Daylight Optimization in a Café through Window to Wall Ratio and Illuminance Analysis: A Case Study of Brew and Chew Café in Bandung, Indonesia

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Abstract

Daylighting is essential for enhancing the lighting ambiance and ensuring occupants' visual comfort in a café. Nowadays, a café is not only a leisure destination, but has also become a preferred place for people working remotely. Consequently, the necessity for proper daylighting in a café becomes crucial to achieve customers' visual comfort. Regarding daylighting, windows play a pivotal role in bringing natural light into a building. Thus, the Window-to-Wall Ratio (WWR) percentage has a significant impact on the illuminance level within the building. To prevent visual discomfort, the Leadership in Energy and Environmental Design (LEED) v4.1 Standard for daylight measurement will serve as the parameter to achieve an acceptable level of illuminance, ranging between 300 lux and 3,000 lux at both 9 AM and 3 PM. The objective of this research is to determine the optimal WWR percentage in a case study café to achieve an acceptable illuminance level based on the LEED v4.1 standard, using Velux as the simulation software. The research methodology involves measuring the existing illuminance level of the case study café using a lux meter to validate the building simulation results. Subsequently, the 3D model of the café will be simulated in Velux with varying Window-to-Wall Ratios (WWR) to identify the optimal WWR that aligns with the LEED v4.1 standard for daylight measurement.

***Keywords**: Window to Wall Ratio, Daylighting, Illuminance Level, Daylight Simulation, Café*

INTRODUCTION

The major purpose of lighting in a building is to support the user's activities through visibilities. Lighting must be provided carefully to ensure a good and comfortable visibility for the user to do the activities inside the building. Artificial lighting and daylighting are two types of lighting which has been use commonly depending on the building typology and user's need. Artificial lighting is widely use and essential when it comes to a room which needs constant amount of light such operating room in a hospital, laboratory, etc.

Daylighting brings natural light into an indoor environment to reduce the energy consumption caused by artificial lighting in the building, thus daylighting also makes an environmentally sustainable solution for designing a space. The importance of daylight penetration is not only dedicated for energy efficiency purposes. It also takes part in determining the quality of health and comfort for the building occupants (Fitria, 2021). As an alternative to artificial lighting, daylighting also offers a lighting source that most closely matches the human visual response (Alrubaih et al, 2013). Studies also suggest that daylighting has a direct impact on the well-being, productivity and overall sense of satisfaction of users, for example, students, employees and retail customers, as people have a natural attraction and need for daylight (Sharaf, 2014).

According to Wardono & Maharani (2019), one type of public space for leisure activities that may need to use natural light as much as possible are eating places. Moreover, nowadays eating places are not just become a place to eat and socialize, but also for working remotely. Remote working phenomenon reveals that technology has changed the way of work and allows people to work from multiple locations; not only at home but also the third place between office and home, including the café (Trisna & Utami, 2020). Thus, the needs of proper lighting in a café as an eating and working space, becomes necessary.

In terms of lighting, costumers in a café will expect a visual comfort while they are enjoying a meal, or working remotely. Lighting comfort is one of the comfort factors that should be considered at work (Karyono, et al 2022). According to Jacquier & Giboreau (2012), light influences the atmosphere perception by consumers, thus adapted lighting ambiances could improve their well-being. When it comes to a space where common daily activities are conducted such as living space and workspace, daylighting is more preferable because it provides a more pleasant and attractive indoor environment (Plympton et al, 2000).

The use of natural lighting may not be secure, because apart from possible exposure to heat from direct sunlight, visual discomfort can also occur (Wardono & Maharani, 2019). The more glazing area, the more daylight the building can get. But, when there are too much sunlight entering the building through the large glazing area, aside from building heat gain, direct sunlight penetration in interior spaces can produce an unpleasant glare which can caused visual discomfort (Sharaf, 2014).

