Natural Lighting in Hotel Room Windows for Visual Comfort

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Abstract: Abundant sunlight in the equatorial region is an energy potential that can be utilized optimally in terms of natural lighting. Natural lighting in architectural design has an important role, especially the window section that determines the visual comfort for occupants and electricity savings. The purpose of this study is how the window design strategy in controlling natural light entering the building to obtain a lux value based on the SNI 03-6197-2000 standard, and how to overcome glare for visual comfort. Quantitative research approach with data collection methods through literature studies, measurements, observations, and documentation. In conducting measurements using a lux meter and concept model simulation using Velux Daylight Visualizer and Dialux evo 10 software. Case study of a 3-star hotel building in Cikarang. The results of this study that the simulated window design that approaches the SNI standard illumination value is a vertical window type on the Center side of 224.6 lux. The most effective horizontal type shading tool is the west and east orientation with a value of 148.5 lux. The eggcrate type shading device can reduce illumination by 48%, while the horizontal and eggcrate type shading devices are the most effective, reducing illumination by 22.1%, followed by the vertical type at 16.9%. The conclusion is that the design of the vertical window on the Center side with a combination of horizontal shading devices is an effective design that approaches the standard values of illumination and glare.

Keywords: Natural light, visual comfort, window design, shading devices, glare

I. Introduction

Indonesia's equatorial location and tropical climate offer abundant sunlight. This represents an energy potential that can be optimally utilized for natural lighting[1]. According to SNI 03-2396-2001, good natural light during the day is between 08:00 and 16:00, and according to[2]natural lighting during the day starts from 08:00 to 17:00.

In all things, light is needed by humans to see, to be able to carry out activities healthily and comfortably, due to the influence of strong lighting, its arrangement must be taken into account in the architectural design stage[1]. The use of natural light in architectural design has long been recognized as one of the key elements in creating comfortable, efficient and aesthetic spaces[3]. The use of natural light in architectural design plays an important role in improving occupant comfort, energy efficiency, and the aesthetic quality of a space[4].

Natural lighting problems related to shading devices can be optimized, including to maximize the use of natural light in buildings [4] ,the quality of natural lighting is influenced by the use of secondary skin on the building facade [5], sunlight can be fully utilized [6], distribution of light into the building [7], the use of natural lighting in contemporary architectural design, highlights the need and importance of natural lighting techniques in the design and construction of all types of buildings intended for human habitation[8], core solar lighting system in improving lighting quality and increasing energy efficiency, natural lighting performance [9].

According to [10]states that the secondary skin or commonly called double skin on a building plays a role in increasing the aesthetic value of the building facade, and plays a role in reducing exposure to solar heat radiation that hits the building surface, reducing wind flow, reducing noise from outside to inside, and reducing the light received by the building. Indirect sunlight received by building users. According to [11]to get a good shading device, you need to pay attention to the orientation, shape and location of the building as well as the activities taking place in the building space. Window design is crucial in providing appropriate visual comfort for occupants and sufficient energy savings in electric lighting [2].

Visual comfort is inseparable from glare, according to[12]glare can be caused by the saturation effect of light and too high contrast. Meanwhile, according to [13]glare problems during the summer period are a major problem due to the use of inappropriate shading devices.

II. Research Methodology

This research includes quantitative research methods with data collection methods through literature studies (government regulations, ebooks and journals) and carry out measurements, observations and documentation. When taking measurements at the site, use a lux meter, which is a measuring tool for measuring light. Meanwhile, for natural lighting simulation, Velux Daylight Visualizer 3 software was used. The case study was conducted at a 3-star hotel located in Indonesia (fig. 1). The site's weather data in the simulation was taken from Ladybug tools. The time of field measurements and simulations was in April, with the sun's path on the north side. The focus of the research was on the building envelope of the hotel rooms.

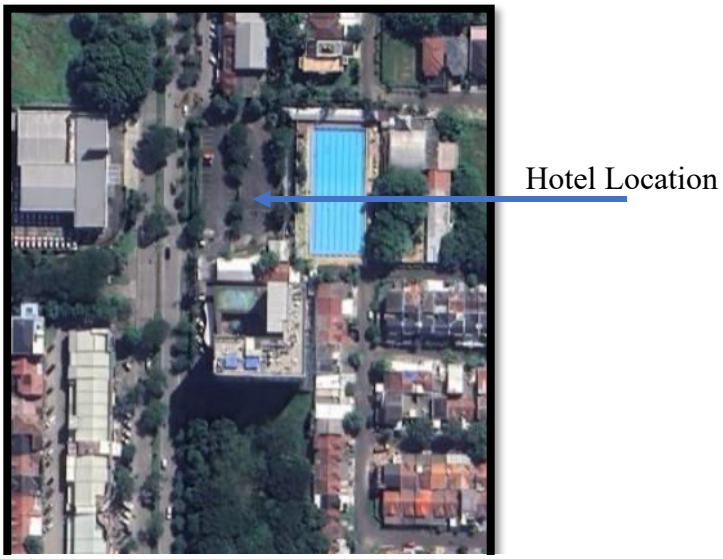


Figure 1: Site location
Source: https:earth.google.com

III. Result and Discussion

This hotel building has 10 floors. There are 6 floors of hotel rooms, from the 4th to the 10th floor. Of the 6 floors of rooms in the hotel, 2 floors were selected as samples. The selected samples were the 4th floor and the 9th floor (Fig. 2). The 4th floor is likely to receive less sunlight than the floors above it, while the 9th floor is likely to receive more sunlight than the floors below it. The 10th floor was not selected because it is not typical of the floors below it.

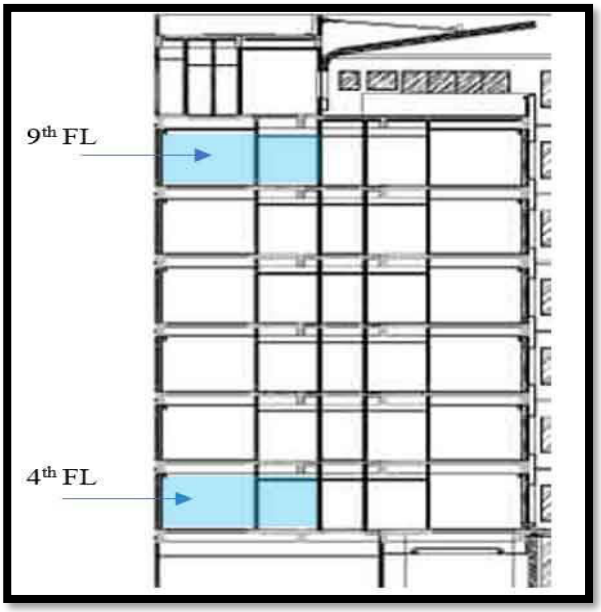


Figure 2: Hotel room section
Source: Architecture consultant

This hotel has windows facing the four cardinal directions: north, south, east, and west. This study focused on the east and west orientations, as they have illumination

exceeding the Indonesian National Standard (SNI) standard of 150 lux, based on direct field measurements using a lux meter. On the east side, two rooms, 416 and 424, were sampled to obtain varying results. The same applies to the west side, rooms 419 and 426.

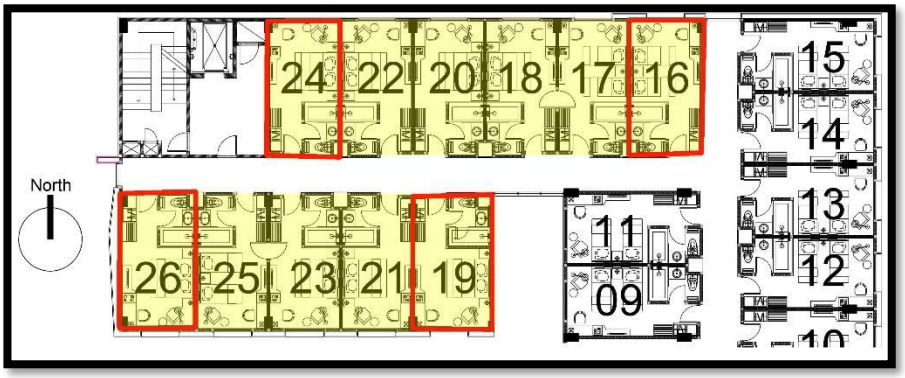


Figure 3: Denah kamar hotel lantai 4 & 9
Source: Architecture consultant

The data inputted into the simulation model are site coordinates, building orientation, and material reflectance. The material reflectance data refers to Lechner 2015 (Table 1). The hotel is located in Cikarang, Indonesia. Weather data was obtained from Ladybug Tools.

