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Evaluation of the Position and Area of Window Openings on Visual Comfort in Classrooms at Budi Luhur University

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Abstract. Window openings in classrooms at Budi Luhur University use glass coated with ray ben stickers to reduce excess heat entering the classroom with different levels of darkness. This can cause the distribution of light in the classroom to be uneven and the light intensity requirements not to meet standards. This research is essential to determine the most efficient and effective position and area of classroom window openings, as well as to propose a window opening design that meets visual comfort standards. The research method used in this research is a quantitative research method with an experimental approach. The Quantitative Method is measuring the intensity of natural lighting in window openings and calculating the area of window openings in classrooms in units 3, 4, 5, 6 of Budi Luhur University, as well as processing questionnaire data about space perception. The results of this research are that the best position and type of window openings are grouped windows with ¾ openings, the lighting intensity is closest to SNI Lighting, namely class 4.3.1, which is 134 lux when the lights are off and 168 lux when the lights are on. The best perception of visual comfort felt by respondents was in classroom 4.3.1, namely 94% of respondents stated that they were visually comfortable when the lights were off, and 93% of respondents stated that they were visually comfortable when the lights were turned on.

1. Introduction

The size of the window has an impact on the intensity of natural lighting that enters the room. The larger the size of the window, the more natural light will enter, resulting in glare which can affect health, vision strain and visual discomfort. On the other hand, the smaller the window size, the less natural light comes in, resulting in poor lighting quality [1].

Every job requires a level of lighting on the surface. Good lighting is important for presenting visual tasks. Better lighting will make people work more productively. The lighting standards used in Indonesia are based on SNI-03-6575-2001 concerning Energy Conservation in Lighting Systems, recommending an illumination standard in classrooms of 250 lux [2].

Classrooms in Units 3, 4, 5, and 6 of Budi Luhur University have window openings that are not uniform in terms of position and area of the window openings with different opening orientations. Classrooms in units 3 and unit 5 are dominated by window openings 3/4 of the way up the wall, classrooms in unit 4 are dominated by window openings at the top of the wall, and the upper room in unit 6 is dominated by 3/4 window openings throughout. wall surface. The window openings in the classrooms in units 4 and 5 were also found to be full openings, that is, the entire wall was a window. The window glass in the classroom uses glass coated with ice and ray ben stickers to reduce excess heat entering the classroom

with different levels of darkness. This can cause the distribution of light in the classroom to be uneven and the need for light intensity not meeting standards. This classroom is used every day from Monday to Saturday from 08.00 WIB – 21.00 WIB. Based on operational hours, it should be able to utilize the potential of natural lighting from morning to evening, while at night it relies on artificial lighting. The existing conditions of classrooms in units 3, 4, 5, and 6 of Budi Luhur University with different window opening positions and different window areas can affect students' comfort in carrying out learning activities in the classroom and can create different perceptions. different to the class conditions.

A study conducted by Z A Kılıç and A Köknel Yener titled Determining Proper Daylighting Design Solution for Visual Comfort and Lighting Energy Efficiency: A Case Study for High-Rise Residential Building demonstrated that an appropriate natural lighting solution that provides visual comfort while enhancing lighting energy efficiency can be determined through both qualitative and quantitative evaluation of natural lighting performance [3]. Another study titled Optimum Characteristics of Windows in an Office Building in Isfahan for Energy Saving and Visual Comfort, conducted by Abbas Maleki and Narges Dehghan in 2021, resulted in energy savings and the maintenance of visual comfort by optimizing the window characteristics in an office building in Isfahan, Iran. The key finding was that an optimal window design provides both energy efficiency and adequate daylighting [4]. Additionally, research by Nazanin Nasrollahi and Elham Shokry titled Parametric Analysis of Architectural Elements on Daylight, Visual Comfort, and Electrical Energy Performance in Study Spaces found that the best orientation for achieving an optimal model using sunlight in study spaces is a north-south orientation. Moreover, the use of windows with maximum height in the center of the front section across the building, with a window-to-wall ratio of 35 to 45 percent along both the vertical and horizontal divisions (grids), is suitable for study spaces [5].