Illuminance Level and WWR

To achieve visual comfort, illuminance becomes one of three fundamental quantitative indices which can be used as daylight parameters. Illuminance refers to the received daylight on a horizontal task plane (Tabadkani, 2021). According to CIBSE for interior lighting, the illuminance and its distribution on the task area and its surrounding area have a great impact on how quickly, safely, and comfortably a person perceives and carries out a visual task. Acceptable Illuminance level may differ depends on the occupants and activities, influenced by physical condition such as window size and people's preferences and satisfaction (Husini, et al, 2021). Thus, the preferred illuminance level was related to occupant's satisfaction in daylighting condition (Husini, 2011).

In terms of daylighting, window plays an important role in bringing natural light into a building. Window-to-wall ratio (WWR) is the ratio between the glazing area and total façade surface in a building. The optimum WWR must be taken into consideration in the early stages of designing a building with respect to the form, orientation, distribution, and dimensions of the windows (Shaeri, et al, 2019). The optimum WWR means the window area that minimizes the total annual energy of cooling, heating, and lighting (Goia, 2016). Thus, the percentage of WWR has an impact on the illuminance level inside the building.

There are some standards regarding the parameters of illuminance level in terms of daylighting issued by three renowned green building certification system in Indonesia and worldwide such as GBCI, BREEAM and LEED. Green Building Council Indonesia (GBCI) stated on their Technical Manual Green Building Rating Tools, if the illuminance level at 30% area of the occupied room should be more than 300 lux. While in Building Research Establishment Environmental Assessment Method (BREEAM), the standards for illuminance required at least 300 lux for 2000 hours per year or more on averaged over entire space. Then, based on Leadership in Energy and Environmental Design (LEED) v4.1 the measurement of illuminance level can be performed in computer simulations with a clear-sky day at the equinox for each regularly occupied space. Thus, the illuminance levels should be between 300 lux and 3,000 lux at both 9 AM and 3 PM. This research will be using the LEED standard as a parameter, because the standards mentioned before, have the same minimum illuminance level at 300 lux, but the LEED standard is the only one which issued the maximum illuminance level threshold of 3000 lux to be considered as acceptable. If the illuminance level goes beyond 3000 lux, it can cause both visual and thermal discomfort to the occupants.

RESEARCH METHODS

This research was conducted in Café Brew and Chew in Bandung, Indonesia. The café is located in the west side of Bandung City in an area famous for its culinary destination for local citizen & visitors. The 2 storey café facades are mostly covered in clear glass for bringing the natural lighting inside. There are three dining area on the building, but this research is focusing on one dining area in the first floor, which directly exposed by sun light. The focus of this research is the dining area located in the first floor which has 4.75 x 9.95 meter in size. which has a total WWR of 65%. The room also equipped with 7 sets of customer table and chair and 1 cashier table as illustrated in Figure 3.1.

Figure 1. Café's plan & isometric (Author, 2022)

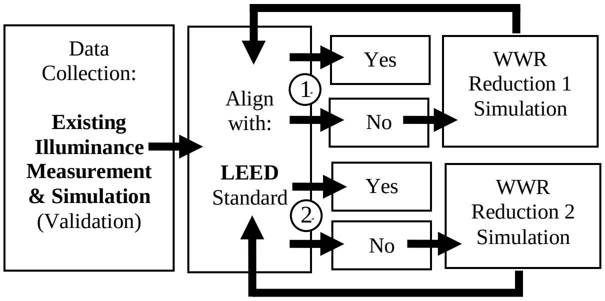


Figure 3. Research Methods (Author, 2023)

The first step of the research began with conducting the measurement of illuminance of the existing room using the light meter in 12 measurements points as shown in figure 3.2. As mentioned in LEED Standard, the illuminance levels should be between 300 lux and 3,000 lux at both 9 AM and 3 PM, thus the measurement was done at 9 AM and 3 PM in a clear sky condition. After the manual measurement, the existing café was modelled in 3D with SketchUp. Then, the 3D model was simulated in Velux to validate if the result of the simulation is not significantly different with the manual measurement. Velux is lighting simulation software which can calculate and visualize the lighting for indoor and outdoor areas. Then, the existing 3D model, will be re-modelled in various WWR, to be simulated again in Velux. The purpose of this research is to find the optimal WWR which meets the acceptable illuminance level in between 300-3000 lux based on LEED standards.

