Estimated Optimum Internal Illuminance Distribution based on Standard Deviation and Mean of Variation of Window Opening Position in a Room

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Abstract: Lighting system is one of the factors that affect the psychological comfort and user activity of a building. Lighting in a room during the day is obtained from the sunlight, diffusion of light in the sky (cloud overcast), and reflection of light from the surrounding environment. The light received indoors is influenced by window openings, which should meet the size requirement under the SNI (Indonesian National Standard) of at least 1/6 of the room area. Previous research only discussed the optimal size of window openings of a room. This time the researchers sought the ideal window opening position of three different window opening positions in one spatial field. Investigation of internal illuminance distribution was carried out by calculations of sky component on the daylight factor. The internal illuminance distribution investigation results obtained from the sky component calculations were later analyzed with standard deviation and average. According to the analysis in this study, the greater the average and the smaller the standard deviation, the better the distribution value of the room. From the analysis in the simulations carried out by the researchers based on calculations, it can be concluded that the window's position in the middle of the wall has the optimal distribution. Further research is expected to be useful to architects in window position decision-making in accordance with activity requirements to optimize energy saving by minimizing the use of artificial lights at the daytime.

1 INTRODUCTION

Natural lighting is the most influential spectrum of adaptation of human vision. Daylight consideration in a room is based on human activity in the room. The most important thing of natural lighting is that it can affect the psychology of the inhabitants indoors. It also allows for energy saving through the reduction of the use of artificial light (Looman, 2017). The distribution of natural lighting in a room depends on three factors: the geometry of the room, the placement and orientation of the window as well as other openings, and internal surface characteristics (Code *et al.*, 2001).

An opening can be oriented to receive direct sunlight in certain times of day. The dimensions of a window or openings can control the amount of light that enters the room. Apertures can be oriented away from direct sunlight and receive very strong lighting from the dome of the sky (Acosta *et al.*, 2015). The dome of the heavens is a very constant source of light, even in cloudy skies. In addition, cloudy sky conditions can soften the direct sunlight and provide balanced distribution of lighting levels in the room (Phillips, 2004).

The amount of light can be measured using the luminace value (flux, lighting), i.e., by assuming the light from the outside and calculating the lighting inside an interior space or using the amount of relative daylight factor, i.e., by calculating the lighting ratio at the indoor measurement point with outdoor lighting (Rizal, Robandi and Yuniarno, 2016). The value of the daylight factor remains—the illumination outside the room corresponds to the indoor illumination; if it is dim outside, the indoors will be dim too. To figure out the optimum illumination in a room among different variants of window opening positions, the researchers conducted research by looking for mean and standard deviation. The space with the largest

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average and the smallest standard deviation was considered the optimal one.

2 DAYLIGHT FACTOR AND WINDOW OPENING

2.1 Daylight Factor

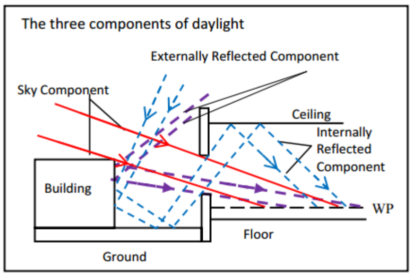


Figure 1: Daylight factor (Rizal, Robandi and Yuniarno, 2016).

Daylight factor is the ratio of the internal illuminance value at the reference point in the room and the external illuminance. These values are obtained in the state of daylight as shown in Figure 1 (cloudy sky conditions or conditions of no sunlight and at the same time) (Rizal, Robandi and Yuniarno, 2016). The definition of daylight factor is represented in equation (1).

$$Df = \left(\frac{Ei}{Eo}\right) 100\ \% \tag{1}$$

Factors that influence the daylight factor at a point in a room are as follows:

- Sc, the illuminace that reaches the reference point in the room directly from the sky;
- ERc, the illuminace that reaches the reference point in the room, which is influenced by the reflection of existing surfaces outside the room, such as buildings and streets; and
- IRc, the illuminace that reaches the reference point in the room, which is influenced by the reflection of the surface in the room, such as material, wall color, etc.

