shading designs: Vertical devices, block the Horizontal Shadow Angle (HSA), horizontal devices block the Vertical Shadow Angle (VSA), then egg-crate devices respond well to both HSA and VSA.

The HSA value is the result of subtracting the angle of azimuth from the angle of the wall orientation. An HSA result with an angle greater than 90° and less than -90° indicates that the side is not exposed to daylight. The VSA value can be found using the formula arctan (tan (Altitude)/cos (HSA)).

2.3 WINDOW-TO-WALL RATIO (WWR)

Window-to-Wall Ratio (WWR) is basically the building openings or the percentage of the window area on one side of a wall to the total surface area of that wall. WWR is used to regulate the intensity of daylight entering a building; the larger the WWR value, the greater the intensity of daylight entering through the openings. (Purwoko & Purwanto, 2022)

The area of an opening is calculated by multiplying its width and height. According to EDGE User Guide, to ensure that daylight entering through an opening can illuminate the entire area within a room, the height of the opening should be at least 2/3 of the width of the room. According to Lechner (2015), one window with an area of 1.35 m^2 is equivalent to 100 artificial lights with a power of 60 W. Therefore, utilizing natural lighting as the source of illumination inside a building can reduce the energy consumption of that building.

2.4 DAYLIGHT STANDARD

According to data from SNI-6197-2020 in Table 1, the standard average illumination level in classrooms should be at least 350 lux, and in drawing rooms, it should be at least 750 lux. Then, according to data from GBCI, the illumination level for 30% of the room area should not be less than 300 lux. Based on this data, the average natural lighting level in school buildings should be at least 350 lux up to 750 lux.

According to Nabil & Mardaljevic (2005), the target for natural lighting in a room during the day is called Useful Daylight Illuminance (UDI). Natural lighting levels below 100 lux annually can result in dark conditions, while levels above 2000 lux annually can cause glare and have negative impacts on visual comfort for users. Therefore, even though there are minimum standards for natural lighting in a room, excessive natural lighting can also lead to visual discomfort for users inside that space.

Table 1 Daylight Standard (SNI 6197-2020)

Standard	Parameter	Source
Classroom Average Illuminance	350 lux	SNI-6197-2020
Art Room Average Illuminance	750 lux	
Daylight Distribution	30% of Room Area >300 lux	GBCI
Minimum	100 lux	Useful Daylight Illuminance
Maximum	2000 lux	

2. METHOD

This research aims to analyze the case study building opening design that maximize natural daylight inside the building. The architectural elements key which affected the natural lighting are including Window-to-Wall Ratio (WWR), building opening placement, window height, and shading devices. These factors significantly influence the level of daylight illuminance that entering the room. By optimizing these design elements, it will be creating the spaces that not only promote optimal learning conditions but also reduce energy consumption. Considerations in modifying architectural designs to achieve appropriate levels of daylight illuminance are done based on the simulations using Dialux Evo, following efficient daylight standard parameters for classrooms, at minimum of 300 lux (SNI, 2020) and a maximum of 2000 lux (Nabil, A. and Mardaljevic, J., 2004).

The case study building involves Xaverius 3 Palembang Senior High School which can be seen in figure 2 as the focus of this research. Xaverius 3 Palembang Senior High School is a private high school with an A accreditation, located on Jl. Kolonel Atmo, Ilir Timur 1 District, Palembang, South Sumatra, Indonesia.

From Xaverius 3 Senior High School building design, there are shading devices in the form of horizontal shading devices and curtains that block the entry of daylight from outdoor to indoor. The presence of curtains at each opening (Figure 3) in the rooms results in the lighting system within the rooms being entirely reliant on artificial light, thus affecting the efficiency of teaching and learning activities in the classroom. From a visual perspective, the openings on each side of the room have substantial dimensions. However, the size of these openings did not lead the school building management to opt for utilizing natural lighting as the primary source of illumination within the rooms. Despite the large dimensions of the openings leading to an increase in indoor temperature, thus this study will also review the design of the openings in Xaverius 3 Senior High School building concerning indoor daylighting in the absence of curtains.

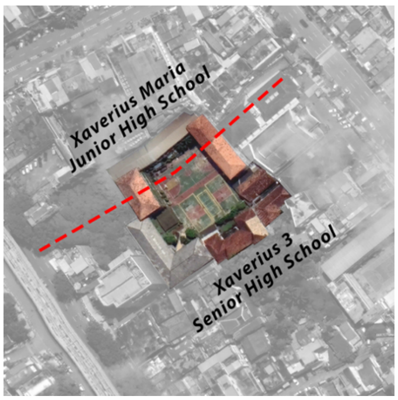

Fig. 2 Xaverius 3 Senior High School Block Plan
Source: Evandy, 2024

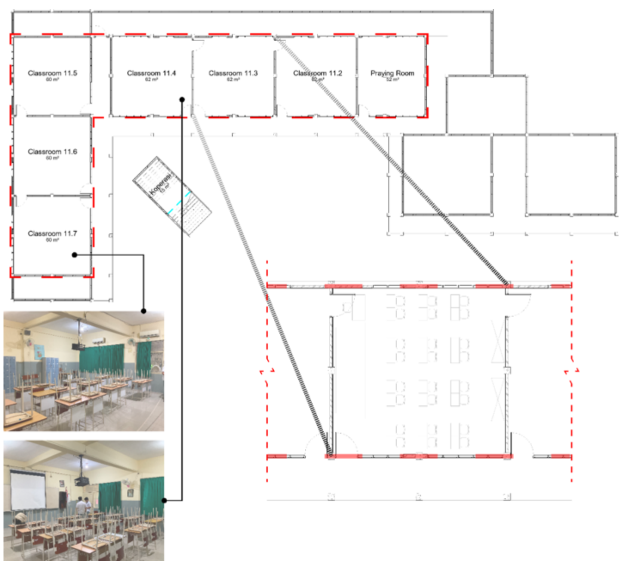

Fig. 3 Existing Classrooms Conditions of Xaverius 3 Senior High School
Source: Evandy, 2024

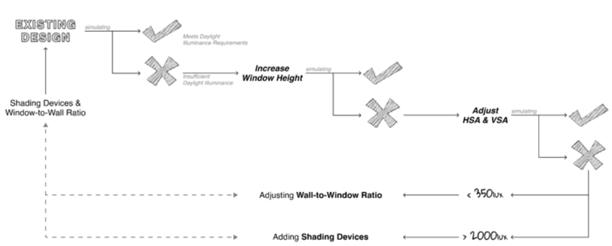

Fig. 4 Research Methodology
Source: Evandy, 2024

The steps of this research can be seen in Figure 4, which adopts an experimental method by simulating indoor daylight using Dialux Evo software. The simulation process involves a 3D model of the Xaverius 3 Senior High School building created using Autodesk Revit software. To develop the 3D model, direct measurements of the school building was done. The simulation results are then correlated with literature theories and standard daylighting parameters for classrooms. There are 9 variables used in the daylighting simulation, March 21st, 2023, at 09:00, 12:00, 15:00; on June 21st, 2023, at 09:00, 12:00, 15:00; and on December 23rd, 2023, at 09:00, 12:00, 15:00. The adjustment made in the Dialux Evo software is to offset the daylight simulating plane to 70 cm from the floor level, which corresponds to the height of the desks in the classroom. Meanwhile, the daylight illuminance average (lux) calculations encompass the entire classroom area because the layout of activities within the room covers nearly all the space, including beside the classroom windows which can be seen in Figure 3.

