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Building Optimization through Overall Thermal Transfer Value Analysis in Abdi Siswa Catholic School Patra Unit, West Jakarta

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Abstract

Overall Thermal Transfer Value is affected by Window-to-Wall Ratio (WWR), which impacts the daylight which enters the building. Thus, OTTV is linearly related to WWR but inversely proportional to the lighting intensity, making SNI Standard-compliant OTTV and lighting design quite challenging. To boost student productivity, schools need proper lighting, which has not been achieved by the case study building: Abdi Siswa Catholic School Unit Patra. With the OTTV standard from SNI 6389-2020, which has a maximum value of 35 W/m², and the room illuminance level from SNI 6197-2020, quantitative evaluations and recommendations were done at the Abdi Siswa Catholic School Unit Patra. Thus, the objective of this research is to give recommendations in optimizing lighting condition which complies with the OTTV standard through WWR and glass type assessment. This study connect the dots of students productivity at school by achieving room lighting standards while still having an ideal OTTV value. The emphasizes on illumination chan ges are given through recommendations simulated using DIALux Evo. This research concludes that buildings' existing OTTV values meet standards. However, student study rooms' lighting is still below standard. However, the relatively small WWR which contributes to the low OTTV, adversely affects the lighting conditions in the classrooms, library, and laboratories. Efforts to utilize and maximize natural lighting proved to be an impractical option because the rooms are shaded by the building itself. Therefore, adding artificial lighting is the most practical solution in terms of cost, labor, and time.

1. INTRODUCTION

Green building is one of the responses of building designers to climate change. The green building concept including the energy efficient building strategy. Overall Thermal Transfer Value (OTTV) is one of various design guidelines and codes of practice formulated to promote and regulate energy-efficient building design (Chan, A.S., 2023). OTTV also becomes one of the performance-based methods for governing the design of energy-efficient building envelope (Chan, A.S., 2021). In Indonesia, OTTV become one of the mandatory criteria in the green building certification by Green Building Council Indonesia (GBCI), which was founded in 2009 as an independent organization. GBCI offers green building certifications using the Greenship Rating Tools. In 2010, GBCI released the first Greenship Rating Tools for New Buildings Version 1.0. This version included Overall Transfer Thermal Value (OTTV) as a mandatory criterion, which limit the value at maximum 45 W/m2 (GBCI, 2010). This OTTV limit also applies in Indonesian Government building regulation on SNI-6389:2000. However, this regulation has not yet become mandatory. The updated version of Greenship Rating Tools is the version 1.2 which has the OTTV limit at maximum 35 W/m2 (GBCI, 2013). This followed by the changes of Government Regulation in SNI-6389:2020, issued in 2020, with the OTTV limit at maximum 35 W/m2.

According to SNI-6389-2020, the OTTV is calculated based on three major heat components: The heat conduction through the solid wall, the heat conduction through the glass or transparent building surfaces, and the solar radiation through the glass or transparent building surfaces. Thus, the Window-to-Wall Ratio (WWR) of the building, has a correlation with the OTTV value, whereas WWR plays an important role for bringing the natural lighting in a building.

The amount of lighting must be provided carefully to ensure a good and comfortable visibility for the user to do the activities inside the building. Lighting also 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). For educational facilities, there are some studies regarding lighting in assessing the effects of windows and daylight on the concentration and academic performance in primary education and above (Vasquez, N.G., et al, 2019). Thus, lighting plays an important role in the level of concentration and productivity of students at school.

2. METHOD

Abdi Siswa Catholic School Patra Unit which located in West Jakarta, was chosen for the case study of this research. As seen from the Figure 1-2, the classrooms are found to not have an adequate lighting, since coupled of renovations carried out in 2020, and several windows were closed in the classrooms using plywood. Thus, the objective of this research is to give recommendations in optimizing lighting condition which complies with the OTTV standard through WWR and glass type assessment.

There are 3 phases conducted for this study as seen in Figure 3. In the first phase, the existing OTTV value is calculated as a baseline, and the lighting of classrooms, the library, and laboratories is evaluated. This existing OTTV value serves as the threshold for potential changes to the type of glass and WWR to improve the natural lighting in these spaces.