Table 1. Faktor Pantul

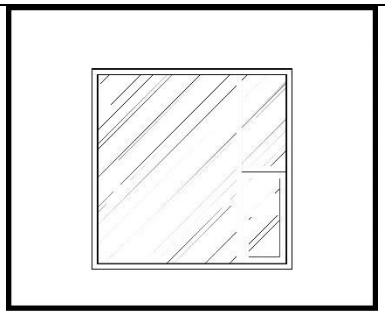
Material	Reflectance (Percent)
Aluminium, reflectors	90-98
Aluminium, polished	70-85
concrete	30-50
Glass, reflective	20-40
Paint	70-90
Porcelain enamel (white)	60-90
stone	5-50

Source: Lechner, 2015

The window orientation used for the calculation model and location is east and west. Three types of windows are made: square, horizontal rectangle, and vertical rectangle (Figure 5.21). The size of the window area still refers to the existing area size with a window area of 3.2 m2 with dimensions of 1.8 m x 1.8 m (Fig. 4). The horizontal size ratio is 1:2 with dimensions of 2.54 meters long and 1.27 meters high, so the area is 3.2 m2. The vertical window size is 1.27 meters wide and 2.54 meters high (Fig. 2). The placement of the window leaves takes into account human height, so that they can still see the view to the outside space through the bedroom windows. The window shape consists of three types: types A, B, and C. From these window types, analysis is carried out with different window positions.

Table 2. Window Model and Code

Window model	Window position	Window code	Size (meter)	Area (m2)
Square Model (A)	Bottom side	ASB	1,8 x 1,8	3,2
	Top side	ASA	1,8 x 1,8	3,2
Horizontal Rectangle Model (B)	Bottom center	BTB	2,54 x 1,27	3,2
	Top center	BTA	2,54 x 1,27	3,2
Vertical Rectangle Model (C)	Center Center	CTT	1,27 x 2,54	3,2
	Center side	CST	1,27 x 2,54	3,2



Existing windows

Figure 4: Existing windows
Source: Author

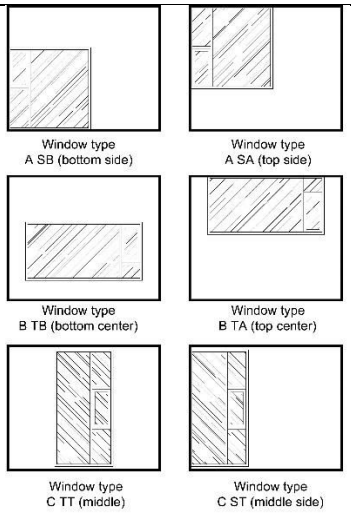


Figure 5: Simulation window model
Source: Author

In this study, the windows were limited to the same materials as the existing ones, including the glass and aluminum window frames, floors, walls, and ceilings (fig.6).

Figure 6: Existing Room Windows & Interior
Source: Author

Room and Window Type

From the window type, it is then applied to the space being studied, resulting in 48 window models as shown in table 3. Next, it is analyzed using Velux 3 software to obtain

illumination and analysis results.

Table 3: Room and Window Type

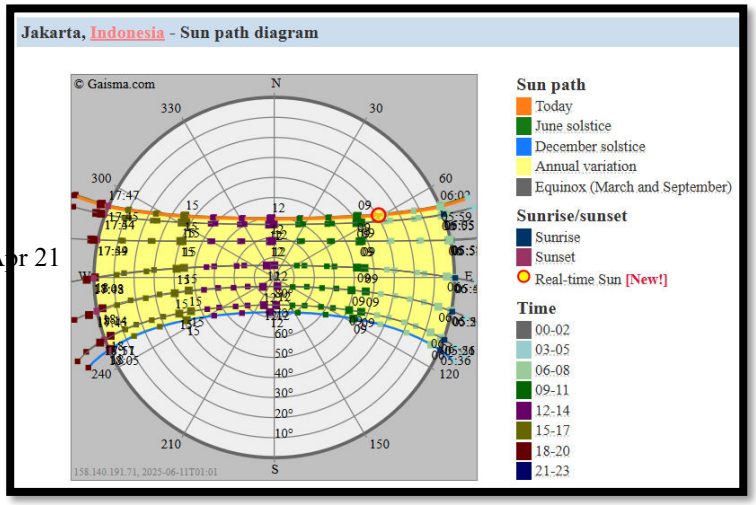
Room and Window Type	Orientation	Window Size (m)	Window Position	Solar glass reflectance	Wall reflectance	Floor Reflectance	Ceiling reflectance
416-ASB	east	1,8x1,8	Bottom side	0,34	0,8	0,5	0,8
416-ASA	east	1,8x1,8	Top side	0,34	0,8	0,5	0,8
416-BTB	east	2,54x1,27	Bottom center	0,34	0,8	0,5	0,8
416-BTA	east	2,54x1,27	Top center	0,34	0,8	0,5	0,8
416-CTT	east	1,27x2,54	Center center	0,34	0,8	0,5	0,8
416-CST	east	1,27x2,54	Center side	0,34	0,8	0,5	0,8
424-ASB	east	1,8x1,8	Bottom side	0,34	0,8	0,5	0,8
424-ASA	east	1,8x1,8	Top side	0,34	0,8	0,5	0,8
424-BTB	east	2,54x1,27	Bottom center	0,34	0,8	0,5	0,8
424-BTA	east	2,54x1,27	Top center	0,34	0,8	0,5	0,8
424-CTT	east	1,27x2,54	Center center	0,34	0,8	0,5	0,8
424-CST	east	1,27x2,54	Center side	0,34	0,8	0,5	0,8
419-ASB	west	1,8x1,8	Bottom side	0,34	0,8	0,5	0,8
419-ASA	west	1,8x1,8	Top side	0,34	0,8	0,5	0,8
419-BTB	west	2,54x1,27	Bottom center	0,34	0,8	0,5	0,8
419-BTA	west	2,54x1,27	Top center	0,34	0,8	0,5	0,8
419-CTT	west	1,27x2,54	Center center	0,34	0,8	0,5	0,8
419-C	west	1,27x2,5	Center	0,34	0,8	0,5	0,8

ST		4	side				
426-A SB	west	1,8x1,8	Bottom side	0,34	0,8	0,5	0,8
426-A SA	west	1,8x1,8	Top side	0,34	0,8	0,5	0,8
426-B TB	west	2,54x1,27	Bottom center	0,34	0,8	0,5	0,8
426-B TA	west	2,54x1,27	Top center	0,34	0,8	0,5	0,8
426-C TT	west	1,27x2,54	Center center	0,34	0,8	0,5	0,8
426-C ST	west	1,27x2,54	Center side	0,34	0,8	0,5	0,8
916-A SB	east	1,8x1,8	Bottom side	0,34	0,8	0,5	0,8
916-A SA	east	1,8x1,8	Top side	0,34	0,8	0,5	0,8
916-B TB	east	2,54x1,27	Bottom center	0,34	0,8	0,5	0,8
916-B TA	east	2,54x1,27	Top center	0,34	0,8	0,5	0,8
916-C TT	east	1,27x2,54	Center center	0,34	0,8	0,5	0,8
916-C ST	east	1,27x2,54	Center side	0,34	0,8	0,5	0,8
924-A SB	east	1,8x1,8	Bottom side	0,34	0,8	0,5	0,8
924-A SA	east	1,8x1,8	Top side	0,34	0,8	0,5	0,8
924-B TB	east	2,54x1,27	Bottom center	0,34	0,8	0,5	0,8
924-B TA	east	2,54x1,27	Top center	0,34	0,8	0,5	0,8
924-C TT	east	1,27x2,54	Center center	0,34	0,8	0,5	0,8
924-C ST	east	1,27x2,54	Center side	0,34	0,8	0,5	0,8
919-A SB	west	1,8x1,8	Bottom side	0,34	0,8	0,5	0,8
919-A SA	west	1,8x1,8	Top side	0,34	0,8	0,5	0,8
919-B	west	2,54x1,2	Bottom	0,34	0,8	0,5	0,8