In this research, the existing rooms are categorized into groups based on the dimensions of openings and the orientation of the rooms to facilitate analysis. The room groups are divided based on two conditions: a group with the highest level of natural lighting and a group with the lowest lighting levels during a specific time. From the results of the existing simulation, the daylighting efficiency can be concluded. These results are then evaluated to formulate suitable modifications to the opening design to enhance daylighting efficiency. The modifications are applied to the 3D model of the building and simulated again. The modification stage is repeated several times until conclusions are drawn regarding the elements of the opening design which affect the level of daylighting inside the classroom.

4. RESULT AND DISCUSSION

The classrooms at Xaverius 3 Senior High School uses artificial lighting as the main source of illuminance. The openings on two sides of the walls in each room as seen in Figure 5, are not effectively utilized as sources of daylight. All openings on every side of the room have curtains installed. The presence of curtains as shading elements, blocks daylight from outside to inside, resulting in the classrooms at Xaverius 3 relying entirely on artificial lighting.

The lack of natural lighting in a room can decrease students' learning efficiency (Heschong, 1999). The lighting sources in each classroom at Xaverius 3 come from artificial lighting without open access to natural lighting, which can impact the efficiency of students' learning process. The use of artificial lighting in the classrooms is not optimal, as occupants in the room do not feel satisfied with the existing lighting levels. This also triggers feelings of boredom and drowsiness while in class.

The mass shape of the Xaverius 3 building is L shape. According Lechner (2015), a building mass with such a shape has the potential for natural lighting, but the orientation of the openings cannot maximize the potential towards the north and south. With the building shape in the environment of Xaverius 3, there are many sides of the walls that receive daylight from the east and west, causing an excessive intensity of daylight.

The sides of the building as seen in Figure 6, facing the field have an angle difference of 55° concerning the north direction. If the building's orientation is projected with the west and east directions, it indicates that all openings in the Xaverius 3 Palembang building receive daylight from the west and east. This leads to a significant increase in the natural lighting intensity difference inside the building at specific times.

First Floor

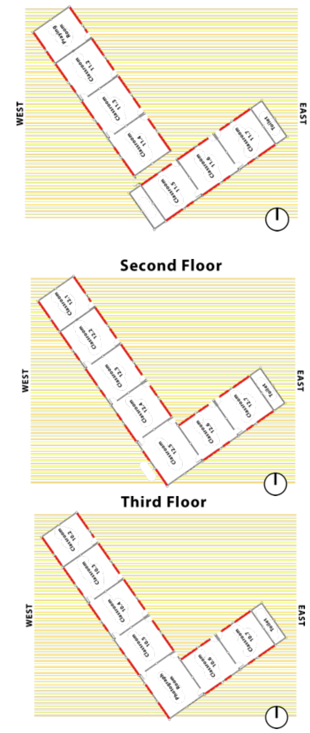

Fig. 5 Xaverius Senior High School 3 Floor Plan
Source: Evandy, 2024

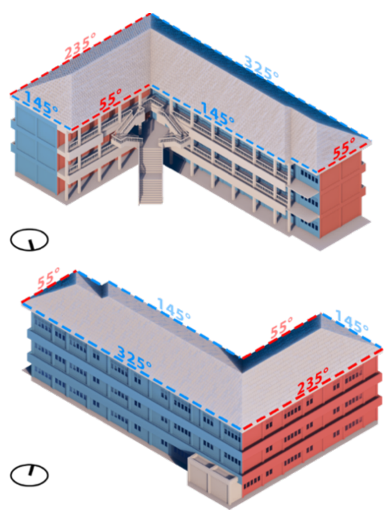

Fig. 6 Xaverius 3 Senior High School Building Mass & Orientation
Source: Evandy, 2024

4.1 SIMULATION

4.1.1 EXISTING DESIGN

From the building openings design for Xaverius 3 Palembang Senior High School building, the daylight enters through the windows. The types of windows used on all three floors of the building include windows with 1 module, 2 modules, 3 modules, and windows with 5 modules. Each module of these windows has a width of 0.55 m and a height of 0.85 m. Based on these dimensions, the opening area for each window is 0.4675 m^2.

For the shading device design of Xaverius 3, it is divided into two types: External shading devices and internal shading devices. Although their placements are different, the dimensions of both shading devices are the same, with a height of 40 cm above their respective levels. These shading devices are only present on the first and second floors. According to Szokolay (2008), vertical shading devices like those in Xaverius 3 Senior High Schools has the function to block the Horizontal Shadow Angle (HSA).

Based on the simulation results using Dialux Evo, the level of natural lighting in the classrooms is not optimal. This is indicated by the numerous room variables at each time that do not comply with the SNI and GBCI standards, which specify an average natural lighting level of 300-750 lux with a minimum of 300 lux of natural light covering at least 30% of the room surface area. In the variable with the lowest lighting level, which is the prayer room and classroom 11.2, the average daylighting level is below the UDI standard, specifically 55.4 lux and 56.1 lux.

In the lowest lighting level variable, none of the daylighting levels meet the standard parameters. The distribution of daylighting inside the room, exceeding 300 lux, does not surpass 30% in this variable. Meanwhile, in the highest lighting level variable, the distribution of daylighting in each room already meets the standard parameters. However, the average daylighting level in each room is above 1000 lux, thus not meeting the SNI standard.

