International Journal of Innovative Computing, Information and Control
Volume **16**, Number **1**, February **2020**

ICIC International ©2020 ISSN 1349-4198
pp. 15–28

DAYLIGHT FACTOR DISTRIBUTION OPTIMIZATION BASED ON SKY COMPONENT ON THE ROOM FOR WINDOW OPENINGS

Yose Rizal[1,3], Imam Robandi[1] and Eko Mulyanto Yuniarno[2]

[1]Department of Electrical Engineering
[2]Department of Computer Engineering
Institut Teknologi Sepuluh Nopember (ITS)
Jln. Teknik Mesin, Kampus ITS, Sukolilo, Surabaya, Jawa Timur 60111, Indonesia
ysrizal77@gmail.com

[3]Department of Architecture Engineering
Universitas Lancang Kuning
Jalan Yos Sudarso Km 8, Kampus Unilak, Rumbai, Pekanbaru, Riau 28265, Indonesia
yose@unilak.ac.id

Received May 2019; revised October 2019

Abstract. *Architectural design is a building system that has room composition and design products that take into account environmental conditions. The thing that most influences the environment and user comfort is lighting, where the more evenly distributed light in the room, the better the level of comfort. The importance of this lighting, so in designing, must think about the process of lighting quantitation in the room. One method of lighting quantitation in the room is the calculation of the Daylight Factor (DF). The value of DF is affected by Sky Component (SC). On the DF, the object used is a window and outside lighting factors. Based on the quantitation process, this research has the idea of analyzing three different variants of space in the character of the wall. In this paper, the best window position is obtained based on the value of the largest number of DF distributions in the room. Optimization in this study can be obtained by calculating the standard deviation value of the DF distribution for each window opening shift. The window position is considered optimal or the best in the DF distribution in the room, if it has the highest DF mean value and the smallest DF variant value.*
Keywords: Distribution, Daylight Factor (DF), Sky Component (SC), Window openings, Optimization

1. **Introduction.** Architecture is a place for humans to carry out their life activities by creating conditions as comfortable as possible. Architectural design as a building system consisting of the composition of spaces is a design product taking into account the conditions in the surrounding environment [1]. In general, one of the most critical factors that must inform in designing buildings is lighting by standard provisions. Lighting is one factor to get a safe and comfortable environment and is closely related to human productivity. Proper lighting allows people to see objects (visual information) done clearly and quickly [2,3]. Adequate lighting and standards can affect health and can make residents able to concentrate well so they can reduce errors in work [4]. Decree of the Minister of Health of the Republic of Indonesia concerning Health Requirements for Office and Industrial Work Environment, the productivity of indoor workers is sufficiently able to increase by 10-50%, while lighting that is less will increase the percentage of errors in doing work where the error rate is 30-60% [5].

DOI: 10.24507/ijicic.16.01.15

One of the lighting sources in the room is natural lighting that comes from sunlight [6]. The quality of natural lighting will revise by the layout of openings to the direction of the arrival of sunlight [3,7]. Positioning windows that affect natural lighting can also affect the interests of visual users, while visual interests that can receive from qualitative and quantitative comfort [8]. Qualitative comfort is the quality of lighting more than subjective phenomena that require experience, knowledge, interpretation between one person can be different from others. While quantitative comfort is better, lighting quality can be set, such as deep space conditioning and the position of a window opening.

Measurements need to be taken using the Daylight Factor (DF) parameter. Daylight Factor is a comparison of the level of lighting at a measuring point from the floor area in the room to the level of flat field lighting outside the room at the same time as well as the conditions of daylight or overcast sky conditions [8,9]. Overcast sky conditions represent the worst daytime conditions to be the minimum threshold of measurement [11].

Daylight Factor (DF) consists of three components, Sky Component (SC), External Reflection Factor (ERC), and Internal Reflection Factor (IRC) [9]. In the study of Mohelnikova and Jiri Hirs, mentioning the external factors and reflection factors in influencing the lighting level during the day of 2-12% on the measuring point, then from that statement the sky factor is the most significant component and has the most considerable influence on the measuring point [12]. In this study, the component used in Daylight Factor (DF) is Sky Component (SC). Eliminating ERC and IRC in this study aims to test the space in the worst conditions without any reflection factors that affect the distribution of lighting in the room. The DF value at each measurement point in the room is called the DF distribution.