TB		7	center				
919-B TA	west	2,54x1,27	Top center	0,34	0,8	0,5	0,8
919-C TT	west	1,27x2,54	Center center	0,34	0,8	0,5	0,8
919-C ST	west	1,27x2,54	Center side	0,34	0,8	0,5	0,8
926-A SB	west	1,8x1,8	Bottom side	0,34	0,8	0,5	0,8
926-A SA	west	1,8x1,8	Top side	0,34	0,8	0,5	0,8
926-B TB	west	2,54x1,27	Bottom center	0,34	0,8	0,5	0,8
926-B TA	west	2,54x1,27	Top center	0,34	0,8	0,5	0,8
926-C TT	west	1,27x2,54	Center center	0,34	0,8	0,5	0,8
926-C ST	west	1,27x2,54	Center side	0,34	0,8	0,5	0,8

Calculation

The simulation measurement time in April is the same as the time of the direct measurement month in the field. Based on the Sunpath diagram from the gaisma.com website, in April the sun is slightly in the northern hemisphere as shown in Fig. 7. In the lighting simulation using Velux Daylight Visualizer 3 software, the measurement time is April 21st as shown in Fig. 8.



Apr 21

Figure 7: Sunpath diagram
source: Gaisma.com

Dalam Software Velux Daylight visualizer 3 menggunakan type render Illuminasi, kondisi langit cerah dan jam pengukuran di jam 09:00, 12:00 dan jam 15:00 (tabel 5.16).. Hasil render terangkum dalam tabel Diagram 1.

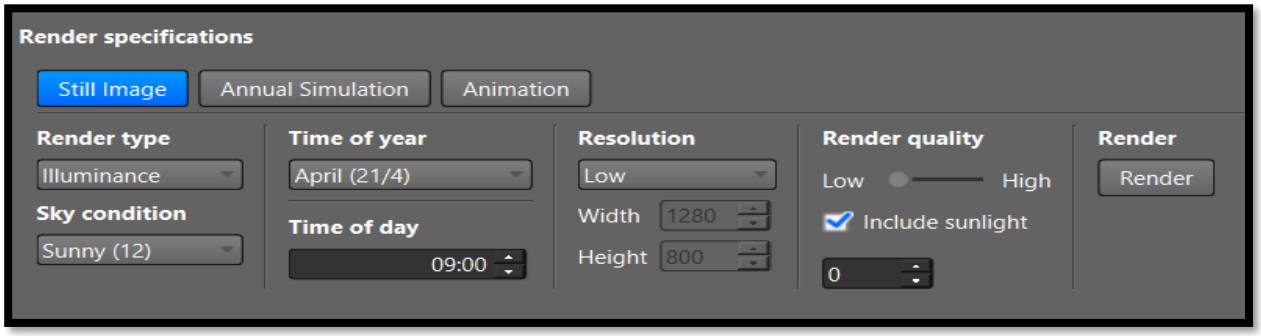


Figure 8: Render specifications
Source: Author

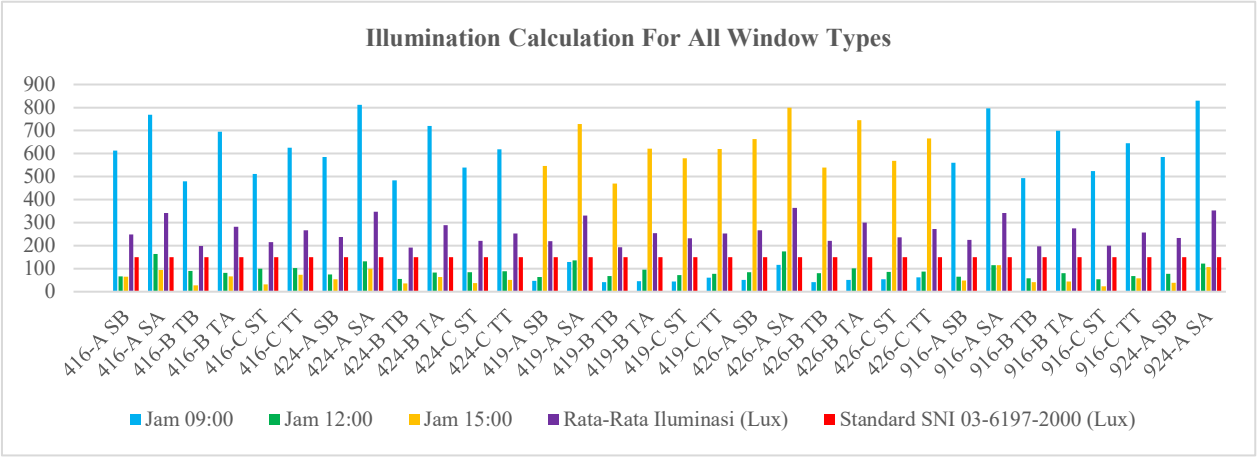


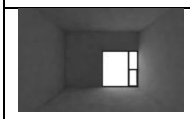
Diagram 1. Illumination calculation for all window types

The results of the window model analysis are discussed for each window type A, B, and C in each room. Each window type consists of two window positions.

Window Model A Bottom Side (ASB) and Top Side (ASA)

Type A window model with 2 types, namely the bottom and top sides. From the measurement results using dialux, the average result of the ASB type is 242.85 lux, the smallest illumination value is 219.15 lux in room 419, and the largest value is 266.38 lux in room 426 (table 4). While the ASA type has an average illumination value of 346.89 lux, the smallest value is 329.09 lux in room 919 and the largest is 366.93 lux in room 926. The room with the lowest illumination value is room 419 ASB with a bottom side window and the highest illumination is room 926 ASA with an upper side window will be discussed further.

Table 4: Window Illumination Calculation Model A

Window Type	Room Space (lux)								Average (lux)
	416 (east)	424 (east)	916 (east)	924 (east)	419 (west)	426 (west)	919 (west)	926 (west)	
 ASB	248,34	237,84	224,68	233,43	219,15	266,38	240,32	272,63	242,85
 ASA	342,5	347,67	342,24	352,52	330,75	363,45	329,09	366,93	346,89

Room 419 ASB (Lowest illumination) and Room 926 ASA (Highest illumination)

Room 419 is located on the west side. The illumination results using the Velux Daylight visualizer 3 measurement at 9 o'clock were 46.5 lux, at 12 o'clock it was 64.2 lux, and at 15 o'clock it was 546.7 lux, so room 419 SB has an illumination of 219.2 lux (fig. 9), almost approaching the SNI standard of 150 lux.

Room 926 ASA is located on the west side on the ninth floor. Illumination measurements using the Velux Daylight Visualizer 3 at 9 o'clock showed 110.1 lux, 167.5 lux at 12 o'clock, and 823.2 m lux at 15 o'clock. Illumination in room 926 ASA is 366.93 lux, exceeding the SNI standard limit of 150 lux. The light distribution is highest at 15 o'clock, while the light at 9 o'clock is quite low.