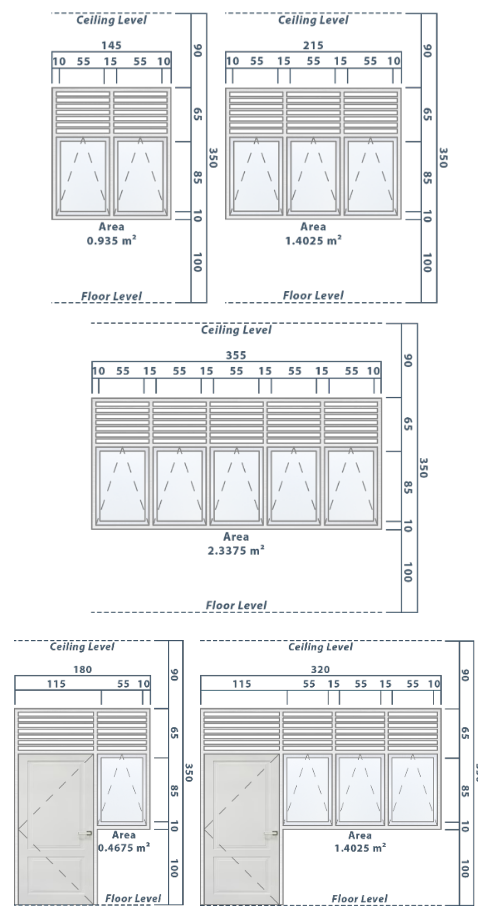

Fig. 7 Existing Opening (Window) Types and Dimension
Source: Evandy, 2024

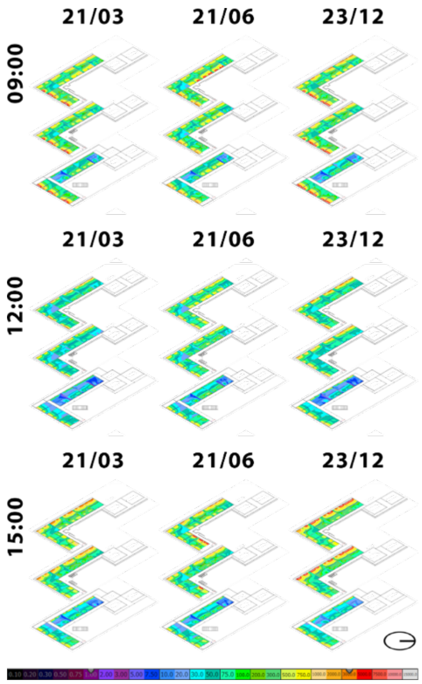

Fig. 8 Existing Building Simulation Result with Dialux
Source: Evandy, 2024

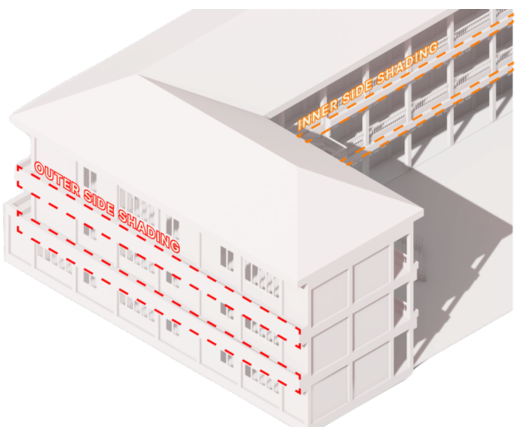

Fig. 9 Existing Building Shading
Source: Evandy, 2024

4.1.2 ADJUSTMENT 1: OPENING/WINDOW HEIGHT

The windows in each room of Xaverius 3 Senior High School have a height of 2 meters (from the floor surface to the upper limit of the opening). Based on the natural lighting parameters from EDGE, the height of the existing openings in Xaverius 3 is not sufficient to illuminate the entire room. With a room area of 7.675 square meters and openings on both opposing sides, the ideal width of the room exposed to daylight is 6 meters (2 x 3 meters). Therefore, adjustments to the height of the windows in each room are needed to ensure that the entire room receives daylight.

With adjustments to the window height based on EDGE's natural lighting parameters, the average lighting levels in each room group with the lowest natural lighting levels become closer to the standard. However, the room group with the highest natural lighting levels also increases. This proves that the height of the opening relative to the width of the building affects the intensity of natural light inside the rooms.

The adjustment to the window height by adding 77.5cm to the opening height has a positive impact on the level of natural lighting in the room with the lowest lighting level. However, this adjustment causes the average natural lighting value in the highest variable to exceed 2000 lux. The effect of adjusting the window height significantly influences the distribution of natural light inside the room, as evidenced by an increase of around 37.5% in the lowest variable and 86.875% in the highest variable. Nevertheless, this adjustment still does not significantly improve natural lighting in the prayer room and classroom 11.4.

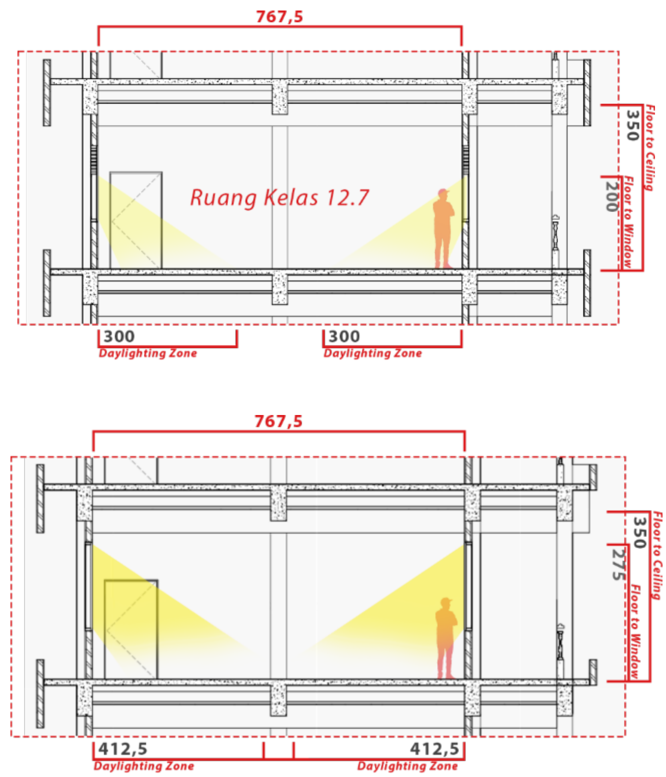

Fig. 10. Opening Height Adjustment
Source: Evandy, 2024

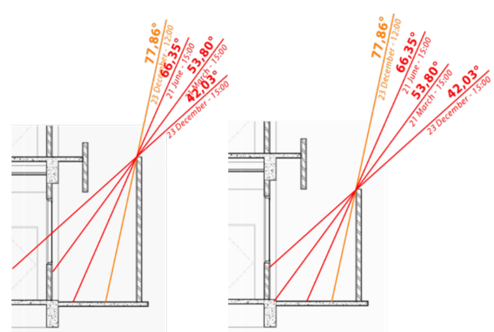

Fig. 11 Exterior Wall Study
Source: Evandy, 2024

Table 2 Existing Building Simulation Result

Lowest Daylight Illuminance

Floor Level	Room	Time	*Window-to-Wall Ratio* 55°	*Window-to-Wall Ratio* 145°	*Window-to-Wall Ratio* 235°	*Window-to-Wall Ratio* 325°	Illuminance Average	Area with Illuminance >350 lx
Ground Floor	Praying Room	21 June - 12:00	-	11.87	-	15.83	55,4 lux	2,78%
	Classroom 11.4	21 March - 12:00	-	11.61	-	11.61	56,1 lux	6,17%
	Classroom 11.5	21 June - 15:00	13.77	-	12.05	-	157 lux	16,04%
	Classroom 11.6	21 June - 15:00	13.77	-	12.05	-	193 lux	17,28%
Second Floor	Classroom 12.1	21 March - 12:00	-	11.87	-	15.83	223 lux	20,83%
	Classroom 12.4	21 March - 12:00	-	11.61	-	11.61	200 lux	14,81%
	Classroom 12.5	21 March - 12:00	-	-	9.68	11.06	198 lux	15%
	Classroom 12.6	21 March - 12:00	13.77	-	12.05	-	206 lux	17,28%
Third Floor	Classroom 10.2	21 June - 12:00	-	11.87	-	15.83	275 lux	22,22%
	Classroom 10.5	21 March - 12:00	-	11.61	-	11.61	285 lux	19,75%
	Photograph Room	21 March - 12:00	-	-	9.68	11.06	168 lux	12,5%
	Classroom 10.6	21 March - 12:00	13.77	-	12.05	-	286 lux	17,28%