The research gap in this paper relates to the distribution of lighting in a room based on the Sky Component (SC) estimation approach, to show the optimization of the Daylight Factor (DF) distribution in a room against horizontal window position shifts on the wall. The objectives and motivations of this paper are 1) applying the calculation of the estimated SC on each window shift towards the measuring point; 2) testing the DF distribution based on SC to the three types of room geometry commonly designed by architects.

Based on the explanation above, this paper seeks optimization of Daylight Factor by shifting the position of the window openings horizontally in the room, to get the best window position. The optimization calculation process uses the mean distribution of each window shift in the room by comparing the value of the variant. Using mathematical, statistical analysis, the value of the object that has the highest mean value with the ratio of the lowest variance value, the object has optimization will be considered the best.

This paper is organized as follows. Section 2 describes the estimation of DF based on SC. Section 3 describes the six positions of the measuring point against the window position and the DF optimization algorithm. In Section 4 test the distribution of 3 types of familiar room characters. Finally, Section 5 concludes the results of the optimization of the DF distribution from testing all three room samples.

2. Preliminaries.

In this section, we will discuss natural lighting estimates and window openings by estimating Daylight Factor quantitation and sky component on Daylight Factor distribution in the room.

2.1. Natural lighting system in the room.

Daylight into the building made into three types, namely direct daylight, diffuse light from a clear sky, and diffuse light from the reflection of the ground or surrounding buildings [13]. The level of natural lighting in a room is determined by the level of illumination of the sky on a flat plane in the open field at the same time. Comparison of natural lighting in the room and flat fields in an open field is determined by the relationship between the measuring point and the light hole [9]. This comparison is useful for predicting areas that get natural light and the amount of light entering space [14]. In general, there are some considerations of openings to distribute natural light into the room. The characteristics of the window, in terms of dimensions and direction on the outside wall of the building, are the most important factors affecting its performance [15]. The type of building, altitude, the ratio of buildings and mass management, and the presence of other buildings around are considerations for selecting lighting strategies [7].

2.2. **Daylight Factor (DF).** Daylight Factor (DF) is the ratio of the value of lighting in the room with the value of outdoor lighting in daylight conditions [16]. The daylight condition in question is the lighting conditions spread evenly or the conditions of the clouds [10]. Daylight calculation factors are generally based on daytime factors regardless of prevailing weather conditions.

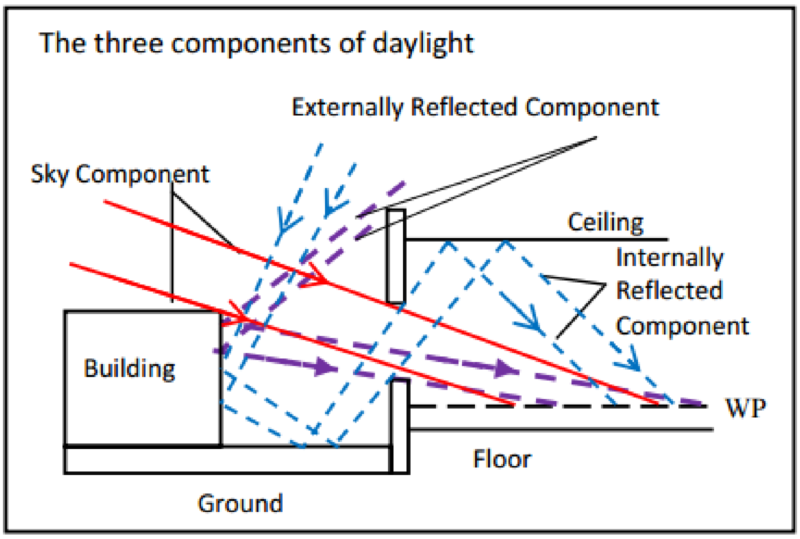


FIGURE 1. Components on Daylight Factor (DF) [10]

Daylight Factor (DF) has three component factors that influence it, namely, Sky Component (SC), External Reflection Components (ERC), and Internal Reflection Components (IRC) [17,18]. The sum of three Daylight Factor (DF) components can be seen in Equation (1).

$$DF = SC + IRC + ERC \tag{1}$$

2.3. **Sky Component (SC) estimation.** Sky Component (SC) is the influence factor of the outer sky, where SC relates to the measuring point with the window. The most significant percentage in DF is influenced by Sky Component [19]. Based on the CIE test [16,20] and SNI 03-2396-2001 [9], SC estimation is measured perpendicular to the window. In Figure 2, SC point $p(x, y, z)$ is located at a distance d perpendicular to the window with size $L \times H$ on the axis z, where H is the height of the window at points $(x_0, 0, z_0)$ and L is the width of the window at the point $(x_0 + L, 0, z_0)$. The SC equation for the position of the measuring point (p) for the window position is stated in Equation (2).