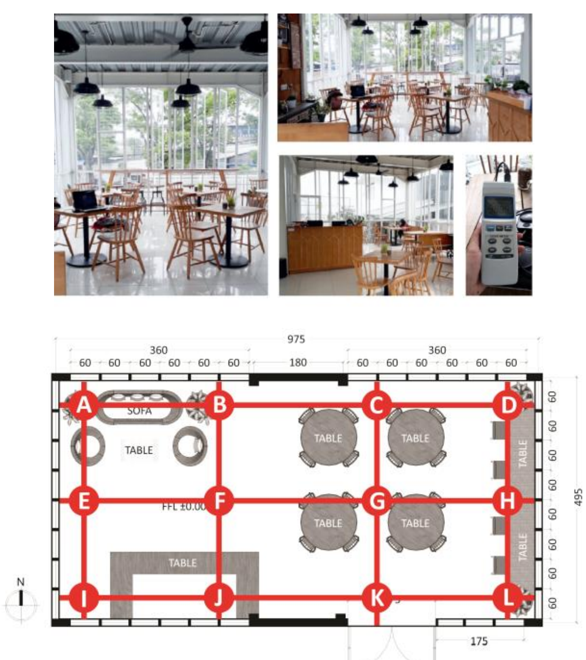


Figure 2. Measurement Points (Author, 2022)

RESULT AND DISCUSSION

The comparison result of the manual measurement and simulation from the existing café with the WWR of 65% can be seen in Table 4.1 based on the measurement points on figure 2. From the manual measurements, at 09:00 AM, the maximum illuminance level reach 3,598 lux on point H and 3,467 lux on point L which directly facing the window, exposed by east sun lights. The lowest illuminance level points are located in the middle of the room at point F and J, which has each illuminance level of 2,178 lux and 1,276 lux. While at 03:00 PM, the illuminance level is on its peak at the point D and H which has the illuminance level of 3,965 lux and 3,874 lux. In the same hour, point F and G also become the points with the least illuminance level at 2,631 lux and 1,887 lux.

Table 1. Existing Illuminance Level Manual Measurement & Simulation (Author, 2023)

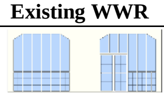
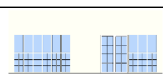
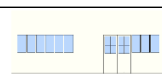
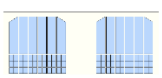
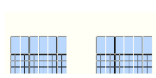
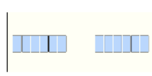
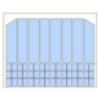
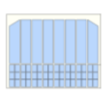
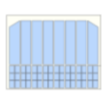
Point	**Manual Measurements**		**3D Model Simulation**	
	09:00 AM	**03:00 PM**	**09:00 AM**	**03:00 PM**
A	3,268	3,812	3,546.0	3,965.9
B	2,486	3,789	2,716.3	3,814.3
C	3,256	3,389	3,189.8	3,437.8
D	2,964	3,965	3,844.0	4,315.5
E	3,076	3,257	3,152.3	3,450.3
F	2,178	2,631	2,230.5	2,572.0
G	2,678	2,952	2,867.3	3,101.9
H	3,598	3,874	3,747.8	4,128.7
I	2,243	2,652	2,493.3	2,832.0
J	1,276	1,887	1,554.2	1,967.9
K	2,988	3,276	3,116.8	3,403.6
L	3,467	3,865	3,744.9	4,069.2
Average	**2,790**	**3,279**	**3,017**	**3,422**