Fig. 1a (Left) Window Closing in Middle School Classrooms
Fig. 1b (Middle) Window Closing in Computer Lab,
Fig. 1c (Right) Window Closing in High School Classrooms
Source: Tee, 2024

Fig. 2a (Left) High School Classroom Lighting Conditions
Fig. 2b (Right) Middle School Classroom Lighting Conditions
Source: Tee, 2024

The OTTV calculation for each building facade was done with the OTTV formula from SNI 6389-2020 (Eq. 1), with the maximum limit at 35 W/m^{2}K. Where α is the solar absorptance of the solid surface of building envelope, U_w is the wall U-Value, WWR is Window-to-Wall Ratio, T_{Dek} is equivalent temperature difference of the building envelope, *SC* is shading coefficient, SF is solar factor, U_f is the U-value of the glass, and ΔT is the inside and outside air temperature difference. Then, the total OTTV of the building will be calculated with Eq. 2, where A_n is the surface area of the building façade in each orientation and $OTTV_n$ is the OTTV result of the building façade in each orientation calculated from the Eq. 1.

$$OTTV = \alpha.[U_w\ (1 - WWR)]\ x\ TD_{ek} + (SC\ x\ WWR\ x\ SF) + (U_f\ x\ WWR\ x\ \Delta T)$$

$$OTTV = \frac{(A_{01}\ x\ OTTV_1) + (A_{02}\ x\ OTTV_2) + \ldots + (A_{0i}\ x\ OTTV_i)}{A_{01} + A_{02} + \ldots + A_{0i}}$$

This research is using SNI 6197-2020 as the standard for lighting as seen in table 1. Thus, in the second phase, lighting improvements are made to the existing rooms that do not meet the SNI 6197:2020 lighting standards, primarily by changing the type of glass and WWR, with the OTTV value not significantly differing from the existing condition. This is achieved by using glass with a higher transmittance and a lower u-value/ shading coefficient than the existing glass. After making these changes, another lighting simulation is conducted to determine which rooms have met the standards and which have not. Rooms that still do not meet the lighting standards will undergo further improvements in phase 3, the practical improvement phase.

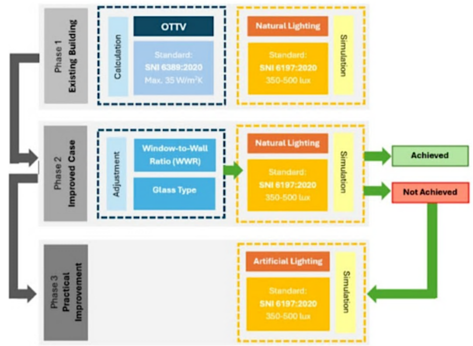


Fig. 3 Research Method
Source: Tee, 2024

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	

In the third phase, rooms that are already adequate will undergo changes to the type of glass and WWR. However, for other rooms that do not meet the lighting standards, artificial lighting will be added without changing the type of glass and WWR from phase 2, as the changes made in phase 2 were not cost-effective. After adding artificial lighting, the rooms that still do not meet the lighting standards will be simulated again to determine the number of lights needed and whether these rooms meet the lighting standards with a minimum of 30% of the area achieving compliance.

3. RESULT AND DISCUSSION

The overall result of the 3 phases from the research methods explained in the previous section for each type of rooms, can be seen in Figure 4-14 below:

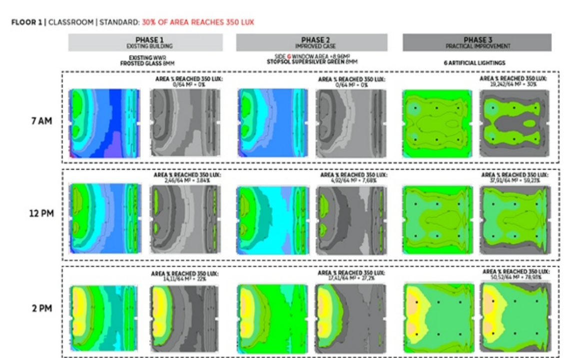


Fig. 4 Recommended Results for the Lighting Level of High School Classroom 1st Floor
Source: Tee, 2024