$$g(L, d, H) = \frac{1}{2\pi} \arctan\left(\frac{L}{d}\right) - \frac{1}{\sqrt{1 + \left(\frac{H}{d}\right)^2}} \arctan\left(\frac{\frac{L}{d}}{\sqrt{1 + \left(\frac{H}{d}\right)^2}}\right) \tag{2}$$

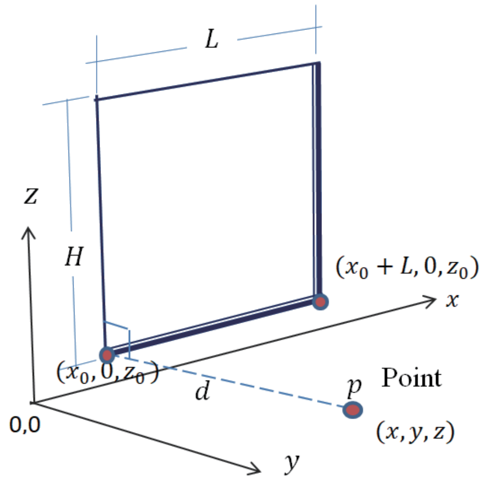


FIGURE 2. Estimated Sky Component (SC) at the measuring point d of the window with height H and width L

2.4. **Daylight Factor based on Sky Component (SC).** The External Reflection Component (ERC) factor in Equation (1) is a factor that is influenced by reflections of objects outside the room (waking up outside space) so that the lighting value is divided into a horizontal plane so that the value of lighting entering the room through the window not the same [21]. In this study, there was no outside wake directly facing or blocking the lighting, so ERC was zero. The reflection factor from inside space (IRC) is a factor that is influenced by reflections of objects that are in space as a result of reflecting objects outside the space and the skylight [16,21,22]. In this study, IRC data is not defined, so IRC is considered zero value.

$$DF = SC \tag{3}$$

Because there is a component value of zero, then from 3 component factors that influence only 1 component, the equation that affects Daylight Factor (DF) is only a Sky Component (SC) factor, which is in Equation (3).

In this section, Daylight Factor (DF) is a percentage value of the lighting distribution and is the sum of the three components that influence it, namely SC, IRC, and ERC. DF is closely related to the position of the window and the size of the window opening to the lighting distribution in the room. When IRC and ERC have no effect or zero value, then $DF = SC$. The SC estimate is measured perpendicular to the window. Thus, there will be several possible measurements of the measuring point against the window position in Section 3 of this paper.

3. Methodology.

3.1. **Position of measuring point on window.** Based on Figure 2, there is an estimate of the sky component, which can only be calculated perpendicular to the window. Then there are six possible conditions for the position of the measuring point against the position of the window.

A. Condition 1: Position of the measuring point (x, y, z) is in between $(x_0, 0, z_0)$ and $(x_0 + L, 0, z_0)$ perpendicular to the y-axis and z-axis.

The reference measurement point DF is shown in Figure 3, the reference point parallel to the edge of the window. The position of the window is in the coordinates x_0, z_0, the length of the window L, the height of the window H with $x_0 < x < x_0 + L$

and $z = z_0$, then

$$SC_1(x, y, z; x_0, z_0, L, H) = g(x - x_0, y, H) + g(x_0 + L - x, y, H) \tag{4}$$

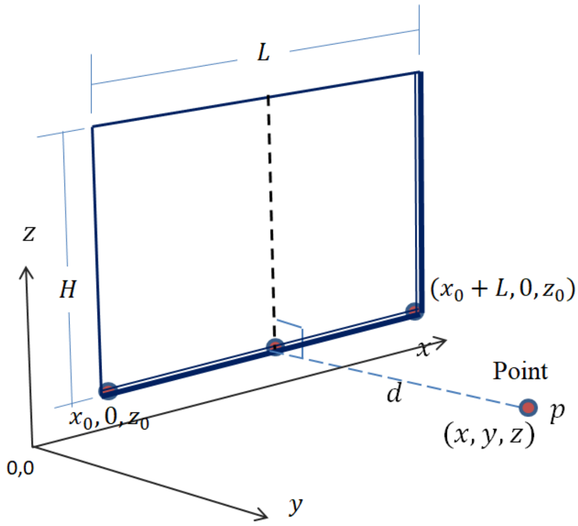


FIGURE 3. Position of measuring point (p) in condition 1

B. Condition 2: The position of the measuring point (x, y, z) is in front of the point $(x_0, 0, z_0)$, perpendicular to the y-axis, and z-axis.