The difference in the current research lies in the modeling of openings in classrooms with varying orientations. Additionally, this study will examine the impact of natural lighting in relation to the use of different shapes and types of window openings. The purpose of this research is to determine the position and area of window openings in the existing condition, whether they are in accordance with the requirements for the area of window openings, and to determine the intensity of classroom lighting and the perception of the existing condition of the classroom in terms of user visual comfort, which in the end will recommend a proposed window opening design for classrooms that can meet visual comfort.

2. Method

The research method used in this research is a quantitative research method with an experimental approach. The experimental research method is a research method used to find the effect of certain treatments on others under controlled conditions [6]. The object used as research is the classroom at Budi Luhur University. This research is a research process that consists of several stages. Each stage is carried out using a different method but is related to each other and supports the next research stage. The sequence of methods used is theoretical study, field observation, measurement, calculation, making working drawings, making questionnaires, and distributing questionnaires, analysis and synthesis, and making conclusions. The research stages conducted can be seen in (Figure 1).

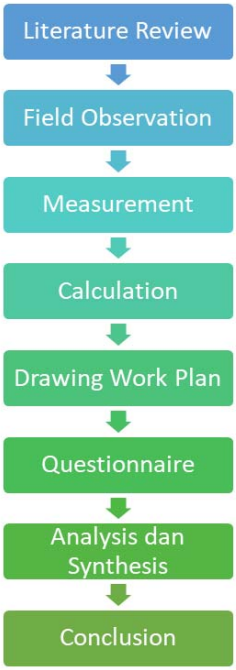


Figure 1. Research phase flowchart
Source: Author, 2023

3. Result and Discussion

According to Einstein, light has the properties of both waves and matter. Light can be considered a wave because it can experience reflection, interference and diffraction events. Light can be viewed as matter or quantum which can cause photoelectric effects, and Compton effects. However, visible light is only a small part of the electromagnetic wave spectrum [7].

Light intensity is a basic physical quantity to measure the power emitted by a light source in a certain direction per unit angle. The SI unit of light intensity is the candela (Cd). Light is produced along with the formation of radiation when particles are heated, such as the sun which is a natural light source. Illumination intensity is the amount of light arriving at one surface area. Lighting based on its source is divided into three, the first is natural lighting, namely lighting that comes from sunlight, the second is artificial lighting, namely lighting that comes from lamps, and the third is natural and artificial lighting, namely a combination of natural lighting from sunlight and artificial lighting that comes from electricity/lights.

Visual comfort is the need for a good level of lighting in a room. Good lighting is lighting that can meet the needs of its users, related to the type of activities carried out in the space. To achieve visual comfort in a room, it is necessary to regulate the intensity of incoming light. The following are the lighting levels in accordance with SNI for energy conservation in lighting systems [2]. Calculations are used to obtain the window area in accordance with applicable formulas and regulations. The calculations are used to find the window area that meets the natural lighting requirements, with the minimum window opening area being as follows[8]: ***the minimum area of the fixed ventilation opening should be 5% of the room floor area.***

Table 1: Recommendation average lighting levels, rendering and color temperature

Room Function	Lighting Level (Lux)	Color Rendering Group
Terrace	60	1 or 2
Sitting room	120-150	1 or 2
Dining room	120-250	1 or 2
Workspace	120-250	1
Bedroom	120-250	1 or 2
Bathroom	250	1 or 2
Kitchen	250	1 or 2
Garage	60	3 or 4
Director's room	350	1 or 2
Workspace	350	1 or 2
Computer room	350	1 or 2
Meeting room	300	1
Image space	750	1 or 2
Archive warehouse	150	1 or 2
Active archive room	300	1 or 2
Classroom	250	1 or 2
Library	300	1 or 2
Laboratoty	500	1
Image space	750	1
Canteen	200	1
Lobby, corridor	100	1
Multipurpose room	200	1
Dining room	250	1
Cafetaria	200	1
Bedroom	150	1 or 2
Kitchen	300	1