Highest Daylight Illuminance

Floor Level	Room	Time	*Window-to-Wall Ratio* 55°	*Window-to-Wall Ratio* 145°	*Window-to-Wall Ratio* 235°	*Window-to-Wall Ratio* 325°	Illuminance Average	Area with Illuminance >350 lx
Ground Floor	Praying Room	21 March - 15:00	-	11.87	-	15.83	112 lux	11,11%
	Classroom 11.3	21 June - 09:00	-	11.61	-	11.61	293 lux	39,50%
	Classroom 11.5	23 December - 09:00	13.77	-	12.05	-	1275 lux	45,67%
	Classroom 11.7	23 December - 09:00	13.77	-	12.05	-	1348 lux	60,49%
Second Floor	Classroom 12.1	23 December - 15:00	-	11.87	-	15.83	1679 lux	56,94%
	Classroom 12.4	23 December - 15:00	-	11.61	-	11.61	1302 lux	55,56%
	Classroom 12.5	23 December - 15:00	-	-	9.68	11.06	1155 lux	55%
	Classroom 12.7	23 December - 09:00	13.77	-	12.05	-	1360 lux	72,83%
Third Floor	Classroom 10.2	12/23/2024 15:00	-	11.87	-	15.83	1777 lux	56,94%
	Classroom 10.5	23 December - 15:00	-	11.61	-	11.61	1414 lux	77,78%
	Photograph Room	23 December - 15:00	-	-	9.68	11.06	666 lux	50%
	Classroom 10.7	23 December - 09:00	13.77	-	12.05	-	1472 lux	83,95%

Table 3 Adjustment 1: Opening/Window Height Simulation Result

Lowest Daylight Illuminance

Floor Level	Room	Time	*Window-to-Wall Ratio* 55°	*Window-to-Wall Ratio* 145°	*Window-to-Wall Ratio* 235°	*Window-to-Wall Ratio* 325°	Illuminance Average	Area with Illuminance >350 lx
Ground Floor	Praying Room	21 June - 12:00	-	16.76	-	22.35	55,7 lux	4,16%
	Classroom 11.4	21 March - 12:00	-	16.40	-	16.40	29,6 lux	0%
	Classroom 11.5	21 June - 15:00	19.43	-	17.00	-	222 lux	23,45%
	Classroom 11.6	21 June - 15:00	19.43	-	17.00	-	268 lux	24,69%
Second Floor	Classroom 12.1	21 March - 12:00	-	16.76	-	22.35	295 lux	30,55%
	Classroom 12.4	21 March - 12:00	-	16.40	-	16.40	263 lux	20,98%
	Classroom 12.5	21 March - 12:00	-	-	13.66	15.61	268 lux	21,25%
	Classroom 12.6	21 March - 12:00	19.43	-	17.00	-	270 lux	22,22%
Third Floor	Classroom 10.2	21 June - 12:00	-	16.76	-	22.35	444 lux	44,44%
	Classroom 10.5	21 March - 12:00	-	16.40	-	16.40	438 lux	43,20%
	Photograph Room	21 March - 12:00	-	-	13.66	15.61	248 lux	22,5%
	Classroom 10.6	21 March - 12:00	19.43	-	17.00	-	444 lux	37,03%

Highest Daylight Illuminance

Floor Level	Room	Time	*Window-to-Wall Ratio* 55°	*Window-to-Wall Ratio* 145°	*Window-to-Wall Ratio* 235°	*Window-to-Wall Ratio* 325°	Illuminance Average	Area with Illuminance >350 lx
Ground Floor	Praying Room	21 March - 15:00	-	16.76	-	22.35	113 lux	6,94%
	Classroom 11.3	21 June - 09:00	-	16.40	-	16.40	343 lux	44,44%
	Classroom 11.5	23 December - 09:00	19.43	-	17.00	-	2039 lux	98,76%
	Classroom 11.7	23 December - 09:00	19.43	-	17.00	-	2054 lux	98,76%
Second Floor	Classroom 12.1	23 December - 15:00	-	16.76	-	22.35	2002 lux	100%
	Classroom 12.4	23 December - 15:00	-	16.40	-	16.40	1556 lux	93,82%
	Classroom 12.5	23 December - 15:00	-	-	13.66	15.61	1433 lux	90%
	Classroom 12.7	23 December - 09:00	19.43	-	17.00	-	2069 lux	98,76%
Third Floor	Classroom 10.2	12/23/2024 15:00	-	16.76	-	22.35	2868 lux	100%
	Classroom 10.5	23 December - 15:00	-	16.40	-	16.40	2261 lux	98,76%
	Photograph Room	23 December - 15:00	-	-	13.66	15.61	925 lux	83,75%
	Classroom 10.7	23 December - 09:00	19.43	-	17.00	-	2510 lux	100%

Standard	*UDI & SNI*	*GBCI*
Very Insufficient	<100 lux	
Insufficient	100-300 lux	(<30) %
Adequate	350-750 lux	(>30) %
Excessive	750-2000 lux	
Very Excessive	>2000 lux	

Table 4 Adjustment 2: Exterior Elements Simulation Result

Lowest Daylight Illuminance								
Floor Level	Room	Time	*Window-to-Wall Ratio 55°*	*Window-to-Wall Ratio 145°*	*Window-to-Wall Ratio 235°*	*Window-to-Wall Ratio 325°*	Illuminance Average	Area with Illuminance >350 lx
Ground Floor	Praying Room	21 June - 12:00	-	16.76	-	22.35	183 lux	19,44%
	Classroom 11.4	21 March - 12:00	-	16.40	-	16.40	151 lux	9,87%
	Classroom 11.5	21 June - 15:00	19.43	-	17.00	-	222 lux	23,45%
	Classroom 11.6	21 June - 15:00	19.43	-	17.00	-	268 lux	24,69%
Second Floor	Classroom 12.1	21 March - 12:00	-	16.76	-	22.35	295 lux	30,55%
	Classroom 12.4	21 March - 12:00	-	16.40	-	16.40	263 lux	20,98%
	Classroom 12.5	21 March - 12:00	-	-	13.66	15.61	268 lux	21,25%
	Classroom 12.6	21 March - 12:00	19.43	-	17.00	-	270 lux	22,22%
Third Floor	Classroom 10.2	21 June - 12:00	-	16.76	-	22.35	444 lux	44,44%
	Classroom 10.5	21 March - 12:00	-	16.40	-	16.40	438 lux	43,20%
	Photograph Room	21 March - 12:00	-	-	13.66	15.61	248 lux	22,5%
	Classroom 10.6	21 March - 12:00	19.43	-	17.00	-	444 lux	37,03%

Highest Daylight Illuminance								
Floor Level	Room	Time	*Window-to-Wall Ratio 55°*	*Window-to-Wall Ratio 145°*	*Window-to-Wall Ratio 235°*	*Window-to-Wall Ratio 325°*	Illuminance Average	Area with Illuminance >350 lx
Ground Floor	Praying Room	21 March - 15:00	-	16.76	-	22.35	506 lux	40,27%
	Classroom 11.3	21 June - 09:00	-	16.40	-	16.40	474 lux	50,08%
	Classroom 11.5	23 December - 09:00	19.43	-	17.00	-	2039 lux	98,76%
	Classroom 11.7	23 December - 09:00	19.43	-	17.00	-	2054 lux	98,76%
Second Floor	Classroom 12.1	23 December - 15:00	-	16.76	-	22.35	2002 lux	100%
	Classroom 12.4	23 December - 15:00	-	16.40	-	16.40	1556 lux	93,82%
	Classroom 12.5	23 December - 15:00	-	-	13.66	15.61	1433 lux	90%
	Classroom 12.7	23 December - 09:00	19.43	-	17.00	-	2069 lux	98,76%
Third Floor	Classroom 10.2	12/23/2024 15:00	-	16.76	-	22.35	2868 lux	100%
	Classroom 10.5	23 December - 15:00	-	16.40	-	16.40	2261 lux	98,76%
	Photograph Room	23 December - 15:00	-	-	13.66	15.61	925 lux	83,75%
	Classroom 10.7	23 December - 09:00	19.43	-	17.00	-	2510 lux	100%