The DF reference measurement point is shown in Figure 4, a certain distance reference point in the left corner of the window. The position of the window in x_0, z_0 coordinates, window length L, window height H, if $x < x_0$ so $z = z_0$, then

$$SC_2(x, y, z; x_0, z_0, L, H) = g(x_0 + L - x, y, H) - g(x_0 - x, y, H) \tag{5}$$

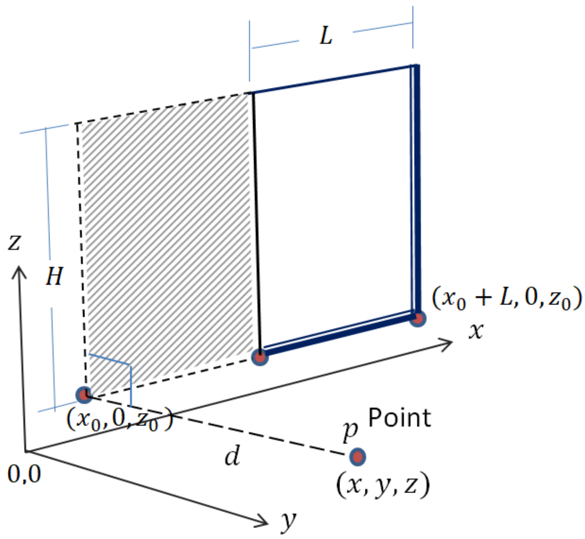


FIGURE 4. Position of measuring point (p) in condition 2

C. Condition 3: Position of the measuring point (x, y, z) is to the right of the point $(x_0 + L, 0, z_0)$ with the width (L) in the direction of the x-axis, perpendicular to the y-axis and z-axis.

The DF reference measurement point is shown in Figure 5, the position of the measuring point (p) in the lower plane of the angle parallel to the right side of the window towards the x-axis with a certain distance (d). The position of the window in the coordinates x_0, z_0, the length of the window L, the height of the window H, if $x_0 + L < x$ and $z = z_0$, then

$$SC_3(x, y, z; x_0, z_0, L, H) = g(x - x_0, y, H) - g(x - x_0 - T, y, H) \tag{6}$$

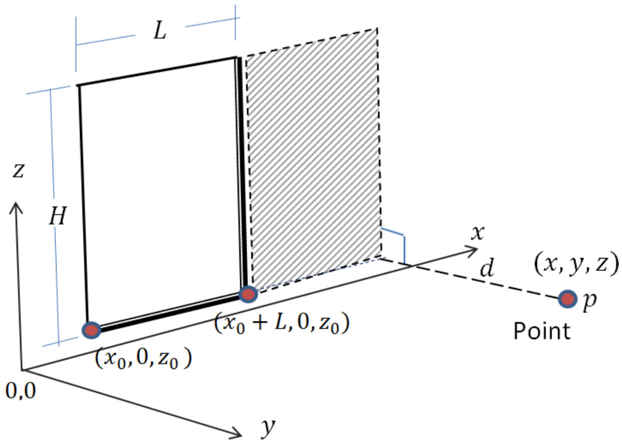


FIGURE 5. Position of measuring point (p) in condition 3

D. Condition 4: The position of the measuring point (x, y, z) is between $(x_0, 0, z_0)$ and $(x_0 + L, 0, z_0)$ below the window with height (H), perpendicular to the y-axis and z-axis.

The reference measurement point DF is shown in Figure 6, the position of the measuring point (p) is in the lower x-axis of the window with a certain height (H) from the bottom center of the spaced window (d) towards the y-axis perpendicular to the z-axis. Position of the window at coordinates x_0, z_0, if $x_0 < x < x_0 + L$ and $z < z_0$, then

$$\begin{aligned} &SC_4(x, y, z; x_0, z_0, L, H) \\ &= g(x - x_0, y, z_0 + H - z) + g(x_0 + L - x, y, z_0 + H - z) \\ &\quad - g(x - x_0, y, z_0 - z) - g(x_0 + L - x, y, z_0 - z) \end{aligned} \tag{7}$$

E. Condition 5: The position of the measuring point (x, y, z) is to the left of the point $(x_0, 0, z_0)$ near the point $(0, 0)$ below the window with a certain height (H) and width (L) towards the y-axis and z-axis.