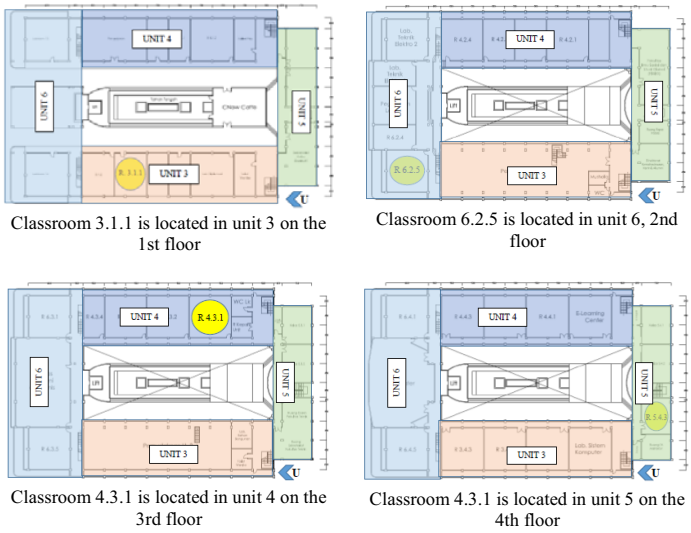
Source: SNI for energy conservation in lighting systems

A window is a form of hole in a wall that is commonly installed/equipped with a drip or is part of an element (house/building element) that can let in natural light or air circulation from inside and outside the building. According to [7], windows are one of the building components that are directly related to aspects of lighting and ventilation. The area of windows in a room to obtain the required natural lighting must comply with the minimum possible window opening area according to the following formula, namely the area of ventilation holes remains a minimum of 5% of the floor area of the room [8].

Previous research related to lighting was research entitled Modeling Openings for Natural Ventilation in Buildings [9]. This research was conducted by Sampoerna Romadhona, M. Ramdlan Kirom, S.Si., M.Sc., and Dr. Ery Djunaedy, S.T., M.Sc. The results of this research are modeling of openings for natural ventilation in three case studies using the Airflow Network model in EnergyPlus software. Furthermore, research was conducted by Adhityo Nur Huda and Abraham Seno B entitled Optimizing Front Openings for Natural Lighting in Shophouses as Office Functions. (Study case: Ruko Bali Viewpoint No. 46D, South Tangerang) [10] results in the orientation of the building towards the Northeast, which is less than optimal in allowing in the sunlight needed to provide visual comfort for the office (workspace). Furthermore, research entitled A Study on Influences of Lighting on Resource Usage in an Institution Library [11] was conducted by Thangaraj & Balaji.

This research aims to study lighting factors and how they influence readers in carrying out activities in the library. The research method used is quantitative using a questionnaire to collect data regarding the use of library resources and measuring light intensity inside and outside the library room. The results of this research are that lighting affects library space users, but the time spent in the library is not affected. 65% of users agree with optimized lighting in libraries. The light intensity in the reading zone is adequate with the brightness and glare factors that are common at night. The light intensity in the newspaper zone is optimal, so the newspaper zone is used more effectively during the morning and in the e-library zone there is no glare and in the reading zone it is less bright and does not allow users to spend a long time in that zone. To overcome this, a diffuser is needed for artificial lighting and using curtains for direct light sources.

The novelty of this research is that it provides new ideas for researchers to conduct research related to window openings and window positions as well as perceptions of space users with cases that are different from existing research. In this study, the research object became a research problem because the width of the window openings and window positions were different in each unit and the classrooms represented various building orientations.
The research case study is located in the lecture buildings in units 3, 4, 5, and 6 of Universitas Budi Luhur (Figure 2).