Standard	*UDI & SNI*	*GBCI*
Very Insufficient	<100 lux	
Insufficient	100-300 lux	(<30) %
Adequate	350-750 lux	(>30) %
Excessive	750-2000 lux	
Very Excessive	>2000 lux	

4.1.3 ADJUSTMENT 2: EXTERIOR ELEMENTS

Even though the window height has been adjusted according to EDGE parameters, the simulation results still indicate that the opening design does not meet natural lighting standards, especially in the rooms located on the first floor of the building. The significant difference between the first-floor level and the levels above it suggests that there are objects outside the building obstructing daylight access. The presence of a dividing wall between the school area and the outside area, with a distance to the building wall of 2.5 meters and a height of 4 meters, hinders optimal daylight penetration into the building from that side.

Therefore, a Vertical Shadow Angle study was conducted to determine the most optimal height for the dividing wall in providing access to daylight entering the building. Based on the VSA study results, if the height of the dividing wall is reduced by 1 meter, daylight entering the rooms on the first level becomes more optimal. This indicates that, apart from elements within the building, elements outside the building can also be factors influencing the intensity of natural lighting inside the rooms.

The presence of the building's exterior dividing wall serves as a shading element, thereby affecting the level of natural lighting inside the rooms. This wall reduces the intensity of daylight entering the rooms on the first level, especially the prayer room and classroom 11.4. Lowering the level of this wall has proven to impact an increase in the level of natural lighting in both rooms. Although at the lowest variable it still does not meet the standards, at the highest variable, the level of natural lighting in both rooms has met the SNI.

4.1.4 ADJUSTMENT 3: EXISTING SHADING

Based on the results of the existing natural lighting simulation, daylight entering through openings on the interior side of the building has a lower level compared to openings on the exterior side of the building. However, there are still shading devices on the interior side of the building. According to the Horizontal Shadow Angle (HSA) study, these shading devices on the interior side of the building limit the entry of daylight, thus affecting the intensity of natural lighting inside the rooms. This indicates that the placement of shading devices

on the wrong side of the wall has a negative impact on natural lighting inside the rooms.
The simulation results without shading devices on the interior side of the building show that the level of natural lighting inside the building becomes more optimal. Daylight access within the building, which originally predominantly entered through openings on the exterior side of the building, now maximizes daylight entry on both sides of the openings. This undoubtedly affects the average and distribution of natural light inside the rooms. Considering the varying direction of daylight at different times, relying on one wall alone as a source of daylight access is not an efficient approach.

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The simulation results without shading devices on the interior side of the building indicate that the level of natural lighting inside the building becomes more optimal. Daylight access within the building, which originally predominantly entered through openings on the exterior side of the building, now maximizes daylight entry on both sides of the openings. Undoubtedly, this also affects the average and distribution of natural light inside the rooms. Considering the varying direction of daylight at different times, relying on one wall alone as a source of daylight access is not an efficient approach.

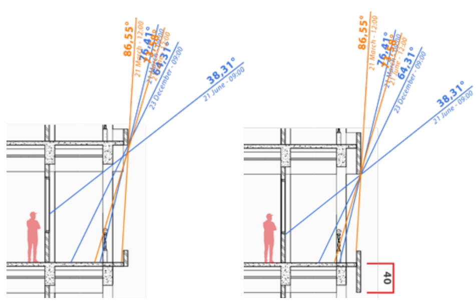

Fig. 12 Existing Shading Device Study
Source: Evandy, 2024

4.1.5 FINAL DESIGN

The adjustment of the Window-to-Wall Ratio (WWR) by increasing the window height by 77.5 cm appears to be insufficient in improving the intensity of natural lighting inside the room at the lowest variable. Therefore, there is a need to increase the WWR value on each side of the room with a lower level of natural lighting. However, before increasing the WWR value to enhance natural lighting at the lowest variable, considerations are needed for the level of natural lighting at the highest variable. By adding the WWR value, the intensity of natural lighting inside the room at the highest variable can also increase. Therefore, an optimal WWR value is required for both variables.

The use of Horizontal Shading Devices to address excessive natural lighting intensity at the highest variable is not optimal in reducing natural light intensity inside the rooms. Based on the Horizontal Shadow Angle study, the direction of daylight entering the rooms varies at each time variable. Therefore, Vertical Shading Devices are needed to reduce daylight entering the rooms at specific time variables with the highest intensity of natural light without significantly reducing the intensity at the lowest variable. The different inclinations of Vertical Shading Devices on each side are as follows: an inclination of 55° for rooms on levels 1 and 2 on the 325° side, and an inclination of 45° for rooms on level 3 on the 325° side and for the entire building on the 235° side.

A well-balanced combination of WWR and Vertical Shading Devices can enhance natural lighting intensity at the lowest variable while simultaneously reducing it at the highest variable. The placement of openings on the room's sides is better not focused on just one side, for example, having all openings on the left side. This uneven distribution of daylight within the room can lead to suboptimal lighting conditions. Therefore, a thoughtful and balanced placement of openings, along with the appropriate use of shading devices, is essential to achieve uniform and optimal natural lighting throughout the room.

The presence of Vertical Shading Devices can reduce the intensity of daylight entering the room. The smaller the inclination of the Vertical Shading Device, the less daylight enters the building. Therefore, inclinations of 45° and 55° are used to ensure that daylight entering the building at the lowest variable is not significantly reduced. In addition to inclination, the quantity of Vertical Shading Devices used also influences the intensity of daylight inside the room, so it is necessary to consider an optimal quantity. In some rooms, Vertical Shading Devices are only applied to certain openings, considering the need to reduce natural light intensity in spaces where it's necessary and maintaining natural light intensity at the lowest.