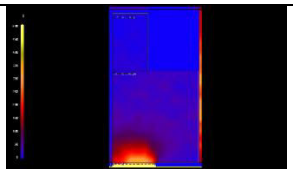
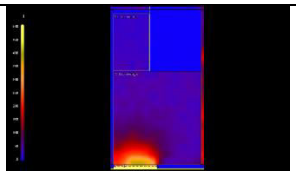
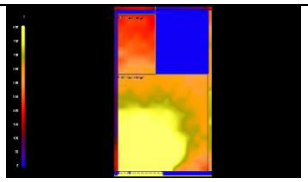
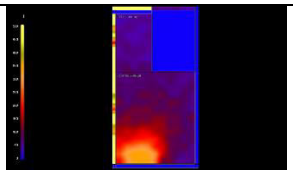
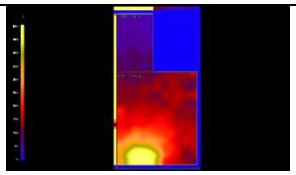
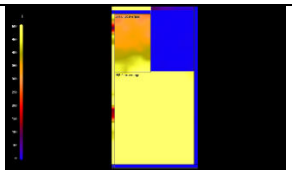
Window Type	Measurement (lux)		
	9 o'clock	12 o'clock	15 o'clock
419 ASB	 46,5 Lux	 64,2 Lux	 546,7 Lux
926 ASA	 110,1 Lux	 167,5 Lux	 823,2 Lux

Figure 9: Room Illumination Calculation 419 ASB & 926 ASA
Source: Author

Room 926 ASA is located on the west side on the ninth floor. From the results of the illumination using Velux Daylight visualizer 3 measurements at 9 o'clock was 110.1 lux, at 12 o'clock was 167.5 lux and at 15 o'clock was 823.2 m lux so that room 926 ASA has an illumination of 366.93 lux, exceeding the SNI standard limit of 150 lux. The highest light distribution is at 15 o'clock, while the light at 9 o'clock is quite low.

Window Model B Middle Bottom (BTB) and Middle Top (BTA)

Type B window model with 2 types, namely the middle bottom and top. From the measurement results using dialux, the average result of the BTB type is 287.29 lux, the smallest illumination value is 260.37 lux in room 419 on the west side, and the largest value is 325.86 lux in room 926 on the west side. While the BTA type has an average illumination value of 277.16 lux, the smallest value is 254.38 lux in room 419 on the west side, and the largest is 299.56 lux in room 426 (table 5).

Table 5: Window Illumination Calculation Model B

Window Type	Room Space (lux)								Average (lux)
	416 (east)	424 (east)	916 (east)	924 (east)	419 (west)	426 (west)	919 (west)	926 (west)	
 BTB	295,78	276,08	277,92	288,98	260,37	305,70	267,59	325,86	287,29
 BTA	281,44	289,18	274,76	261,74	254,38	299,56	256,7	299,53	277,16

Rooms with window type B with the lowest and highest values were further analyzed. The room with the lowest illumination value was room 419 BTA with the upper middle window position, and the room with the highest illumination value was room 926 BTB with the lower middle window position.

Room 419 BTA (Lowest illumination) Room 926 BTB (Highest illumination)

Room 419 BTA is located on the west side. From the results of the illumination using Velux Daylight visualizer 3 measurements at 9 o'clock was 45.7 lux, at 12 o'clock was 95.8 lux and at 15 o'clock was 621.7 lux so that room 419 BTA has an illumination of 254.38 lux, almost close to the SNI standard of 150 lux (figure 5.30). The highest light distribution is at 15 o'clock, while the light at 9 o'clock is quite low.

Room 926 BTB is located on the west side. From the results of the illumination using Velux Daylight visualizer 3 measurements at 9 o'clock was 70.6 lux, at 12 o'clock was 117.8 lux and at 15 o'clock was 789.2 lux so that room 926 BTB has an illumination of 325.86 lux, far from the SNI standard of 150 lux (figure 5.32). The highest light distribution is at 15 o'clock, while the light at 9 o'clock is quite low (fig. 10).

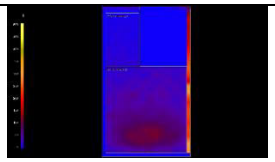
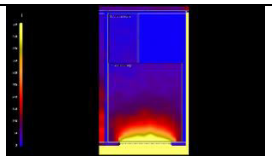
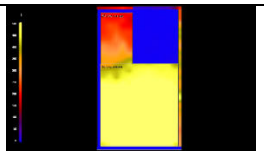
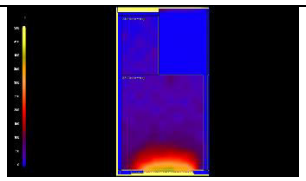
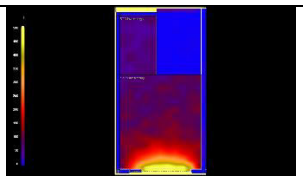
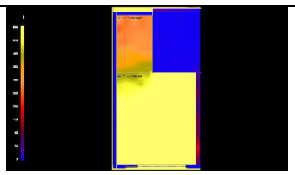
Window Type	Measurement (lux)		
	9 o'clock	Jam 12	9 o'clock
419 BTA	 45,7 Lux	 95,8 Lux	 621,7 Lux
926 BTB	 70,6 Lux	 117,8 Lux	 789,2 Lux

Figure 10: Room Illumination Calculation 419 BTA & 926 BTB
Source: Author

Window Model C Center Side (CST) and Center Center (CTT)

Type C window model with 2 types, middle bottom and top. From the measurement results using dialux, the average result of the CST type is 224.66 lux, the smallest illumination value is 205.89 lux in room 924 on the east side, and the largest value is 244.53 lux in room 926 on the west side. While the CTT type has an average illumination value of 257.89 lux, the smallest value is 252.29 lux in room 419 on the west side, and the largest is 293.19 lux in room 919 (table 6).

Table 6: Perhitungan Iluminasi jendela model C

Bentuk jendela	Ruang Kamar (lux)								Rata-rata (lux)
	416 (timur)	424 (timur)	916 (timur)	924 (timur)	419 (barat)	426 (barat)	919 (barat)	926 (barat)	
 CST	214,76	214,38	206,67	205,89	232,25	236,62	242,18	244,53	224,66
 CTT	267,03	253,22	257,28	250,13	252,29	271,81	293,19	277,61	257,89

Rooms with window type C with the lowest and highest values were further analyzed. The room with the lowest illumination value was room 924 CST with the middle window position, and the highest illumination value was room 919 CTT with the middle window position.

Kamar 924 CST (Iluminasi terendah) Kamar 919 CTT (nilai Iluminasi tertinggi)

Room 924 CST is located on the east side. From the results of the illumination using the Velux Daylight visualizer 3 measurements at 9 o'clock is quite large, namely 524 lux, at 12 o'clock 58.5 lux and 35.1 lux so that room 926 BTB has an illumination of 205.89

lux, almost close to the SNI standard of 150 lux. The highest light distribution is at 9 o'clock, while the lowest light is at 15 o'clock(fig. 11).

Room 919 CTT is located on the west side. From the results of the illumination using Velux Daylight visualizer 3 measurements at 9 o'clock was 80.3 lux, at 12 o'clock was 104.2 lux and at 15 o'clock was 695 lux (figure 5.36) so that room 919 CTT has an illumination of 293.19 lux, far from the SNI standard of 150 lux. The highest light distribution is at 15 o'clock, while the light at 9 o'clock is quite low.