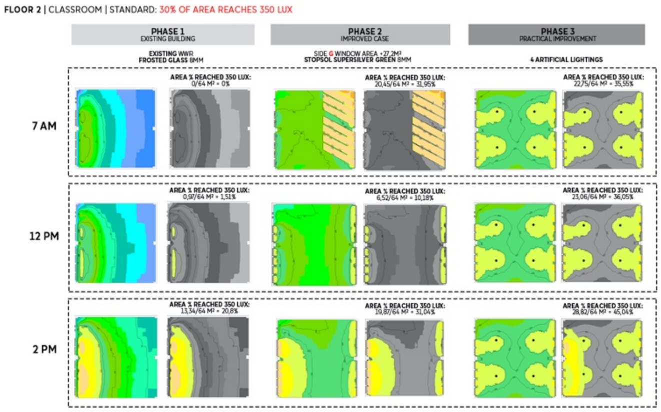


Fig. 5 Recommended Results for Lighting Level of High School Classroom 2nd Floor
Source: Tee, 2024

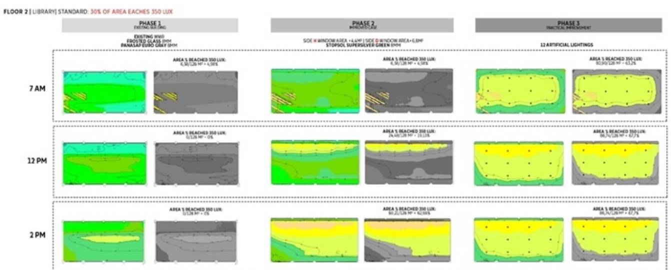


Fig. 6 Recommended Results for the Lighting Level of the 2nd Floor Library
Source: Tee, 2024

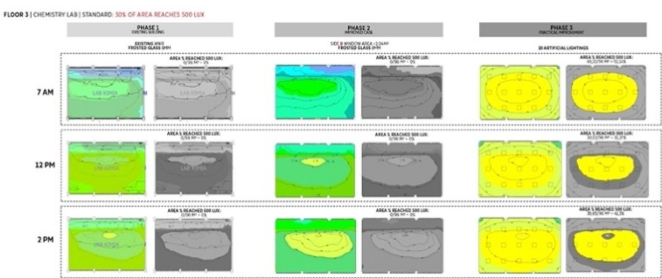


Fig. 7 Recommended Results for the Lighting Level of the 3rd Floor Chemical Lab
Source: Tee, 2024

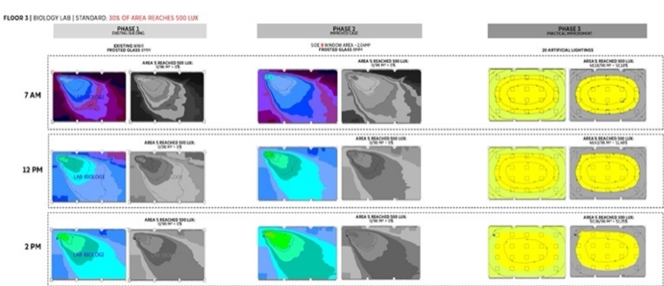


Fig. 8 Recommended Results for the Lighting Level of the 3rd Floor Biology Lab
Source: Tee, 2024

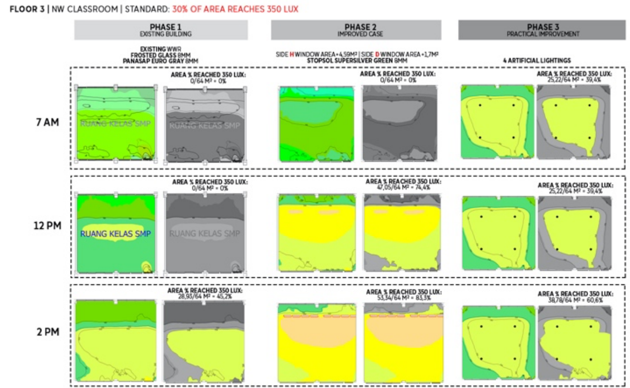


Fig. 9 Recommended Results for the Lighting Level of the Northwest Classrooms of the Middle School 3rd Floor
Source: Tee, 2024