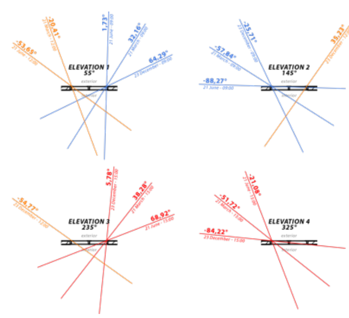

Fig. 13 Horizontal Shadow Angle Study
Source: Evandy, 2024

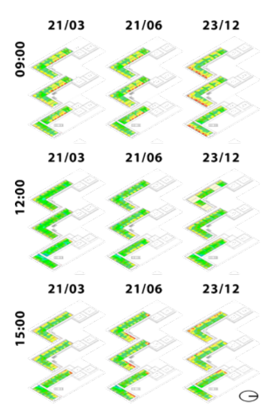

Fig. 14 Final Simulation Result
Source: Evandy, 2024

Table 5 Adjustment 3: Existing Shading Simulation Result

Lowest Daylight Illuminance

Floor Level	Room	Time	*Window-to-Wall Ratio 55°*	*Window-to-Wall Ratio 145°*	*Window-to-Wall Ratio 235°*	*Window-to-Wall Ratio 325°*	Illuminance Average	Area with Illuminance >350 lx
Ground Floor	Praying Room	21 June - 12:00	-	16.76	-	22.35	211 lux	19,44%
	Classroom 11.4	21 March - 12:00	-	16.40	-	16.40	177 lux	11,11%
	Classroom 11.5	21 June - 15:00	19.43	-	17.00	-	222 lux	23,45%
	Classroom 11.6	21 June - 15:00	19.43	-	17.00	-	305 lux	35,80%
Second Floor	Classroom 12.1	21 March - 12:00	-	16.76	-	22.35	307 lux	30,55%
	Classroom 12.4	21 March - 12:00	-	16.40	-	16.40	263 lux	28,39%
	Classroom 12.5	21 March - 12:00	-	-	13.66	15.61	268 lux	21,25%
	Classroom 12.6	21 March - 12:00	19.43	-	17.00	-	279 lux	24,69%
Third Floor	Classroom 10.2	21 June - 12:00	-	16.76	-	22.35	444 lux	45,83%
	Classroom 10.5	21 March - 12:00	-	16.40	-	16.40	440 lux	43,20%
	Photograph Room	21 March - 12:00	-	-	13.66	15.61	249 lux	21,25%
	Classroom 10.6	21 March - 12:00	19.43	-	17.00	-	445 lux	37,03%

Highest Daylight Illuminance

Floor Level	Room	Time	*Window-to-Wall Ratio 55°*	*Window-to-Wall Ratio 145°*	*Window-to-Wall Ratio 235°*	*Window-to-Wall Ratio 325°*	Illuminance Average	Area with Illuminance >350 lx
Ground Floor	Praying Room	21 March - 15:00	-	16.76	-	22.35	506 lux	41,66%
	Classroom 11.3	21 June - 09:00	-	16.40	-	16.40	1146 lux	96,29%
	Classroom 11.5	23 December - 09:00	19.43	-	17.00	-	2040 lux	98,76%
	Classroom 11.7	23 December - 09:00	19.43	-	17.00	-	2116 lux	98,76%
Second Floor	Classroom 12.1	23 December - 15:00	-	16.76	-	22.35	2010 lux	100%
	Classroom 12.4	23 December - 15:00	-	16.40	-	16.40	1592 lux	95,06%
	Classroom 12.5	23 December - 15:00	-	-	13.66	15.61	1432 lux	90%
	Classroom 12.7	23 December - 09:00	19.43	-	17.00	-	2136 lux	100%
Third Floor	Classroom 10.2	12/23/2024 15:00	-	16.76	-	22.35	2863 lux	100%
	Classroom 10.5	23 December - 15:00	-	16.40	-	16.40	2262 lux	98,76%
	Photograph Room	23 December - 15:00	-	-	13.66	15.61	925 lux	83,75%
	Classroom 10.7	23 December - 09:00	19.43	-	17.00	-	2509 lux	100%

Standard	*UDI & SNI*	*GBCI*
Very Insufficient	<100 lux	
Insufficient	100-300 lux	(<30) %
Adequate	350-750 lux	(>30) %
Excessive	750-2000 lux	
Very Excessive	>2000 lux	

Table 6 Fineal Shading Device Simulation Result

Floor Level	Room	*Window-to-Wall Ratio 55°*		*Window-to-Wall Ratio 145°*		*Window-to-Wall Ratio 235°*		*Window-to-Wall Ratio 325°*	
		Existing	Recommendation	Existing	Recommendation	Existing	Recommendation	Existing	Recommendation
Ground Floor	Praying Room	-	12.15	11.87	16.76	-	-	15.83	22.35
	Classroom 11.2	-	-	10.61	16.40	-	-	10.61	18.74
	Classroom 11.3	-	-	11.61	18.74	-	-	11.61	18.74
	Classroom 11.4	-	-	11.61	18.74	-	-	11.61	23.43
	Classroom 11.5	13.77	19.43	-	-	12.05	24.29	-	-
	Classroom 11.6	13.77	19.43	-	-	12.05	24.29	-	-
	Classroom 11.7	13.77	19.43	-	-	12.05	24.29	-	-
Second Floor	Classroom 12.1	-	12.15	11.87	16.76	-	-	15.83	16.76
	Classroom 12.2	-	-	11.61	18.74	-	-	11.61	18.74
	Classroom 12.3	-	-	12.61	21.08	-	-	12.61	18.74
	Classroom 12.4	-	-	11.61	18.74	-	-	11.61	21.08
	Classroom 12.5	-	-	-	-	9.68	19.43	11.06	19.52
	Classroom 12.6	13.77	19.43	-	-	12.05	24.29	-	-
	Classroom 12.7	13.77	19.43	-	-	12.05	24.29	-	-
Third Floor	Classroom 10.2	-	12.15	11.87	16.76	-	-	15.83	16.76
	Classroom 10.3	-	-	11.61	14.06	-	-	11.61	18.74
	Classroom 10.4	-	-	12.61	16.40	-	-	12.61	18.74
	Classroom 10.5	-	-	11.61	16.40	-	-	11.61	18.74
	Photograph Room	-	-	-	-	9.68	14.58	11.06	19.52
	Classroom 10.6	13.77	19.43	-	-	12.05	24.29	-	-
	Classroom 10.7	13.77	19.43	-	-	12.05	24.29	-	-

Vertical Shading Device	
Application	Angle
Half Applied	45
Fully Applied	45
Fullty Applied	55

Table 7 Final Simulation Result

Lowest Daylight Illuminance

Floor Level	Room	Time	*Window-to-Wall Ratio* 55°	*Window-to-Wall Ratio* 145°	*Window-to-Wall Ratio* 235°	*Window-to-Wall Ratio* 325°	Illuminance Average	Area with Illuminance >350 lx
Ground Floor	Praying Room	21 June - 12:00	12.15	16.76	-	22.35	351 lux	48.61%
	Classroom 11.4	21 March - 12:00	-	18.74	-	23.43	168 lux	12.34%
	Classroom 11.5	21 June - 15:00	19.43	-	24.29	-	209 lux	24.69%
	Classroom 11.6	21 June - 15:00	19.43	-	24.29	-	368 lux	38.27%
Second Floor	Classroom 12.1	21 March - 12:00	12.15	16.76	-	16.76	277 lux	22.22%
	Classroom 12.4	21 March - 12:00	-	18.74	-	21.08	248 lux	26.25%
	Classroom 12.5	21 March - 12:00	-	-	19.43	19.52	255 lux	27.16%
	Classroom 12.6	21 March - 12:00	19.43	-	24.29	-	269 lux	19.44%
Third Floor	Classroom 10.2	21 June - 12:00	12.15	16.76	-	16.76	299 lux	31.94%
	Classroom 10.5	21 March - 12:00	-	16.40	-	18.74	269 lux	20.98%
	Photograph Room	21 March - 12:00	-	-	14.58	19.52	309 lux	31.25%
	Classroom 10.6	21 March - 12:00	19.43	-	24.29	-	304 lux	30.86%