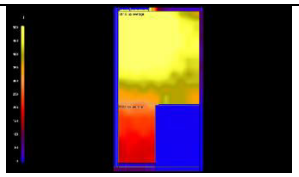
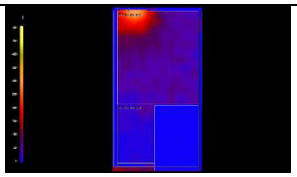
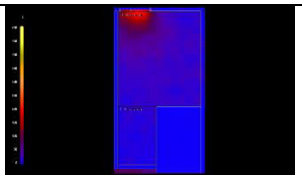
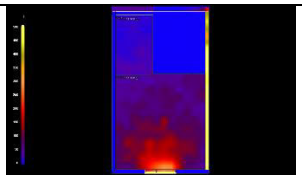
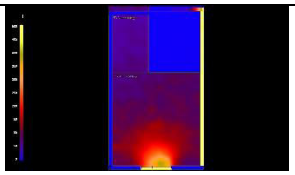
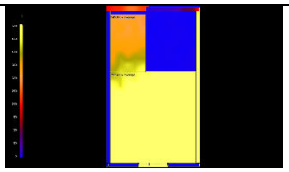
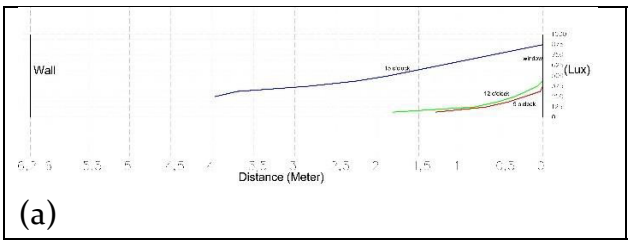
Window Type	Measurement (lux)		
	9 o'clock	Jam 12	9 o'clock
Window Type	Measurement (lux)	Window Type	Measurement (lux)
924 CST	 524 Lux	 58,5 Lux	 35,1 Lux
919 CTT	 80,3 Lux	 104,2 Lux	 695 Lux

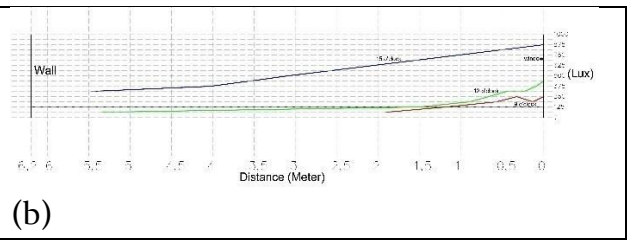
Figure 11: Perhitungan Iluminasi kamar 924 CST & 919 CTT
Source: Author

Light distribution

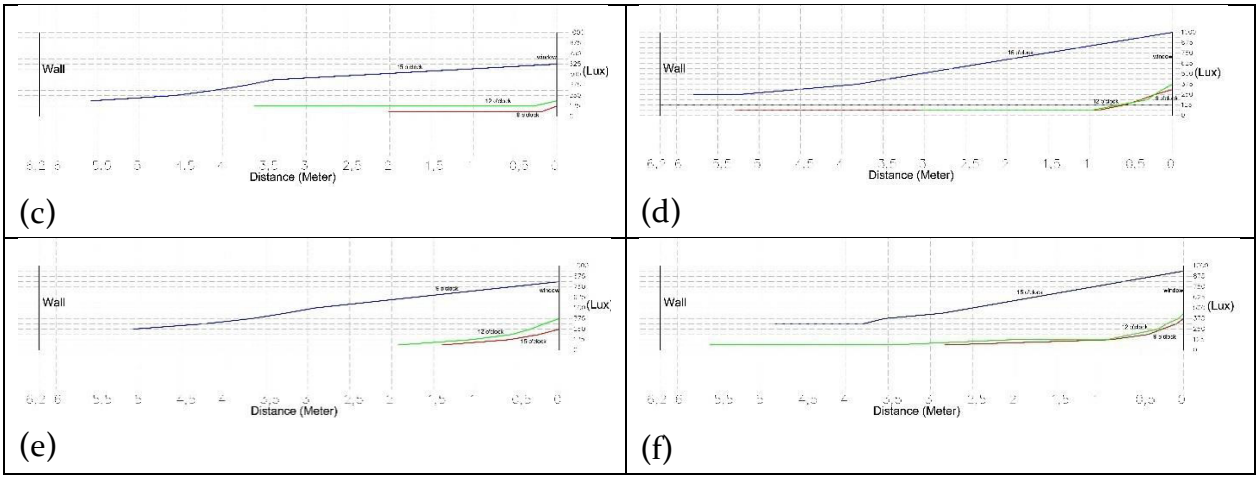
From the analysis of window types A, B, and C (fig. 12), the type that is closest to the SNI illumination standard is the Center sideC window type (CST) with an average illumination value of 224.6 lux approaching the 150 lux limit. The even distribution of light in each room is the middle bottom B window type (BTB) with an illumination of 287.29 lux. The window type with maximum light entering the room is the upper side A type (ASA) with an average illumination of 346.89 lux. Meanwhile, the middle middle C window type (CTT) is the type with the deepest distribution of light entering the room.



(a)



(b)



a=419 ASB; b=926 ASA; c=419 BTA; d=926 BTB; e=924 CST; f=919 CTT

Figure 12: Distribution of light in the depth of the room

Source: Author

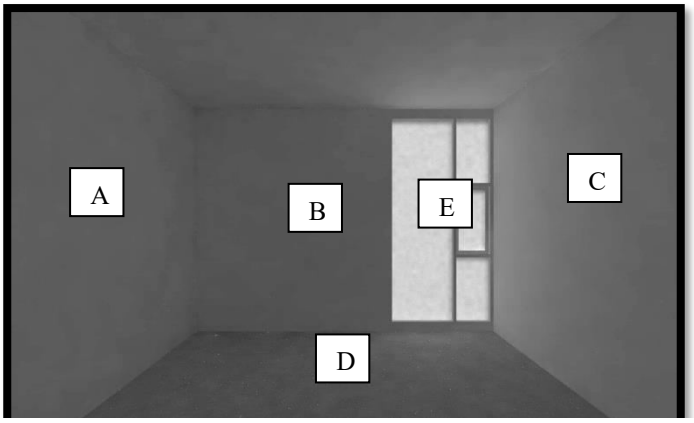
Visual Comfort

Visual comfort is influenced by the reflection of light onto a surface or from direct sunlight or what is commonly called glare. In this study, the types of simulated CST type windows and existing hotel room windows that are used as samples of hotel rooms on the 4th and 9th floors are discussed. Glare is the comparison between field of view: field of vision and background, with a standard of ≤1:10 maximum recommendation when doing work (table 7).

Table 7: Tingkat Silau

≤ 1: 10	Maximum recommendation to do the job
1:11 – 1: 20	Triggering Discomfort Glare
1: 21 – 1: 50	Discomfort Glare Occurs
> 1: 50	Disability glare occurs

In calculating the field of view value, calculate it at 4 points. These points are the left wall of the room, the wall next to the light source, the right wall of the room, and the floor (fig. 13).



Note: A= Left wall; B= Wall next to the light source; C= Right wall; D= Floor; E= Light source

Figure 13: Glare measurement
Source: Author

Glare Analysis of the Center Side C-Type Window Model (CST)

The window model that approaches the SNI standard illumination value of 150 lux with a type C window model on the Center side (CST). The rooms are oriented east and west. Based on the simulation results using Velux Daylight Visualizer 3, the east orientation experiences the highest glare with a ratio of 1:30.14, while the west orientation is 1:28.6. While the lowest is the east orientation at 1:15.9, and the west orientation is 1;17.2 (table 8).

Table 8: Luminance Measurement

Window Type C Center side(CST)	Field of vision : Field of view			Average Luminasi (cd/m2)	Orientation	results
	90'clock	12 o'clock	15 o'clock			
416	1:8,9	1:8,1	1:34,8	1:17,3	east	Triggers discomfort glare
424	1:2,4	1:21,9	1:23,4	1:15,9	east	Triggers discomfort glare
419	1:37,6	1:25,1	1:10,3	1:24,3	east	Discomfort Glare Occurs
426	1:47,2	1:33,5	1:9,7	1:30,14	east	Discomfort Glare Occurs
916	1:9,3	1:15,3	1:41,2	1:21,9	west	Discomfort Glare Occurs
924	1:8,5	1:14,5	1:28,7	1:17,2	west	Triggers discomfort glare
919	1:28,8	1:24,6	1:10,3	1:21,2	west	Discomfort Glare Occurs
926	1:48,3	1:26,7	1:10,8	1:28,6	west	Discomfort Glare Occurs

Based on the discussion of the glare analysis on the CST type windows in the rooms on the 4th and 9th floors, the west and east orientations still exceed the glare limit ratio, namely 1:10, and the glare analysis on the existing windows on the 4th and 9th floors, the west and east orientations also still exceed the glare limit ratio except for the windows of rooms 901 and 911 which have been recommended. To overcome glare according to [13]Glare during the summer is a major issue due to the inappropriate use of shading devices. Eight room models will then be simulated using shading devices.