The sum of the above three factors produces Df as represented in equation (2) (Code *et al.*, 2001)(Cibse, 1999).

$$Df = Sc + IRc + ERc \tag{2}$$

2.2 Window Opening Composition

Window is a component that is often used in buildings and has a great influence in regulating the entry of light in the room. Functional design and shapes of a window have the advantage of maximizing incoming light in a room that affects the activity of the occupant or user in the room. In addition, window has the advantage of minimizing the use of artificial lighting. Window size, position, characteristics, and relationship with the wall surface can define the light in the room. For this task, the development of façade technology sets the most important window element to ensure the quantity of natural light in the room, followed by two elements of window composition, namely the size and position of the window placement (Acosta, Campano and Molina, 2016).

Window dimensions and positions affect the amount, distribution or penetration, as well as the diversity of natural light. Dimensions (height and width) of exposed walls on facades with window positions affect the transition of natural light (Iversen *et al.*, 2013). High positioning of a window will affect the natural light penetrating the room, while the width of the window affects the evenness of the distribution of natural light in the room (IEA, 2000).

3 ESTIMATED OPTIMAL INTERNAL ILLUMINANCE DISTRIBUTION

3.1 Window Opening Variants

In this paper, the estimation of internal illuminance distribution was performed on window opening variants of a 12 m^2 (4 m long and 3 m wide) room. For the window to meet the size requirement of 1/6 of the room area, it should have the size of 2 m^2 (1.33 m wide and 1.5 m tall). There were 3 variants differentiated by the position of the window openings horizontally.

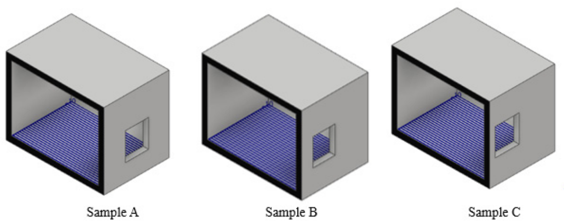


Figure 2: Three variants of window openings horizontally. (A: against the corner of the window, B: against the intersection of the window opening, C: against the outer window).

The window position was horizontally shifted to the middle position (Sample A), the edge position (Sample B), and the corner position (Sample C). The positions of the window openings can be seen more clearly in Figure 2. Meanwhile, the size and position of the window landing against the room are outlined in Table 1.

Table 1: Three variants of window opening horizontally

Sample	Window Position	Distance of the bottom of the window to the floor	Distance of the right side of the window to the wall
A	Middle	0.75	0.835
B	Edge	0.75	0.435
C	Corner	0.75	1.67

3.2 Calculation of Sky Component

Sky component is the most influential in daylight factor as seen in equation (2). The calculation of the sky component value in this paper was derived from the calculation of window dimensions (rectangular-shaped) and the distance to the floor point in the room by utilizing the BRE table (Cie Standard Overcast Sky) (Mangkuto, 2017). The dimensions of the window in question include the window height, width, and distance to the point representing the average of the surrounding area on the floor as shown in Figure 3.

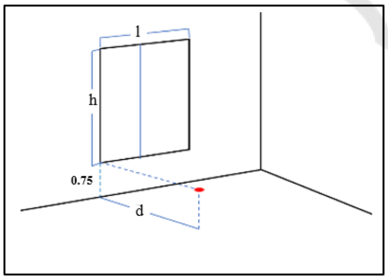


Figure 3: Three-variable calculation

The point on the floor generated by the sky component is called a reference point. The value at this reference point will be used to distribute the internal illuminance. The reference point was obtained by determining the minimum distance limit under the window to the floor, namely 0.75 m. If the distance of the bottom of the window to the floor exceeded 0.75 m, the additional distance would be calculated. The sky component estimate was based on the reference point against the window angle as shown in equation (3).

$$SC = \frac{1}{2\pi}\left(\arctan\frac{L}{D} - \frac{1}{\sqrt{1+\left(\frac{H}{D}\right)^2}}\arctan\frac{\frac{L}{D}}{\sqrt{1+\left(\frac{H}{D}\right)^2}}\right) \quad (3)$$

3.3 Calculation of Sky Component

After obtaining the sky component value as described in equations (3) and (4), we distributed the internal illuminance in accordance with the condition of the room area. The internal illuminance distribution was performed in several stages. The first stage was dividing the room in a grid. The grid value was filled from the reference point of the sky component and represented the average distance value of the grid area. In the next stage, the internal illuminance value was input into the daylight factor formula in equation (5).