Highest Daylight Illuminance

Floor Level	Room	Time	*Window-to-Wall Ratio* 55°	*Window-to-Wall Ratio* 145°	*Window-to-Wall Ratio* 235°	*Window-to-Wall Ratio* 325°	Illuminance Average	Area with Illuminance >350 lx
Ground Floor	Praying Room	21 March - 15:00	12.15	16.76	-	22.35	1257 lux	65.27%
	Classroom 11.3	21 June - 09:00	-	18.74	-	18.74	1107 lux	92.69%
	Classroom 11.5	23 December - 09:00	19.43	-	24.29	-	1697 lux	95.06%
	Classroom 11.7	23 December - 09:00	19.43	-	24.29	-	1299 lux	86.41%
Second Floor	Classroom 12.1	23 December - 15:00	12.15	16.76	-	16.76	631 lux	87.50%
	Classroom 12.4	23 December - 15:00	-	18.74	-	21.08	845 lux	96.06%
	Classroom 12.5	23 December - 15:00	-	-	19.43		769 lux	86.25%
	Classroom 12.7	23 December - 09:00	19.43	-	24.29	-	1856 lux	100%
Third Floor	Classroom 10.2	12/23/2024 15:00	12.15	16.76	-	16.76	846 lux	79.16%
	Classroom 10.5	23 December - 15:00	-	16.40	-	18.74	853 lux	92.59%
	Photograph Room	23 December - 15:00	-	-	14.58	19.52	998 lux	83.75%
	Classroom 10.7	23 December - 09:00	19.43	-	24.29	-	1556 lux	98.76%

Standard	*UDI & SNI*	*GBCI*
Very Insufficient	<100 lux	
Insufficient	100-300 lux	(<30) %
Adequate	350-750 lux	(>30) %
Excessive	750-2000 lux	
Very Excessive	>2000 lux	

Table 8 Comparison of Daylight in Existing and Alternative Design of Daylight Simulation Result

Lowest Daylight Illuminance

Floor Level	Room	Time	*Window-to-Wall Ratio* 55°		*Window-to-Wall Ratio* 145°		*Window-to-Wall Ratio* 235°		*Window-to-Wall Ratio* 325°		Illuminance Average		Area with Illuminance >350 lx		**Illuminance Increase Percentage**
			Existing	Recommendation	Existing	Recommendation	Existing	Recommendation	Existing	Recommendation	Existing	Recommendation	Existing	Recommendation	
Ground Floor	Praying Room	21 June - 12:00	-	12.15	11.87	16.76	-	-	15.83	22.35	55,4 lux	351 lux	2,78%	48.61%	**295.6**
	Classroom 11.4	21 March - 12:00	-	-	11.61	18.74	-	-	11.61	23.43	56,1 lux	168 lux	6,17%	12.34%	**111.9**
	Classroom 11.5	21 June - 15:00	13.77	19.43	-	-	12.05	24.29	-	-	157 lux	209 lux	16,04%	24.69%	**52**
	Classroom 11.6	21 June - 15:00	13.77	19.43	-	-	12.05	24.29	-	-	193 lux	368 lux	17,28%	38.27%	**175**
Second Floor	Classroom 12.1	21 March - 12:00	-	12.15	11.87	16.76	-	-	15.83	16.76	223 lux	277 lux	20,83%	22.22%	**54**
	Classroom 12.4	21 March - 12:00	-	-	11.61	18.74	-	-	11.61	21.08	200 lux	248 lux	14,81%	26.25%	**48**
	Classroom 12.5	21 March - 12:00	-	-	-	-	9.68	19.43	11.06	19.52	198 lux	255 lux	15%	27.16%	**57**
	Classroom 12.6	21 March - 12:00	13.77	19.43	-	-	12.05	24.29	-	-	206 lux	269 lux	17,28%	19.44%	**63**
Third Floor	Classroom 10.2	21 June - 12:00	-	12.15	11.87	16.76	-	-	15.83	16.76	275 lux	299 lux	22,22%	31.94%	**24**
	Classroom 10.5	21 March - 12:00	-	-	11.61	16.40	-	-	11.61	18.74	285 lux	269 lux	19,75%	20.98%	-16
	Photograph Room	21 March - 12:00	-	-	-	-	9.68	14.58	11.06	19.52	168 lux	309 lux	12,5%	31.25%	**141**
	Classroom 10.6	21 March - 12:00	13.77	19.43	-	-	12.05	24.29	-	-	286 lux	304 lux	17,28%	30.86%	**18**

Highest Daylight Illuminance

Floor Level	Room	Time	*Window-to-Wall Ratio* 55°		*Window-to-Wall Ratio* 145°		*Window-to-Wall Ratio* 235°		*Window-to-Wall Ratio* 325°		Illuminance Average		Area with Illuminance >350 lx		**Illuminance Decrease Percentage**
			Existing	Recommendation	Existing	Recommendation	Existing	Recommendation	Existing	Recommendation	Existing	Recommendation	Existing	Recommendation	
Ground Floor	Praying Room	21 March - 15:00	-	12.15	11.87	16.76	-	-	15.83	22.35	112 lux	1257 lux	11,11%	65.27%	-1145
	Classroom 11.3	21 June - 09:00	-	-	11.61	18.74	-	-	11.61	18.74	293 lux	1107 lux	39,50%	92.69%	-814
	Classroom 11.5	23 December - 09:00	13.77	19.43	-	-	12.05	24.29	-	-	1275 lux	1697 lux	45,67%	95.06%	-422
	Classroom 11.7	23 December - 09:00	13.77	19.43	-	-	12.05	24.29	-	-	1348 lux	1299 lux	60,49%	86.41%	**49**
Second Floor	Classroom 12.1	23 December - 15:00	-	12.15	11.87	16.76	-	-	15.83	16.76	1679 lux	631 lux	56,94%	87.50%	**1048**
	Classroom 12.4	23 December - 15:00	-	-	11.61	18.74	-	-	11.61	21.08	1302 lux	845 lux	55,56%	96.06%	**457**
	Classroom 12.5	23 December - 15:00	-	-	-	-	9.68	19.43	11.06		1155 lux	769 lux	55%	86.25%	**386**
	Classroom 12.7	23 December - 09:00	13.77	19.43	-	-	12.05	24.29	-	-	1360 lux	1856 lux	72,83%	100%	-496
Third Floor	Classroom 10.2	12/23/2024 15:00	-	12.15	11.87	16.76	-	-	15.83	16.76	1777 lux	846 lux	56,94%	79.16%	**931**
	Classroom 10.5	23 December - 15:00	-	-	11.61	16.40	-	-	11.61	18.74	1414 lux	853 lux	77,78%	92.59%	**561**
	Photograph Room	23 December - 15:00	-	-	-	-	9.68	14.58	11.06	19.52	666 lux	998 lux	50%	83.75%	-332
	Classroom 10.7	23 December - 09:00	13.77	19.43	-	-	12.05	24.29	-	-	1472 lux	1556 lux	83,95%	98.76%	-84

UDI & SNI	*GBCI*	Standard
<100 lux		Very Insufficient
100-300 lux	(<30) %	Insufficient
350-750 lux	(>30) %	Adequate
750-2000 lux		Excessive
>2000 lux		Very Excessive

4.1.6 EFFICIENT OPENING DESIGN FOR DAYLIGHTING

After several improvements to the opening designs, there are still some rooms within the Xaverius 3 Palembang Senior High School building that do not meet the standards for natural lighting. In certain time variables, there are several rooms whose average natural lighting levels exceed the standard maximum of 750 lux. With lighting levels in these rooms exceeding the maximum limit, reaching 1000 lux and even up to 2000 lux, it will impact the visual comfort of users when engaging in activities inside them.