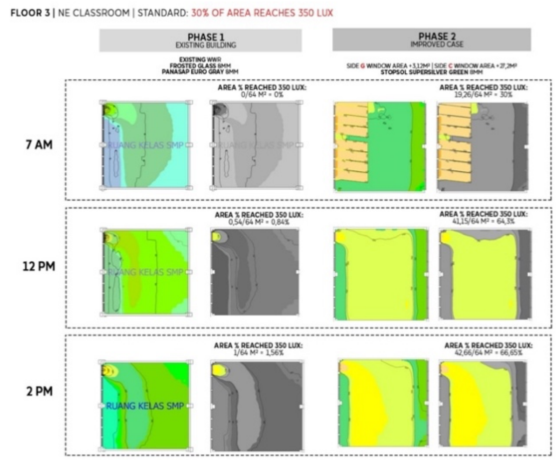


Fig. 10 Recommended Results for Lighting Levels in Northeast Classrooms of Middle School 3rd Floor
Source: Tee, 2024

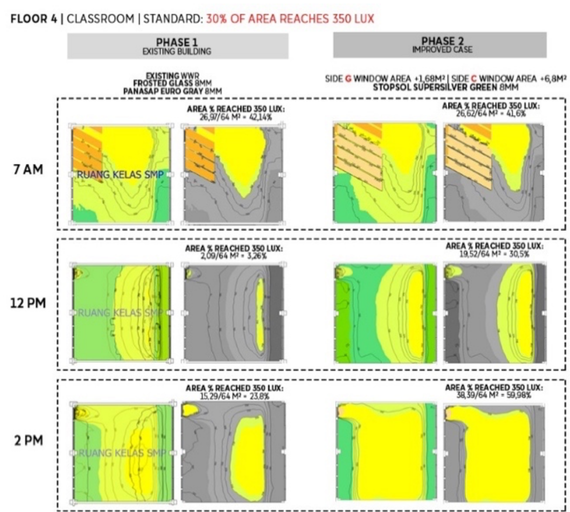
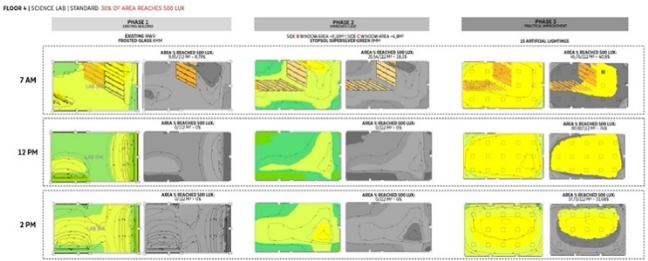


Fig. 11 Recommended Results for Lighting Levels in 4th Floor Junior High School Classrooms
Source: Tee, 2024



Fig, 12 Recommended Results for the Lighting Level of the 4th Floor IPA Lab
Source: Tee, 2024

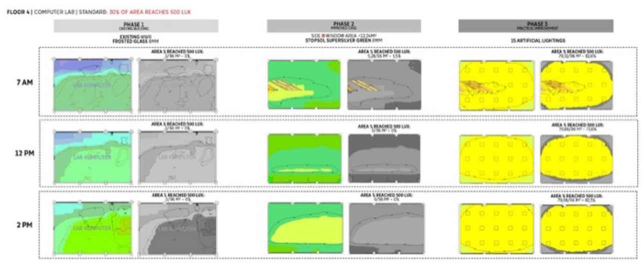


Fig. 13 Recommended Results for the Lighting Level of the 4th Floor Computer Lab
Source: Tee, 2024

3.1 PHASE 1 – EXISTING BUILDING

3.1.1 CALCULATING EXISTING OTTV VALUE

The first thing that was done for the first phase is calculating the existing OTTV value. The calculation of the existing OTTV value is carried out on each side of the building. In this school building, the sides are divided into eight, which are called A-H. The division of the side can be seen in Table 2.

After dividing the building into several sides, the existing OTTV calculations were carried out, which consisted of wall conduction, glass conduction, and glass radiation calculations. Each detailed calculation is carried out using survey data results, such as opening sizes, glass types, wall colors, plans, views, and sections. The existing calculation summary for OTTV is presented in Table 3, which shows that the existing OTTV value is in accordance with SNI 6389-2020, which has a maximum OTTV value of 35 W/m².