3.3.1 Grid Distribution

Prior to estimating the internal illuminance distribution based on the sky component (Sc), a grid was first made to determine the 0.2 m^2 grid spacing reference point. Grid preparation in each room had the purpose to include the internal illuminance value at each midpoint of the grid based on the sky component at the reference point. The internal illuminance value was the average of the grid area (0.2 m^2) as shown in Figure 4.

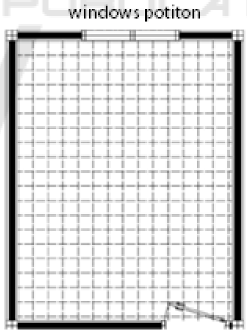


Figure 4: Grid Distribution

3.3.2 Entry of the Sky Component Value on Each Grid

The value of component sky was derived from the window dimensions. This value is one of the most influential in daylight factor. In addition, the value of daylight factor is and , but the value of both was ignored. This is because the effect of reflection in the room, such as refraction of the color of the walls, objects in the room, materials, among others, was not used, and neither was the influence of the reflection outside the room, such as the reflection of buildings and objects outside. So the only factor affecting Df that was considered in this paper was Sc as seen in equation (4).

$$Df = Sc \quad (4)$$

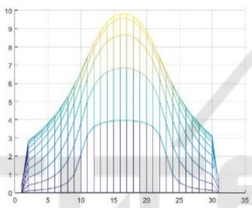
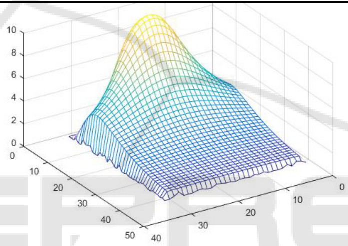
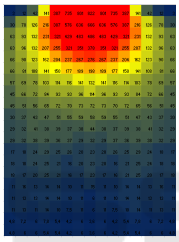
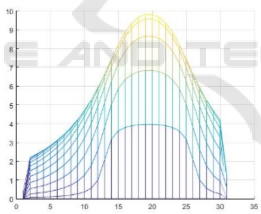
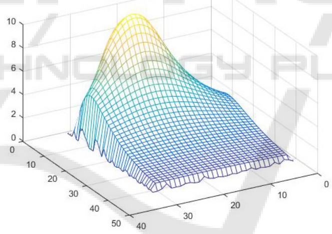
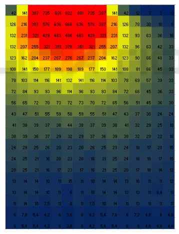
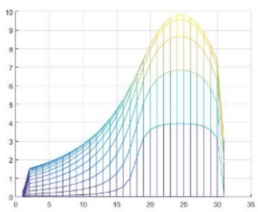
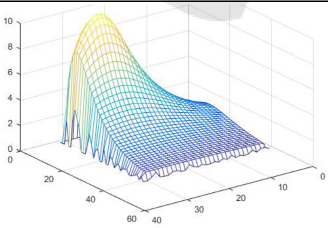
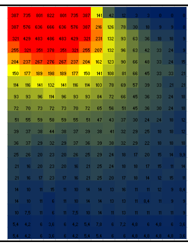
3.3.3 Calculating Internal Illuminance

After the daylight factor value based on sky component was obtained, the Ei (internal illumination) value was found with equations (4) and (5), that is Daylight Factor ratio. The daylight factor value was derived from the sky component value. The external illumination was 3000 lux. This value was obtained under the average external illumination condition in Indonesia in April. Then, the internal illuminance value was obtained as seen in equation (5).

$$Ei = \left(\frac{Df}{100\%}\right) E \quad (5)$$

Afterwards, the internal illuminance distribution in the room based on the window variants was obtained as seen in Table 2.