The excess intensity of natural light in those rooms is influenced by the orientation of the building mass. The suboptimal orientation, with many openings facing west and east, leads to high daylight intensity inside the rooms. One way to address the issue of excessive daylight intensity without changing the building orientation is by using shading devices. The function of shading as a barrier to daylight entering the building can reduce the level of natural light intensity inside the space. However, when adding these shading devices, it is crucial to consider the direction of daylight at other times to ensure optimal natural lighting inside the rooms.

The improvements made have not provided an optimal solution in increasing daylight intensity inside the rooms with average natural light levels that do not meet the minimum standards. Based on the light distribution diagram inside the rooms visualized using Dialux Evo, the placement of openings in each room is also a factor influencing natural lighting inside the space.

In several rooms, the placement of openings is still not optimal, resulting in some sides of the room not receiving daylight supply. This certainly affects the average lighting value and the percentage of rooms with natural lighting levels meeting the standards. Therefore, additional and/or repositioning of openings is needed so that the average and percentage of natural lighting in these rooms can meet the standards.

The Window-to-Wall Ratio (WWR) significantly influences the lighting conditions in each room. However, the placement of openings in a room is also a crucial aspect determining the level of lighting. Inappropriate placement cannot maximize the entry of daylight into the room, leading to insufficient lighting intensity inside. Therefore, besides considering the WWR, the placement of openings must also be well-designed.

The use of shading can reduce light intensity at specific times. In design solutions, adding shading through Horizontal Shadow Angle (HSA) studies can decrease the average natural lighting at certain times. Therefore, the use of shading serves to control the amount of daylight entering a room to prevent it from being excessive.

After several attempts to find optimal Window-to-Wall Ratio (WWR) and shading device designs for Xaverius 3 Palembang Senior High School at different times, the conclusion is that it is challenging to achieve a design that meets every existing standard. For instance, if increasing the WWR value in one room addresses the lack of natural lighting at time A, it may lead to excessive natural lighting at time B, and vice versa. This issue indicates that changes to the WWR and shading of the building may not be sufficient to meet ideal standards.

Although the design solutions for openings in Xaverius 3 Palembang have not fully met the existing standards, these design solutions have successfully increased the light intensity in rooms with minimal natural lighting from the existing design. This improvement was achieved without significantly increasing the natural lighting level in rooms with excessive natural lighting. Furthermore, the design solutions have also managed to reduce the level of excessive natural lighting in some rooms, although these results still do not meet the maximum standard of 750 lux.

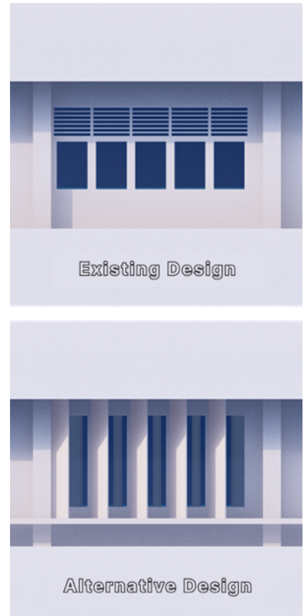

Fig. 15 Comparison of Existing and Final Shading Device
Source: Evandy, 2024

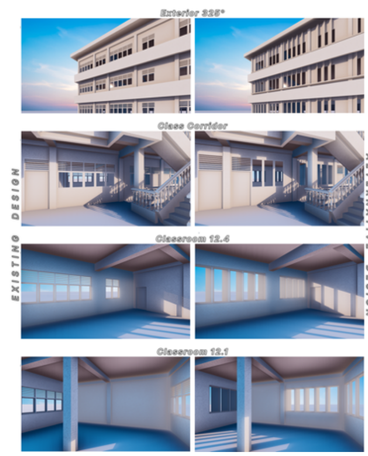

Fig. 16 Comparison of Existing and Final Opening Design
Source: Evandy, 2024

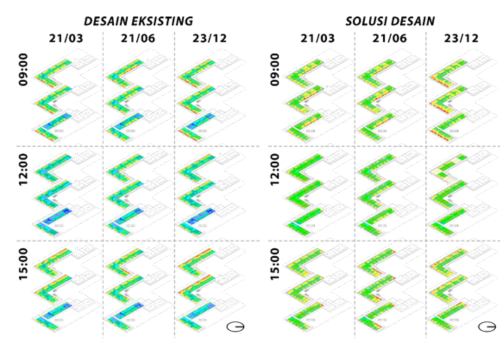

Fig. 17 Comparison of Daylight in Existing and Alternative Design Simulation
Source: Evandy, 2024

Fig. 18 Comparison of Existing and Final Design Opening
Source: Evandy, 2024

5. CONCLUSION

The opening design of Xaverius 3 Palembang's building has many issues, one of which is the mass shape that doesn't allow for designing openings to optimize natural lighting in each room. The building's orientation causes every side of the building to be exposed to daylight from the west and east. This significantly increases the level of natural lighting inside the classrooms at certain times.

In addition to orientation, in the design of multi-story buildings, the geometry and dimensions of the floor surfaces on upper levels also impact the quality of natural lighting in rooms on the lower levels. In the case of Xaverius 3 building, the floors on the upper level, particularly level 2, obstruct the access of daylight into the rooms on the lower level. The geometry and dimensions of the floor surfaces above a room on a certain level indirectly act as shading elements, thereby affecting the intensity of natural lighting inside those rooms.

The use of shading devices can be a solution to reduce excessive lighting intensity, while adjusting the Window-to-Wall Ratio (WWR) and placement of openings can be solutions to enhance natural lighting intensity. Increasing the height of the openings by 77.5 cm has a significant impact on the level of natural light distribution inside the room. The improvement resulted in an increase in the existing building's WWR (Window-to-Wall Ratio) and design solutions by 65.92%. With the improved distribution of natural light within the room, the average value of natural lighting inside the space also increases. Therefore, the window height in relation to the dimensions of the opening wall is a crucial factor influencing the quality of natural lighting inside the room.

The application of Vertical Shading Devices with inclinations of 45° and 55° can address excessive natural light intensity at the highest variable. However, this application also reduces intensity at the lowest variable. Using Vertical Shading Devices that cannot adjust their inclination makes it challenging to achieve a consistent level of natural lighting throughout the rooms at all times.

The inadequate natural lighting in the rooms at Xaverius 3 is attributed to various factors, including the orientation and mass of the building that cannot optimize daylight, as well as the inefficient design of openings and shading devices regarding natural lighting inside the rooms. This is evident with openings on the 55° and 235° sides being less optimal as daylight entry points compared to openings on the 145° and 325° sides. Despite adjustments made to the Window-to-Wall Ratio (WWR) and shading devices, the passive daylighting approach in the Xaverius 3 Palembang building still falls short of meeting the standards for natural lighting intensity inside.

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