3.1.2 SIMULATING EXISTING NATURAL LIGHTING

A low OTTV value does not always correlate with good lighting. This is why it is necessary to find a balance between the two. The rooms of concern in this study are those used for learning, such as classrooms, the library, and laboratories. Table 4 presented the types of rooms to be simulated and improved for lighting quality, along with their positions and the number of rooms. While the results for these types of rooms existing lighting condition with existing glass type and WWR can be seen in Table 5.

With the current WWR and type of glass, natural lighting simulations were conducted in classrooms, the library, and laboratories. It was found that most of these spaces achieved 0% compliance with a minimum of 30% of the area meeting the SNI 6197:2020 standard, which requires 350 lux for classrooms and the library, and 500 lux for laboratories. These natural lighting simulations were conducted at three different times: 7 a.m., 12 p.m., and 2 p.m. This timing is based on when the students enter school, leave school, and the time in between. None of the rooms met the standard in 30% of their area at any of these times.

The simulation results indicate that although the existing OTTV value is good, being significantly lower than the maximum allowable value of 35 W/m², the lighting in the rooms is still far from adequate. Therefore, improvements need to be made in the second phase.

Table 2 Division of Building Sides Based on Facade Orientation

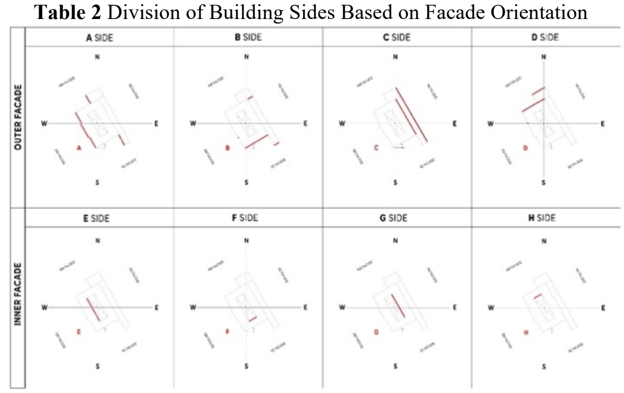


Table 3 Calculation of the Existing OTTV Value for Each Side and Overall

Side	Wall Conduction (W/m²)	Glass Conduction (W/m²)	Glass Radiation (W/m²)	OTTV of Each Side (W/m²)
A	8,56	7,10	26,71	42,37
B	9,16	5,62	11,39	26,18
C	9,63	1,89	4,54	16,48
D	8,38	1,89	34,96	45,23
E	9,88	4,78	16,81	31,48
F	10,06	6,34	22,11	38,52
G	8,04	6,56	19,31	33,91
H	8,21	5,62	9,29	23,13
Overall Building's OTTV (W/m²): 30,69				

3.2 PHASE 2 – IMPROVED CASE

3.2.1 CALCULATING NEW OTTV VALUE

The new OTTV value is calculated after making changes to the type of glass and WWR in rooms where the lighting was insufficient. This OTTV value is maintained to ensure it does not differ significantly from the existing OTTV value, so the resulting thermal conditions are similar to the existing ones. The changes made for the second phase can be seen in Figure 14.

Table 4 Study Rooms Provided with Recommendations and Descriptions

No.	Room Name	Floor	Quantity
1	High School Classrooms	1	4
2	High School Classrooms	2	4
3	Library	2	1
4	North Middle School Classrooms	3	2
5	East Middle School Classrooms	3	4
6	Biology Lab	3	1
7	Chemistry Lab	3	1
8	Middle School Classrooms	4	4
9	Computer Lab	4	1
10	Science Lab	4	1

Table 5 Phase 1 Natural Lighting Simulation Results

No.	Room Name	Floor	Area Percentage That Reached Standard (%) Min 30%		
			7 AM	12 PM	2 PM
1	High School Classrooms	1	0	3,84	22,00
2	High School Classrooms	2	0	1,51	20,80
3	Library	2	4,98	0	0
4	North West Middle School Classrooms	3	0	0	45,20
5	North East Middle School Classrooms	3	0	0,84	1,56
6	Biology Lab	3	0	0	0
7	Chemistry Lab	3	0	0	0
8	Middle School Classrooms	4	20,1	0	4,96
9	Computer Lab	4	0	0	0
10	Science Lab	4	8,79	0	0