Table 2: Results of the analysis of the illumination distribution for three window opening variants

Sample of Room	Room View		
	The front (Window Opening) *(Df* in Room (%))	The back side *(Df* in room (%))	The top position (*Ei* in Room (lux))
A			
B			
C			

Sample To	Window Position	Standard Deviation	Mean	Internal illuminance Percentage Value		
				High (%)	Average (%)	Low (%)
A	middle	148.1	95.58	10	27	63
B	edge	148.8	93.46	9.7	24.3	66
C	corner	149.5	86.2	9	20	71

4 RESULTS AND ANALYSIS

4.1 Analysis of the Internal illuminance distribution

After the internal illuminance distribution value of the sky component was obtained, it was then analysed to determine the optimal window variant among the three variants of the window positions. The analysis of the distribution used standard deviation and mean equations. The standard deviation of the internal illuminance in a predetermined room was found using equation (6).

$$S_{Ei} = \sqrt{\frac{\sum_{i=1}^{n}(x-\sum Ei)^2}{n-1}} \quad (6)$$

Meanwhile, the mean of the internal illuminance in the room was found using equation (7).

$$A_{Ei} = \frac{\sum_{i=1}^{n} x}{n} \quad (7)$$

4.2 Internal illuminance distribution Results

The results of the analysis of the internal illuminance distribution was illustrated using colors (Table. 2), with the lowest illuminance of 0–65 lux being represented by dark blue-yellowish blue, medium illuminance of 66–237 lux being represented by yellow-orange, and the highest illuminance of 238–822 lux being represented by orange-bright red. The analysis of the window samples is described below.

4.2.1 Sample A

The room with a window in the middle had three areas, namely one with the lowest illuminance of 0–65 lux (63% dark blue area-yellowish blue), one with medium illuminance of 66–237 lux (27% orange), and one with the highest illuminance of 238–822 lux (10% orange-bright red), with illumination tending to be distributed in front of the window. From the 300 reference points in the sample area, a mean (AEi) of 86.2 lux and a standard deviation (SEi) of 149.5 lux were obtained.

4.2.2 Sample B

The room with a window located on the edge had three areas, namely one with the lowest illuminance of 0–65 lux (66% dark blue-yellowish blue), one with medium illumination of 66–237 lux (24.3% orange), and one with the highest illuminance of 238–822 lux (9.7% orange-bright red), with illumination tending to be distributed in front of the window. From the 300 reference points in the sample area, a mean (AEi) of 93.46 lux and a standard deviation (SEi) of 145.8 lux were obtained.

4.2.3 Sample C

The room with a window located in the corner had three areas, namely one with the lowest illuminance of 0–65 lux (71% dark blue-yellowish blue), one with medium illuminance of 66–237 lux (20% orange), and one with the highest illuminance of 238–822 lux (9% orange-bright red), with illumination tending to be distributed in front of the window. From the 300 reference points in the sample area, a mean (AEi) of 86.2 lux and a standard deviation (SEi) of 149.5 lux were.

Based on the description of Sample A, Sample B, and Sample C, we show the results of the explanation in the Df and illumination value on the number of sides of the 3D reconstruction (from the simulation we created) as in Table 2.

5 CONCLUSIONS

Based on the standard deviation and mean values, the room with the biggest mean and the smallest standard deviation of the three sample rooms was the room which had the most optimal value of internal illuminance distribution. It can be concluded that in this study, of the three room samples studied, the position of window openings that had the optimal internal illuminance distribution value was one of Sample A, with the window opening positioned in the middle of the wall plane.

The more the window opening position is away from the side of the wall, the smaller the value of the internal illuminance distribution, meaning that if the room is far apart, the opening of the window will darken. On the contrary, if the wall is closer to the window opening, the value of the internal illuminance distribution will be greater, meaning that the room will be brighter.

This research proves quantitatively that the position of window openings can affect the value of sky component on daylight factor and internal illuminance. This is evidenced when the window openings in the room are shifted, the value of daylight factor and internal illuminance at the reference point will change.

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APPENDIX NOMENCLATURE

Df Daylight factor
Ei Internal illuminance
Eo External illuminance
Sc Sky component
IRc Internal reflection component
ERc External reflection component
h Window opening height
l Window opening width
d Distance of the window opening to the reference point
A_{Ei} The mean of internal illuminance
S_{Ei} Standart deviation total internal illuminance
x Reference point
n Total reference point