After the manual measurement, the existing 3D model was simulated in Velux to validate if the result of the simulation with the manual measurement, because after all, the simulation to find the optimal WWR will be done on Velux. On the 3D model simulation with Velux, at 09:00 AM, the maximum illuminance level reach 3,844 lux on point D and 3,747 lux on point H which directly facing east sun lights. The lowest illuminance level points are located in the middle of the room at point F and J, which has each illuminance level of 2,230.5 lux and 1,554.2 lux. While at 03:00 PM, the illuminance level is on its peak at the same point on point D and H which has the illuminance level of 4,315.5 lux and 4,128.7 lux. In the same hour, point F and J also become the points with the least illuminance level at 2,572 lux and 1,967 lux.

From the comparison of the manual measurements and simulation with Velux, the results indicate that the value of illuminance level on the simulation result is higher than the manual measurements. The result of the simulation at 09:00 AM is 8% higher than the existing measurement, while the result of the simulation at 03:00 PM is 5% higher than the existing measurement. This can occurs due to many environmental and technical factors which can affect the existing measurement result. However, because the margin of error is less than 10%, the result of both existing measurement and simulation are considered valid.

From the results, both of the simulation and existing measurement have some similiarities. The result has show if point D and H have the highest illuminance level at 09:00 AM and 03:00 PM. This might be occurs due the position of those points which facing east window and exposed by east sun light in the morning. Point F and J become the points which has the least illuminance level at both 09:00 AM and 03:00 PM because they're located in the middle of the room facing south window, not directly exposed by the east sunlight. However, at some point such as point A and B, the illuminace level is much higher at 03:00 PM compared to the illuminance level at 09:00 AM. This might be occurs because point A and B are exposed to the west sun light at 03:00 PM.

Table 2. WWR Reduction from the Existing Building (Author, 2023)

	Existing WWR	WWR 1	WWR 2
South	 57.2%	 37.2%	 22.2%
North	 58.5%	 38.5%	 23.5%
East	 75.7%	 50.7%	 25.7%
West	 75.7%	 50.7%	 25.7%

Regarding the WWR, the existing building has the WWR of 65%. Based on the illuminance level measurements on table 4.1, the average illuminance level at both 09:00 AM and 03:00 PM are exceed 3000 lux. Moreover, in some measurement points near the east and west window, the illuminance level hit the value of more than 4000 lux. This issue can potentially cause a visual and thermal discomfort for the café's customer, since the recommended illuminance level based on LEED standard is ranged from 300-3000 lux.

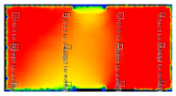
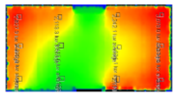
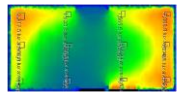
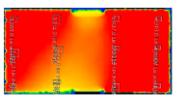
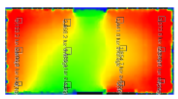
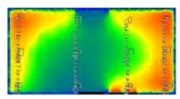
The high percentage WWR on the existing building have significant impact on the high illuminance level measurement, since the size of the window affected the amount of the daylight which entered the building. Thus, WWR reduction is needed to decrease the illuminance level on the existing building, nonetheless the WWR percentage should be enough to bring the daylight into the building in acceptable illuminance level based on LEED Standard of 300-3000 lux. Table 2 showed the 2 possibilities of WWR reduction in the building façades model in each building orientation.

Based on the existing illuminance measurement and simulation on the table 3, the highest illuminance level are found at the points near the east and west windows. Thus, the WWR on the east and west facades should be reducted more than the WWR of north and south facades. The WWR reduction was done based on the divide window segments. The windows height on each façade orientation is approximately 3,6 meters. Thus the height is divided into 3 segments: upper, middle and lower windows, which has 1,2 meters of height for each segments. The WWR reduction was done only to the upper and lower windows segments because the middle window segments is essential for maintain natural daylight and customer's eye-level view to the outside.