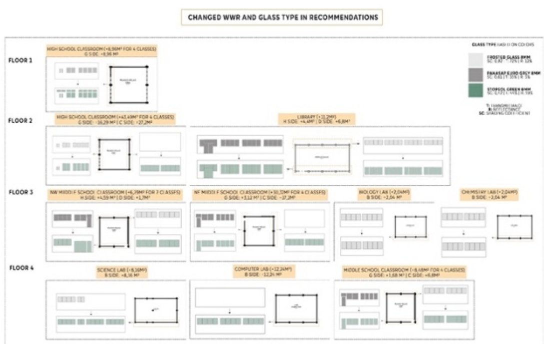


Fig. 14 Changes in WWR and Types of Glass in Study Rooms Based on Recommendations

Figure 14 shows that the changes made in Phase 2 include increasing the Window-to-Wall Ratio (WWR) and replacing the glass with a higher transmittance and a lower u-value/shading coefficient. For example, in the library's entrance area, the WWR increased by 44 m², and the transmittance of the glass improved by 9%. This improvement is balanced by using glass with a lower shading coefficient, reduced from 0.61 to 0.42. The summary of WWR increase which applied to each side can be seen in Table 6.

Table 6 Additional Window Area for 2nd Floor

Side	Orientation	Window Area Addition
A	South West (SW)	0 m²
B	South East (SE)	24,48 m²
C	North East (NE)	68 m²
D	North West (NW)	8,5 m²
E	North East (NE)	0 m²
F	North West (NW)	0 m²
G	South West (SW)	30,05 m²
H	South East (SE)	8,99 m²
Total Window Area Addition		**133,22 m²**

Table 7 Phase 1 and Phase 2 WWR Comparison

Side	Orientation	Existing WWR	New WWR
A	South West (SW)	32,1%	32,1%
B	South East (SE)	19,3%	25,6%
C	North East (NE)	6,48%	15,6%
D	North West (NW)	26,7%	29,1%
E	North East (NE)	31,7%	31,7%
F	North West (NW)	28,6%	28,6%
G	South West (SW)	29,6%	42%
H	South East (SE)	25,4%	37,9%

Table 8 New OTTV Value Summary for Each Side

Side	Wall Conduction (W/m²)	Glass Conduction (W/m²)	Glass Radiation (W/m²)	OTTV of Each Side (W/m²)
A	8,56	7,10	26,71	42,37
B	8,59	7,46	7,73	23,78
C	8,88	4,55	5,60	19,04
D	8,15	4,55	31,09	43,80
E	9,54	4,78	16,81	31,14
F	10,06	6,34	14,52	30,93
G	8,28	9,29	19,03	36,61
H	7	8,39	9,25	24,64
Overall Building's OTTV (W/m²): 31,21				

The most significant increase in window area was made on sides B and G. These sides are adjacent to all the classrooms, with four classrooms per floor, totalling 16 classrooms. The large number of classrooms contributes to the substantial increase in window area on these two sides. However, when compared room by room, the increase in window area was evenly distributed across each room. Table 7 illustrates the increase in WWR (Window-to-Wall Ratio) from this addition and compares it to the existing WWR.
It is evident that the most significant increase is similar to the table showing the increase in window area. This addition is not applied to all sides, as changes were made only to three types of rooms: classrooms, the library, and the laboratory.

After these changes, as shown in Figure 15, the new OTTV value obtained was 31.210 W/m² (Table 8), compared to the existing OTTV value of 30.696 W/m². The new OTTV value, resulting from the selection of glass with higher transmittance and lower u-value/shading coefficient, increased by 0.514 W/m², but it remains within the maximum OTTV standard of 35 W/m².
Table 8 shows the recalculated OTTV values. However, when compared with the existing OTTV values in table XYZ3, the order of OTTV values from lowest to highest on each side remains almost unchanged. This indicates that the changes in OTTV values are not significant, as the adjustments made did not affect the OTTV results on those sides but rather the values for wall conduction, glass conduction, and glass radiation.