Classroom 3.1.1 is located in unit 3 on the 1st floor

Classroom 6.2.5 is located in unit 6, 2nd floor

Classroom 4.3.1 is located in unit 4 on the 3rd floor

Classroom 4.3.1 is located in unit 5 on the 4th floor

Figure 2. Research case study location
Source: Author, 2023

Classroom 3.1.1 faces East – West and is characterized by good natural lighting in the morning and evening because natural light enters directly through the wide windows on the front and back walls. The walls facing East and West use full glass material, so that natural lighting entering the classroom is more than sufficient. However, to reduce the incoming heat radiation from the glass walls, this can be overcome by using ice stickers. Towards the afternoon the lighting in this classroom decreases. Therefore, to get good lighting, it is helped by using lamps as an artificial lighting system, especially used during the day until evening. The exterior and interior walls are finished with white grey (grayish white) paint. On the other side of the wall is a full glass opening which also functions as a window (Figure 3).

Figure 3. Classroom 3.1.1 conditions
Source: Author, 2023

Classroom 6.2.5 is characterized by poor natural lighting in the morning and evening. This is due to the location of the room which is in the corner of unit 6 on the 2nd floor and is oriented South – North. The

position of the window is only on 1 side of the wall, namely on the wall facing North. Apart from that, the use of Ray ben glass is quite dark with a darkness level of up to 60% on the window glass. To optimize the natural lighting system, it is assisted by using lamps as artificial lighting (Figure 4).

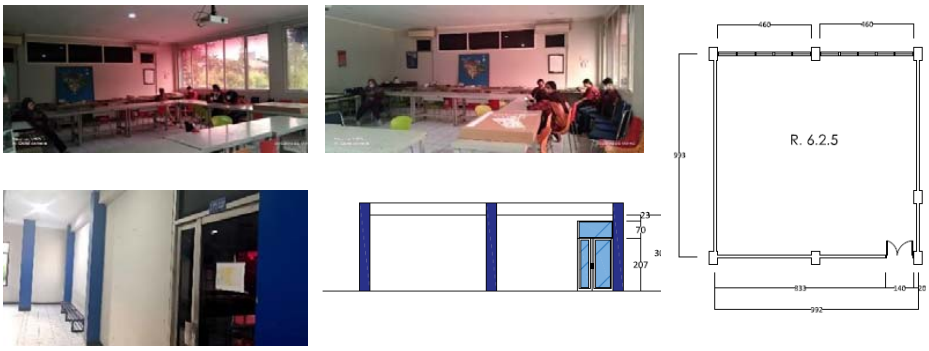


Figure 4. Classroom 6.2.5 conditions
Source: Author, 2023

Classroom 4.3.1 faces West - East and is characterized by good natural lighting because natural light enters through windows on two sides of the wall (cross ventilation) with the window positioned at the top of the wall facing East, while the opposite wall facing West using 3/4 windows. However, it is still necessary to use artificial lighting in the afternoon (Figure5).

Figure 5. Classroom 4.3.1 conditions
Source: Author, 2023

Classroom 5.4.3 faces North - South and is characterized by good natural lighting because natural light enters through windows on two sides of the wall (cross ventilation) with the window positioned at the top of the wall facing South, while the opposite wall facing North using 3/4 windows. This classroom is on the 4th floor and natural lighting can enter the room directly and through reflections on the floor surface. The glass used in the windows on the North side uses Rey ben glass with a darkness level of 60%, while on the South side the windows are at the top of the wall and use clear glass. However, it is still necessary to use artificial lighting in the afternoon (Figure 6).

Figure 6. Classroom 5.4.3 conditions
Source: Author, 2023

Lighting intensity measurement results.
Lighting intensity measurements were carried out when the lights were off, and the lights were on in each classroom that was the object of research.