On the first WWR reduction (WWR 1) the aim is to reduce the WWR by eliminate the upper segments of the window. As can be seen at the table 2, after the elimination of upper window segments, the total WWR of the west and east facades are 50.7%, while the total WWR of south and north facades are 37.2% and 38.5%. After the simulation of first WWR reduction (WWR 1), as the result can be seen in table 3, the illuminance level at point A, D and L still exceed 3000 lux, while there are few measurement points which has the illuminance level above 2500 lux. Thus the second WWR reduction is needed to achieve the acceptable illuminance level below 3000 lux.

The second WWR reduction (WWR 2) is aimed to reduce the WWR by eliminate the upper and lower segments of the window. As can be seen at the table 2, after the elimination of upper and lower window segments, the total WWR of the west and east facades are 25.7%, while the total WWR of south and north facades are 22.2% and 23.5%. After the simulation of second WWR reduction (WWR 2), the result in table 3 indicates that all the illuminance level on each measurement points are within 300-3000 lux range, align with LEED standard.

Table 3. WWR Reduction Simulation (Author, 2023)

	Existing WWR	WWR 1	WWR 2
09:00 AM			
03:00 PM			

Pt	Existing WWR		WWR 1		WWR 2	
	09:00 AM	03:00 PM	09:00 AM	03:00 PM	09:00 AM	03:00 PM
A	3,546.0	3,965.9	2,827.9	3,133.2	2,217.5	2,410.2
B	2,716.3	3,814.3	2,113.3	2,068.2	1,432.8	890.9
C	3,189.8	3,437.8	2,242.1	2,441.0	1,568.9	1,854.2
D	3,844.0	4,315.5	3,078.0	3,373.8	2,306.9	2,598.3
E	3,152.3	3,450.3	2,229.0	2,496.2	1,630.6	1,326.7
F	2,230.5	2,572.0	1,413.0	1,505.1	736.8	733.5
G	2,867.3	3,101.9	1,634.1	1,854.7	975.7	1,168.6
H	3,747.8	4,128.7	2.634.6	2,840.0	1,370.4	2,188.1
I	2,493.3	2,832.0	1,362.2	2,162.6	1,348.4	1,326.5
J	1,554.2	1,967.9	1,133.0	1,220.1	622.1	572.4
K	3,116.8	3,403.6	2,171.7	2,461.7	1,574.9	1,369.9
L	3,744.9	4,069.2	2,861.5	3,264.3	2,217.3	2,337.4
Av	**3,016.9**	**3,421.5**	**2,096.8**	**2,401.74**	**1,500.1**	**1,564.73**

The result on table 3 indicates if from the simulation of existing WWR 65%, there are more than half of the total measurement points which has the illuminance level exceed 3000 lux, especially on the point D, H, L which have more than 4000 lux illuminance level at 03:00 PM. Then, after the first WWR reduction (WWR 1), the result are much better since there are only few measurement points which have the illuminance level exceed 3000 lux. Thus, the second simulation of WWR reduction was conducted. For the second WWR reduction, (WWR 2) the aim of the research is achived since the illuminance level result of all the measurement point are ranged between 300-3000 lux, in accordance with the LEED standard.

CONCLUSION

The optimal daylight for the case study building is highly depends on the WWR, because WWR will affect the indoor illuminance level of the building. The existing building has 75.7% WWR on the west and east façade, then 58.5% on the north façade and 57.2% for the south façade. The high WWR percentage resulted on high indoor illuminance level which exceed LEED standard of 300-3000 lux in 09:00 AM and 03:00 AM, especially on the measurement points near the window. The high level of illuminance can caused visual discomfort to the building user. Thus, the WWR reduction simulation was done to optimize the daylight which means keep the illuminance level according to LEED standard. The conclusion of this research is, in order to maintain the illuminance level in the range of 300-3000 lux at 09:00 AM and 03:00 PM, the optimum WWR percentage is 25.7% on the west and east facades, 22% on the north façade, and 23.5% for the south façade.

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