Overall, when comparing the new OTTV values with the existing ones, the highest OTTV values are on sides A and D. Side A faces the southwest, which has a high solar factor, and side D uses glass with a higher u-value/shading coefficient. This is evident from the glass conduction value for side A, which is 7.10 W/m² with a glass radiation of 26.71 W/m², while side D, with a smaller glass conduction of 4.55 W/m², has a higher glass radiation of 31.09 W/m².

3.2.2 SIMULATING EXISTING NATURAL LIGHTING

Then, changes from Figure 15, were applied to the 3D models of the existing rooms that did not meet the standards, and natural lighting simulations were conducted again. The results indicated that 8 out of 10 rooms still did not meet the lighting standards after these changes. The improved case areas that met the SNI 6197:2020 standards mostly remained below 5%, with a minimum of 30% of the area achieving the standard. Only two rooms successfully met the standards in 30% of their area at all three times: Northeast Middle School Classrooms (3rd Floor) and Middle School Classrooms (4th Floor).

The simulation results in Table 9 indicate that the efforts to maximize natural lighting were not significantly impactful, as only two rooms met the standards. Therefore, for the eight types of rooms that did not meet the standards, the more practical improvements will be made by adding artificial lighting instead of the Phase 2 improvements. The Phase 2 improvements for these eight types of rooms are not ideal because the cost and time invested are not justified by the minimal increase in lighting, which is still below the standards. Thus, these practical improvements will be implemented in the Phase 3.

Table 9 Phase 2 Natural Lighting Simulation Result

No.	Room Name	Floor	Area Percentage That Reached Standard (%) Min 30%		
			7 AM	12 PM	2 PM
1	High School Classrooms	1	0	7,68	27,2
2	High School Classrooms	2	31,95	10,18	31,04
3	Library	2	4,98	19,13	62,66
4	North West Middle School Classrooms	3	0	74,40	83,30
5	North East Middle School Classrooms	3	30,00	64,30	66,65
6	Biology Lab	3	0	0	0
7	Chemistry Lab	3	0	0	0
8	Middle School Classrooms	4	41,60	30,50	59,98
9	Computer Lab	4	5,50	0	0
10	Science Lab	4	18,30	0	0

Table 10 Phase 3 Natural + Artificial Lighting Simulation Result

No.	Room Name	Floor	Area Percentage That Reached Standard (%) Min 30%		
			7 AM	12 PM	2 PM
1	High School Classrooms	1	30,00	59,23	78,93
2	High School Classrooms	2	35,55	36,05	45,04
3	Library	2	63,20	67,70	67,70
4	North West Middle School Classrooms	3	39,40	39,40	60,60
5	North East Middle School Classrooms	3	Achieved Lighting Condition in Phase 2		
6	Biology Lab	3	50,18	51,48	52,25
7	Chemistry Lab	3	51,14	31,27	41,30
8	Middle School Classrooms	4	Achieved Lighting Condition in Phase 2		
9	Computer Lab	4	82,60	73,60	82,30
10	Science Lab	4	40,80	74,00	33,68

Table 11 Number of Artificial Lighting Needed for Each Room Type

No.	Room Name	Floor	Number of Artificial Lighting Needed 3700 Lumen LED Bulb for Classrooms and Library 5500 Lumen LED Panel for Classrooms and Library
1	High School Classrooms	1	6
2	High School Classrooms	2	4
3	Library	2	12
4	North West Middle School Classrooms	3	4
5	North East Middle School Classrooms	3	Achieved Lighting Condition in Phase 2
6	Biology Lab	3	20
7	Chemistry Lab	3	20
8	Middle School Classrooms	4	Achieved Lighting Condition in Phase 2
9	Computer Lab	4	15
10	Science Lab	4	15

4. CONCLUSION

The existing OTTV of the Abdi Siswa School Patra Unit building meets the maximum value standards. However, the relatively small WWR which contributes to the low OTTV, adversely affects the lighting conditions in the classrooms, library, and laboratories. Efforts to utilize and maximize natural lighting proved to be an impractical option for this building because the rooms are shaded by the building itself. The most significant shading comes from the 2-meter-wide corridor that covers the windows of the classrooms on the Northeast side. Therefore, adding artificial lighting is the most appropriate option. It not only significantly improves lighting but is also the most practical solution in terms of cost, labour, and time.

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