Table 2. Classroom Lighting Intensity 3.1.1 when the lights are off.
Source: Author, 2023

Classroom 3.1.1 (Lights off condition)

Time (WIB)	Lighting Intensity (lux)			Average Lighting Intensity (lux)
	Tuesday August 22, 2023	Wednesday August 23, 2023	Monday August 28, 2023	
09:00	213	353	337	**361**
12:00	551	340	254	
15:00	1542	372	369	
Average	**769**	**355**	**320**	

Table 3: Classroom Lighting Intensity 3.1.1 when the lights are on
Source: Author, 2023

Classroom 3.1.1 (Lights on condition)

Time (WIB)	Lighting Intensity (lux)			Average Lighting Intensity (lux)
	Tuesday August 22, 2023	Wednesday August 23, 2023	Monday August 28, 2023	
09:00	527	544	634	**558**
12:00	788	720	665	
15:00	1705	522	590	
Average	**1007**	**595**	**630**	

Based on the results of measuring the lighting intensity in classroom 3.1.1, the average lighting intensity for conditions when the lights are completely turned off is 361 lux. When the light is turned on, the lighting intensity that occurs is 558 lux. Based on SNI for Lighting Systems in Buildings, the standard lighting intensity for study rooms is 250 lux - 300 lux. The lighting conditions in classroom 3.1.1, whether the lights are turned off or on, the average lighting intensity exceeds SNI standards and can be said to meet lighting standards for classrooms. This is caused using glass material on the entire wall area in the West – East direction, apart from that, solar heat radiation is very likely to enter the classroom and affect student comfort. Using ice stickers is a solution to reduce heat entering walls made of full glass material.

Table 4: Classroom Lighting Intensity 6.2.5 when the lights are off.
Source: Author, 2023

Classroom 6.2.5 (Lights off condition)

Time (WIB)	Lighting Intensity (lux)			Average Lighting Intensity (lux)
	Tuesday August 22, 2023	Wednesday August 23, 2023	Monday August 28, 2023	
09:00	38	33	40	**30**
12:00	33	35	49	
15:00	60	37	39	
Average	**44**	**35**	**43**	

Table 5: Classroom Lighting Intensity 6.2.5 when the lights are on
Source: Author, 2023

Classroom 6.2.5 (Lights on condition)

Time (WIB)	Lighting Intensity (lux)			Average Lighting Intensity (lux)
	Tuesday August 22, 2023	Wednesday August 23, 2023	Monday August 28, 2023	
09:00	63	75	74	**53**
12:00	66	65	75	
15:00	95	68	59	
Average	**75**	**69**	**69**	

Based on the results of measuring the lighting intensity in classroom 6.2.5, it is known that the lighting intensity in the room when the lights are completely turned off is 30 lux, and the lighting intensity with the lights on is 53 lux. This condition does not meet the lighting intensity standards required for lecture halls or classrooms, namely 250 lux - 300 lux. When the lights are turned on, the light intensity increases even though it still does not meet classroom lighting standards. This is due to the use of a type of lamp, namely a downlight, where the reflection and distribution of light that occurs is reflected first on the luminaire/lamp armature which is then distributed to the work area. Thus, the distribution of light received by the work area is not optimal. Apart from that, the use of Ray ben glass with a darkness level of up to 60% also affects the intensity of the lighting that occurs.

Table 6: Classroom Lighting Intensity 4.3.1 when the lights are off.
Source: Author, 2023

Classroom 4.3.1 (Lights off condition)

Time (WIB)	Lighting Intensity (lux)			Average Lighting Intensity (lux)
	Tuesday August 22, 2023	Wednesday August 23, 2023	Monday August 28, 2023	
09:00	330	333	205	**134**
12:00	117	213	63	
15:00	101	119	127	
Average	**183**	**222**	**132**	

Table 7: Classroom Lighting Intensity 4.3.1 when the lights are on
Source: Author, 2023

Classroom 4.3.1 (Lights on condition)