Shading device on the window

According to[14]The type of shading in architecture consists of vertical, horizontal and vertical-horizontal (eggcrate) envelopes. This research will use three types of imaging tools, and the depth measurement is limited to one size.

In SNI 6389:2020, the depth of the shading device varies from 20 cm, 40 cm, 60 cm, and so on. The depth of the shading device in this study is 40 cm because the material weight factor is a consideration, so that it can be applied to the existing building envelope. The model that will be taken is the CST type simulation window and the existing bedroom window that has a high illumination value, west and east orientation.

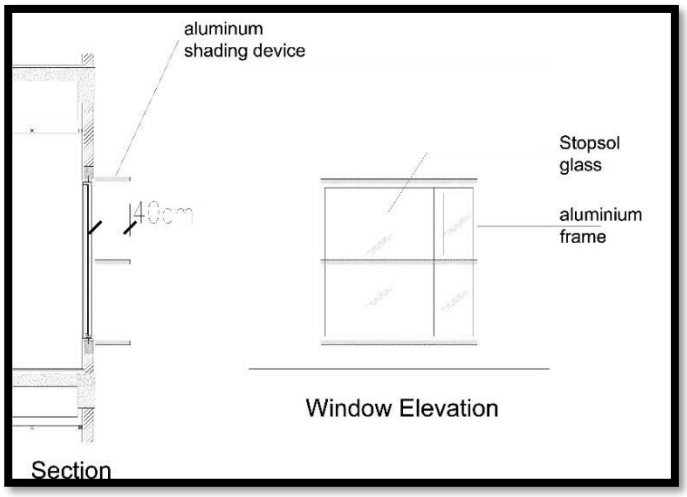


Figure 14: horizontal shading device
Source: Author

Shading devices that will be applied to rooms with CST type windows. The shading devices used are horizontal, vertical, and eggcrate types with a depth of 40 cm, as in Fig. 15. The design of the shading device is in the form of horizontal and vertical blades that follow the window design. The window design has the same opening as the existing window.

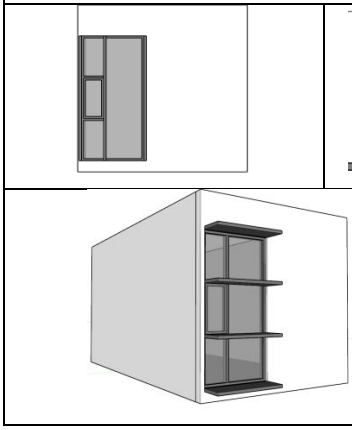
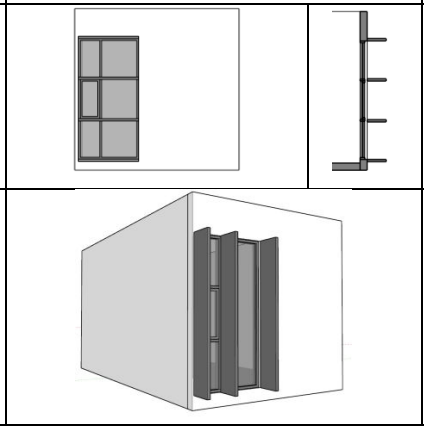
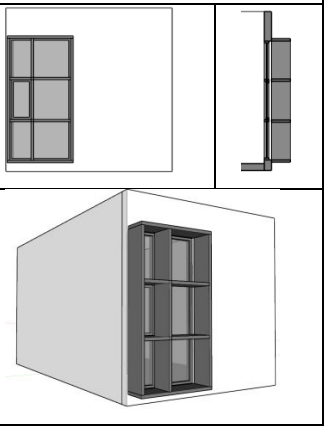
Horizontal type shading device	Vertical type shading device	Egg crate type shading device
		

Figure 15: Simulation Room Window shading device type
Source: Author

Horizontal shading device

a. Illumination Analysis

Based on simulations using Velux Daylight visualizer 3, the illumination results are close to the SNI standard of 150 lux. Room 424 CST with an average illumination value of 91.29 lux is still below the standard. The highest room is room 426 CST with a value of 162.6 lux, as shown in table 9. Horizontal shading devices are quite effective in reducing illumination. Rooms that use horizontal shading devices will change the luminance value.

Table 9: Horizontal shading device illumination measurement

Window Type C Center side (CST)	Measurement			Average Illumination(Lux)
	90'clock	12 o'clock	15 o'clock	
416	348,4	70,6	52,5	157,16
419	36,2	50,3	394,2	160,25
424	169,5	31,5	72,9	91,29
426	50,1	66,1	371,6	162,60
916	344,6	51,2	28,3	141,38
919	37,1	77,2	389,2	167,83
924	353,6	60,6	34,6	149,62
926	32,9	60,9	379,8	157,90
Average	171,6	58,6	215,4	148,5

b. Luminance Analysis

Based on simulations using Velux Daylight visualizer 3, the luminance results trigger discomfort glare, and discomfort glare occurs, as in table 10. The lowest luminance value is 1:12.52 and the highest is 1:24.46 (table 10). Using a horizontal shading device still does not overcome glare with a limit of ≤ 1:10.

Table 10: Horizontal shading device luminance measurement

Window Type C Center side(CST)	90'clock	12 o'clock	15 o'clock	Average Luminance(cd/m2)	Orien tation	results	Standard
416	1:9,3	1:14,94	1:13,27	1:12,52	east	Triggers discomfort glare	≤ 1:10
424	1:9,2	1:21,05	1:17,98	1:14,47	east	Triggers discomfort glare	≤ 1:10
916	1:8,6	1:13,70	1:19,71	1:14,01	east	Triggers discomfort glare	≤ 1:10

924	1:9,1	1:14,81	1:33,13	1:19,00	east	Triggers discomfort glare	≤ 1:10
419	1:26,8	1:22,34	1:9,57	1:19,56	west	Triggers discomfort glare	≤ 1:10
426	1:17,5	1:21,90	1:10,77	1:16,72	west	Triggers discomfort glare	≤ 1:10
919	1:35,4	1:27,60	1:10,38	1:24,46	west	Discomfort glare occurs	≤ 1:10
926	1:35,2	1:27,31	1:9,66	1:24,06	west	Discomfort glare occurs	≤ 1:10
Average	1:18,9	1:20,5	1:14,9	1:18,1			

Glare with high luminance values occurred at 9 and 15 o'clock in the west orientation. Meanwhile, the east orientation occurred in room 924 CST at 15 o'clock with a fairly high luminance value (diagram 2).