Time (WIB)	Lighting Intensity (lux)			Average Lighting Intensity (lux)
	Tuesday August 22, 2023	Wednesday August 23, 2023	Monday August 28, 2023	
09:00	379	363	144	**168**
12:00	144	256	245	
15:00	130	160	192	
Average	**218**	**260**	**194**	

From the results of measuring the average lighting intensity in classroom 4.3.1, the average lighting intensity in the room when the lights are completely turned off is 134 lux and the average lighting intensity when the lights are turned on is 168 lux. The average lighting intensity in classroom 4.3.1 still does not meet the lighting intensity standards required for lecture halls or classrooms, namely 250 lux - 300 lux. When the lights are turned on, the light intensity increases even though it still does not meet classroom lighting standards. This is due to the use of a type of lamp, namely a downlight, where the reflection and distribution of light that occurs is reflected first on the luminaire/lamp armature which is then distributed to the work area. Thus, the distribution of light received by the work area is not optima1.

Table 8: Classroom Lighting Intensity 5.4.3 when the lights are off.
Source: Author, 2023

Classroom 5.4.3 (Lights off condition)

Time (WIB)	Lighting Intensity (lux)			Average Lighting Intensity (lux)
	Tuesday August 22, 2023	Wednesday August 23, 2023	Monday August 28, 2023	
09:00	65	51	26	**28**
12:00	14	63	45	
15:00	17	25	29	
Average	**32**	**46**	**33**	

Table 9: Classroom Lighting Intensity 5.4.3 when the lights are on
Source: Author, 2023

Classroom 5.4.3 (Lights on condition)

Time (WIB)	Lighting Intensity (lux)			Average Lighting Intensity (lux)
	Tuesday August 22, 2023	Wednesday August 23, 2023	Monday August 28, 2023	
09:00	123	144	108	**84**
12:00	82	150	118	
15:00	84	99	101	
Average	**96**	**131**	**109**	

From the results of measuring the average lighting intensity in room 5.4.3, the average lighting intensity in the room when the lights are turned off is 28 lux and the average lighting intensity when the lights are turned on is 84 lux. This condition shows that the lighting intensity that occurs still does not meet standards, because the lighting intensity required for lecture halls or classrooms is 250 lux - 300 lux. When the lights are turned on, the light intensity increases even though it still does not meet classroom

lighting standards. This is due to the use of a type of lamp, namely a downlight, where the reflection and distribution of light that occurs is reflected first on the luminaire/lamp armature which is then distributed to the work area. Thus, the distribution of light received by the work area is not optimal. Apart from that, the use of Ray ben glass with a darkness level of up to 60% also affects the intensity of the lighting that occurs.

Furthermore, based on the calculation of the required minimum window opening area, the minimum opening area for classroom 3.1.1 is 4 m2, classroom 6.2.5 is 5 m2, classroom 4.3.1 is 5 m2, and classroom 5.4.3 is 3 m2.

Below are presented the results of the room character analysis, lighting intensity analysis, analysis of opening area requirements, position and area analysis of window openings that have been carried out.

Table 10: Lighting Analysis Conclusion
Source: Author, 2023

No.	Classroom	Classroom Characters	Average lighting intensity (Lux)		Opening Area Requirements	Opening Position	Opening Area
			Natural (lights off)	Artificial (lights on)			
1	Classroom 3.1.1	The room is on the 1st floor The room orientation faces East-West In the form of a wall of windows in the East and West orientations Using ice stickers to reduce heat Whitegrey colored walls both exterior and interior	361 lux	558 lux	4 m2	The window is on the wall (window wall) Full use of glass on the window walls Dead window (non-movable) Cross ventilation, window openings in East-West orientation The number of window shutters is 6 pieces	41 m2
2	Classroom 6.2.5	The room is on the 2nd floor The room orientation faces South-North Using 60% Rayben on window glass to reduce heat Whitegrey colored walls both exterior and interior	30 lux	53 lux	5 m2	In the South orientation, there are no windows, only glass door openings In the North orientation, the window positions are grouped Window type 3/4 openings in North orientation The number of window shutters is 10	56 m2
3	Classroom 4.3.1	The room is on the 3rd floor The room orientation faces West-East Using 60% Rayben on window glass to reduce heat Whitegrey colored walls both exterior and interior	134 lux	168 lux	5 m2	In the West orientation, the position of the window is in the middle of the group 3/4 opening window type with 8 shutters In the East orientation, the windows are at the top and lined up horizontally The number of horizontal shutters is 8	21 m2
4	Classroom 5.4.3	The room is on the 4th floor The room orientation faces North-South	28 lux	84 lux	3 m2	In the North orientation, there are doors and windows in groups The position of the window openings is grouped and angled	16 m2

	towards the structural columns
Using 60% Rayben on window glass to reduce heat	3/4 opening window type with 5 shutters
Whitegrey colored walls both exterior and interior	In the South orientation, the windows are at the top and lined up horizontally
	The number of horizontal shutters is 5 pieces

Based on the results of the lighting analysis in the table above, the average lighting intensity is close to SNI Lighting for classrooms both when the lights are off and on, namely classroom 4.3.1 with an average intensity of 134 lux when the lights are off and on. 168 lux when the light is on. The average intensity obtained in classroom 4.3.1 does not meet the standard for rooms that function as classrooms, namely 250 lux, this is due to the use of ray ben with a darkness level of up to 60% on the window glass so that the use of lamps is really needed to increase the intensity of lighting in the classroom. This. Classroom orientation 4.3.1 faces West – East, where natural lighting in the morning and evening can be obtained optimally if there are no obstructions outside the room. Apart from that, the window opening area of 21 m^2 meets the minimum requirements for the opening area in a room.

The average lighting intensity in classroom 3.1.1 exceeds the SNI Lighting provisions for classrooms, namely 361 lux when the lights are off and 558 lux when the lights are on. The average intensity obtained in class 3.1.1 exceeds the standard for rooms that function as classrooms, namely 250 lux, this is due to the use of wall windows or the entire wall area in the form of windows in the East - West orientation and the use of ice stickers on the window glass. Classroom orientation 3.1.1 faces West – East, where natural lighting in the morning and evening can be obtained optimally if there are no obstructions outside the room. Apart from that, the window opening area is 41 m^2 and exceeds the minimum requirements for the opening area in a room.

The worst classroom lighting conditions are in classroom 6.2.5 with an average lighting intensity of 30 lux when the lights are off and 53 lux when the lights are on. This is due to the use of Ray ben with a darkness level of up to 60% on the window glass so that the use of lamps is very necessary to increase the intensity of lighting in this classroom. Apart from that, the window openings in classroom 6.2.5 do not have cross ventilation. On the South orientation wall there are only glass doors, while the windows are in the North orientation.

4. Conclusion

Based on data processing, analysis, and calculations of lighting intensity, as well as respondents' comfort perceptions in the classroom used as a case study in this research, it can be concluded that the best window orientation, which is West-East, is found in classroom 4.3.1. The best window position and type is a clustered window with ¾ opening. Moreover, the lighting intensity that most closely meets the SNI Lighting standards is in classroom 4.3.1, measuring 134 lux when the lights are off and 168 lux when the lights are on. The window area in all the classrooms studied, namely classroom 3.1.1, classroom 6.2.5, classroom 4.3.1, and classroom 5.4.3, already meets the minimum required window area. The use of ray ben glass with 60% darkness reduces the lighting intensity inside the room. The best visual comfort perceived by the respondents was found in classroom 4.3.1, with 94% of respondents stating they felt visually comfortable when the lights were off, and 93% stating they felt visually comfortable when the lights were on.

Thus, it can be stated that in designing classrooms, it is essential to consider window standards, both in terms of the required window area and the placement of windows on the wall, to achieve optimal natural lighting that aligns with the visual comfort standards for classrooms.

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