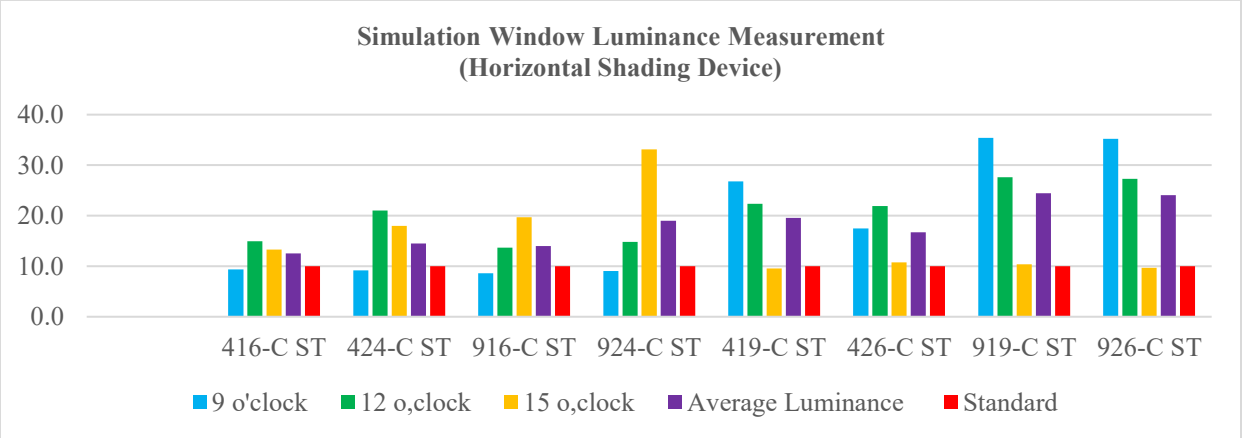


Diagram 2: Horizontal shading device simulation window luminance

Vertical Shading Device

a. Illumination Analysis

ased on simulations using Velux Daylight visualizer 3, the illumination results are close to the SNI standard of 150 lux. Room 416 CST has the lowest value with an average illumination value of 185.23 lux, almost close to the standard. The highest room is room 426 CST with a value of 206.92 lux, as shown in table 5.27. Vertical shading devices are quite effective in reducing illumination. Rooms that use vertical shading devices will change the luminance value.

Table 11: Pengukuran Iluminasi shading device vertikal

Window Type C Center side(CST)	Measurement			Average Illumination (Lux)
	90'clock	12 o'clock	15 o'clock	
416	475,2	61,0	19,5	185,23
419	31,6	72,8	465,4	189,94
424	431,1	41,2	33,5	168,64
426	33,3	84,9	502,5	206,92
916	461,3	66,6	32,5	186,77
919	48,8	101,8	481,6	210,73
924	485,0	69,6	25,5	193,40
926	34,8	75,4	452,2	187,44
Average	250,1	71,7	251,6	191,1

b. Luminance Analysis

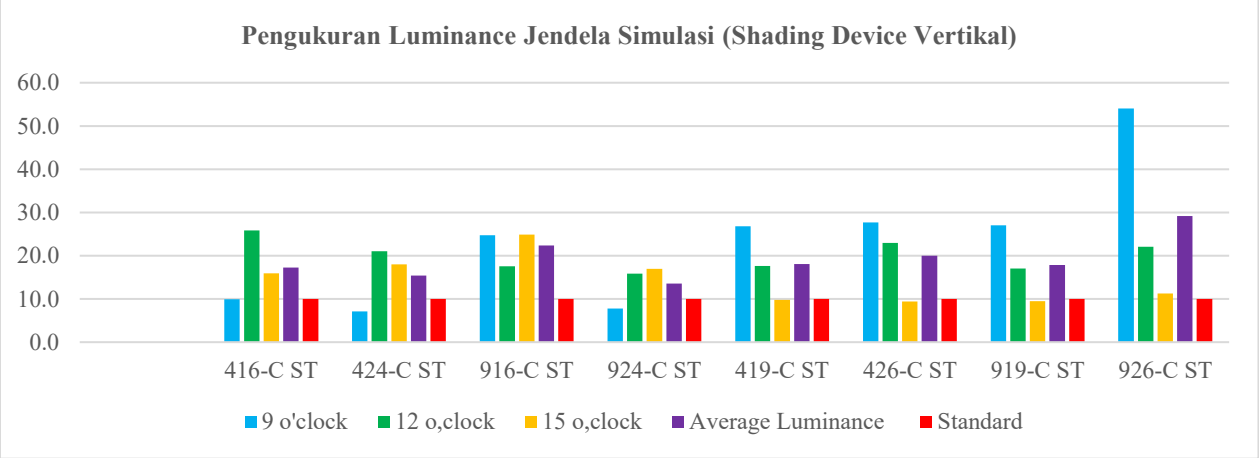
Based on simulations using Velux Daylight visualizer 3, the luminance results trigger discomfort glare, and discomfort glare occurs, as shown in table 5.28. The lowest luminance value is 1:17.24 and the highest is 1:29.14. Using a vertical shading device still does not overcome glare with a limit of ≤ 1:10.

Table 12: Vertical shading device luminance measurement

Window Type C Center side (CST)	9 o'clock	12 o'clock	15 o'clock	Average Luminance (cd/m2)	Orientation	results	Standard
416	1:9,9	1:25,85	1:15,95	1:17,24	east	Triggers discomfort glare	≤ 1:10
424	1:7,1	1:21,05	1:17,98	1:15,38	east	Triggers discomfort glare	≤ 1:10
916	1:24,7	1:17,52	1:24,89	1:22,37	east	Discomfort glare occurs	≤ 1:10
924	1:7,8	1:15,87	1:16,96	1:13,54	east	Triggers discomfort glare	≤ 1:10
419	1:26,8	1:17,63	1:9,76	1:18,06	west	Triggers discomfort glare	≤ 1:10
426	1:27,7	1:22,93	1:9,43	1:20,02	west	Triggers discomfort glare	≤ 1:10
919	1:27,0	1:17,00	1:9,48	1:17,83	west	Triggers discomfort glare	≤ 1:10
926	1:54,0	1:22,10	1:11,28	1:29,14	west	Discomfort glare occurs	≤ 1:10
Average	1:23,1	1:20	1:14,5	1:19,2			

Glare with a high luminance value occurred at 9 o'clock in room 926 CST with a west orientation. Meanwhile, in room 924 CST with an east orientation, the glare tended to be even (diagram 3).

Diagram 3: Window luminance simulation vertical shading device



Alat peneduh Eggcrate

a. Illumination Analysis

Based on simulations using Velux Daylight visualizer 3, the illumination results are below the SNI standard of 150 lux. Room 424 CST with an average illumination value of 96.01 lux is still below the standard. The highest room is room 919 CST with a value of 139.11 lux, as shown in table 5.29. The eggcrate shading device is not effective enough to reduce illumination. Rooms that use eggcrate shading devices will change the luminance value.

Table 13: Eggcrate shading device illumination measurement

Window Type C Center side (CST)	Measurement			Average Illumination (Lux)
	9 o'clock	12 o'clock	15 o'clock	
416	261,6	20,3	16,5	99,44
419	40,8	31,1	328,4	133,45
424	245,5	19,7	22,8	96,01
426	34,4	29,2	318,9	127,50
916	276,2	26,8	13,7	105,55
919	38,2	68,7	310,4	139,11
924	277,3	18,9	27,9	108,03
926	16,3	25,2	335,4	125,62
Average	148,8	30,0	171,8	116,8

b. Luminance Analysis

Based on simulations using Velux Daylight visualizer 3, the resulting luminance triggers discomfort glare, and discomfort glare occurs. The lowest luminance value is

1:12.90 and the highest is 1:23.41 (table 14). Using a horizontal shading device still does not address glare with a limit of ≤ 1:10.

Table 14: Eggcrate shading device luminance measurement

Window Type C Center side (CST)	9 o'clock	12 o'clock	15 o'clock	Average Luminance (cd/m2)	Orientation	results	Standard
416	1:9,5	1:16,30	1:23,59	1:16,47	Timur	Memicu discomfort glare	≤ 1:10
424	1:8,9	1:27,83	1:12,11	1:16,27	Timur	Memicu discomfort glare	≤ 1:10
916	1:10,2	1:9,79	1:18,73	1:12,90	Timur	Memicu discomfort glare	≤ 1:10
924	1:8,5	1:10,37	1:32,00	1:16,97	Timur	Memicu discomfort glare	≤ 1:10
419	1:21,7	1:23,69	1:10,14	1:18,52	Barat	Memicu discomfort glare	≤ 1:10
426	1:33,4	1:27,33	1:9,45	1:23,41	Barat	Terjadi discomfort glare	≤ 1:10
919	1:21,9	1:19,30	1:9,71	1:16,96	Barat	Memicu discomfort glare	≤ 1:10
926	1:31,6	1:25,23	1:10,04	1:22,28	Barat	Terjadi discomfort glare	≤ 1:10
Average	1:18,2	1:20	1:15,7	1:18			

Glare with high luminance values occurred at 9 and 15 o'clock in the west orientation as shown in diagram 4. Meanwhile, the east orientation occurred in room 924 CST at 15 o'clock with a fairly high luminance value.

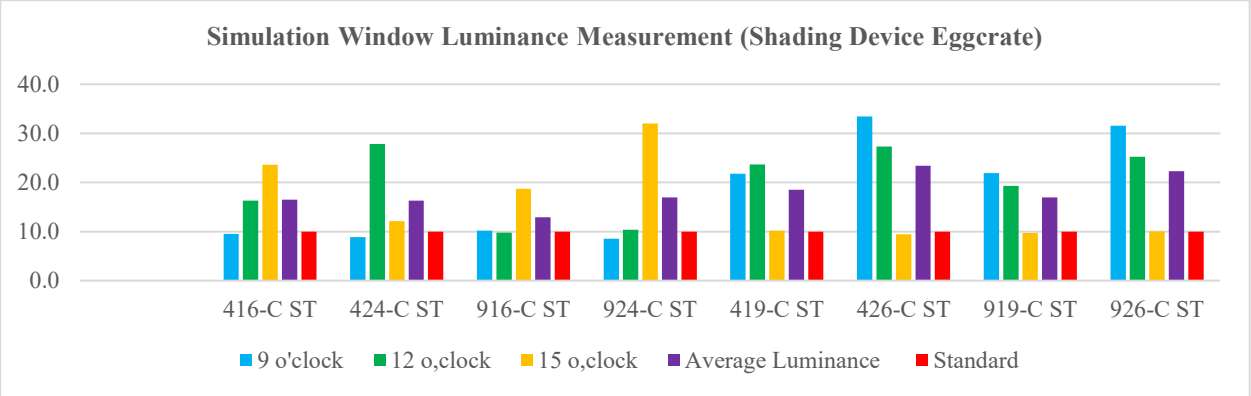


Diagram 4: Egg crate simulated window luminance shading device

Illuminance and Lumination Analysis of Shading Devices

Based on the analysis results of the illumination and luminance values in the simulation window, there is a decrease in the illumination and luminance values using a shading device. Using the eggcrate shading device reduces the illumination value by 48%, horizontally by 33.9% and vertically by 14.9% (table 15).

Meanwhile, using shading devices reduces the luminance value. Using horizontal and eggcrate types reduces it by 22.1%, and vertical by 16.9%, as shown in Table 5.32 (Table 5.31). In this study, using horizontal shading devices is the most appropriate because it can reduce the illumination value up to 148.5 lux, and the luminance is 1:18.

Table 15: Decrease in illumination value and shading device luminance

Window Type C Centerside (CST)	Iluminasi (lux)				Luminasi (cd/m2)			
	Without shading device	Horizontal	Vertikal	Eggcrate	Without shading device	Horizontal	Vertikal	Eggcrate
416	214,76	157,16	185,23	99,44	1:17,3	1:12,52	1:17,24	1:16,47
424	220,38	160,25	189,94	133,45	1:24,3	1:14,47	1:15,38	1:16,27
916	232,25	91,29	168,64	96,01	1:24,3	1:14,01	1:22,37	1:12,90
924	236,62	162,60	206,92	127,50	1:30,1	1:19,00	1:13,54	1:16,97
419	200,67	141,38	186,77	105,55	1:21,9	1:19,56	1:18,06	1:18,52
426	205,89	167,83	210,73	139,11	17,2	1:16,72	1:20,02	1:23,41
919	242,18	149,62	193,40	108,03	1:21,2	1:24,46	1:17,83	1:16,96
926	244,53	157,90	187,44	125,62	1:28,6	1:24,06	1:29,14	1:22,28
Average	224,66	148,5	191,1	116,8	1:23,1	1:18	1;19,2	1:18
Decrease		**33,9%**	**14,9%**	**48,0%**		**22,1%**	**16,9%**	**22,1%**

Simulation Model of CST type window changes

Based on the discussion results, the appropriate use of shading devices to produce illumination and luminance values within the SNI 03-6197-2000 standard limits and glare ratio is to use horizontal shading devices. Changes to existing windows and the addition of horizontal shading devices are shown in Figure 16.

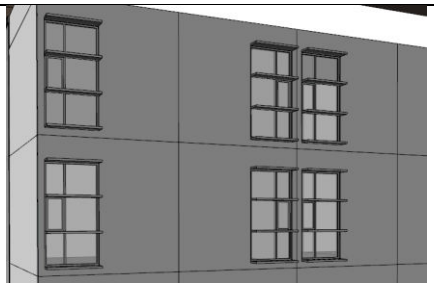
Existing Windows	CST Type Window Simulation Model
	
	
	

Figure 16: CST Type Window Simulation Model

IV. Conclusion

Natural lighting is crucial for architecture and can be optimally utilized. Indonesia's location on the equator provides abundant natural light. Window openings are crucial for bringing natural light into buildings. Hotel rooms receive natural light exposure exceeding the SNI 03-6197-2000 standard of 150 lux, and glare is a major concern.

To obtain standard lux values and glare recommendations for hotel rooms, existing windows can be modified. Changing windows will increase costs and halt hotel operations. This study did not include cost calculations. Simulations of changing room windows used the same material and color as the existing ones, both in terms of glass and window frames. The window area used remains the same but the shape is different. Shading devices in hotel rooms use lightweight materials with a depth of 40 cm, which can still be applied to existing buildings.

From the discussion in Chapter IV regarding the simulated window types, the following conclusions can be drawn:

- From the analysis of window types A, B, and C, the type closest to the SNI illumination standard is window type C, center side (CST), with an average illumination value of 224.6 lux, approaching the 150 lux limit. Window type B, center bottom (BTB), with an even distribution of light in each room is window type B, center bottom (BTB), with an illumination of 287.29 lux. The window type with the maximum light entering the room is window type A, top side (ASA), with an average illumination of 346.89 lux. Meanwhile, window type C, center middle (CTT), has the deepest distribution of light entering the room.
- The room experiencing the least glare is room 416 CTT, oriented east, with a result of 1:11.7. Meanwhile, the room experiencing the highest glare is room 419 BTB, with a result of 1:45.2, oriented west.
- Analysis results using a horizontal shading device show that Room 424 CST, with an average illumination value of 91.29 lux, is still below the standard. The highest room is Room 426 CST, with a value of 162.6 lux. The lowest illumination value is 1:12.52 for the window type 416 CST, and the highest is 1:24.46 for the type 919 CST.
- Analysis results using a vertical shading device show that Room 416 CST has the lowest value, with an average illumination value of 185.23 lux, nearly approaching the standard. The highest room is Room 426 CST, with a value of 206.92 lux. The lowest illumination value is 1:17.24 and the highest is 1:29.14 for Rooms 416 CST and 926 CST.
- Analysis results using the eggcrate shading device show that Room 424 CST has an average illumination value of 96.01 lux, which is still below the standard. The highest illumination value is Room 919 CST, with a value of 139.11 lux. The lowest illumination value is 1:12.90 in Room 916 CST, and the highest is 1:23.41 in Room 426 CST.
- Horizontal shading devices are most effective in west and east orientations, with a value of 148.5 lux, approaching the SNI 03-6197-2000 limit of 150 lux, compared to the vertical type at 191.1 lux and the eggcrate at 116.8 lux.
- Eggcrate shading devices can reduce illumination by 48%, followed by horizontal and vertical at 33.9% and 14.9%, respectively.
- Horizontal and eggcrate type shading devices in west and east orientations are the most effective in reducing luminance by 22.1%, followed by the vertical type by 16.9%.

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