The reference measurement point DF is shown in Figure 7, the position of the measuring point (p) parallel to the y-axis spacing (d) with a certain width (L) from the bottom corner of the left window parallel to the x-axis with height (H) approaching position $(0, 0)$. The position of the window in coordinates x_0, z_0 window length, window height H, if $x < x_0$ so $z < z_0$, then

$$\begin{aligned} &SC_5(x, y, z; x_0, z_0, L, H) \\ &= g(x_0 - x, y, z_0 + H) \\ &\quad - g(x_0 - x, y, z_0 + H)(x_0 + L, y, z_0 - z) \\ &\quad + g(x_0 + L - x, y, z_0 - z) \end{aligned} \tag{8}$$

F. Condition 6: The position of the measuring point (x, y, z) is to the right of the point $(x_0 + L, 0, z_0)$ parallel to the x-axis below the window with a certain height (H) and width (L) perpendicular to the y-axis and z-axis.

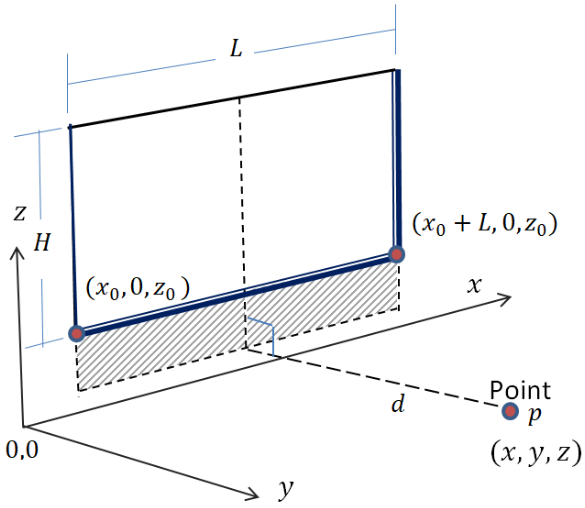


FIGURE 6. Position of measuring point (p) in condition 4

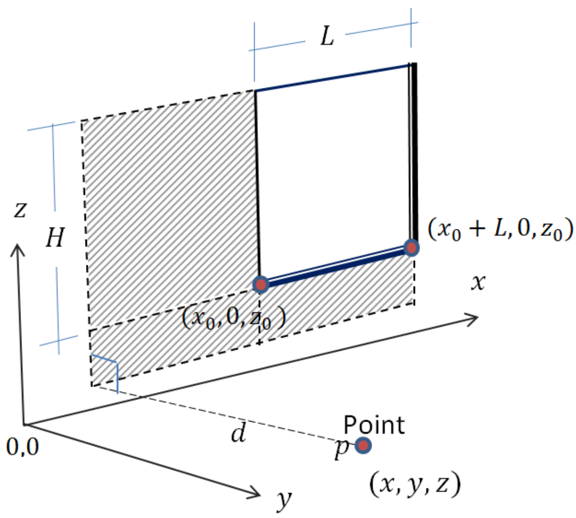


FIGURE 7. Position of measuring point (p) in condition 5

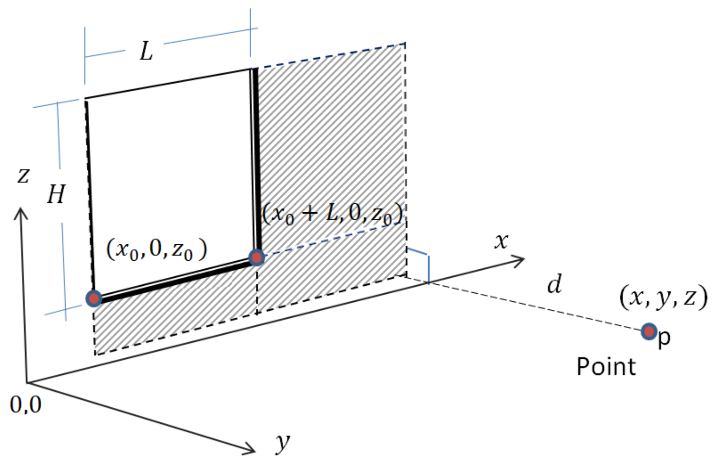


FIGURE 8. Position of measuring point (p) in condition 6

The reference measurement point DF is shown in Figure 8, the position of the measuring point (p) with a distance (d) that is parallel to the y-axis perpendicular to the z-axis with a certain width (L) has a height (H) to the lower right corner of the window. Position of the window is at coordinates x_0, z_0. If $x_0 + L < x$ and $z < z_0$, then,

$$\begin{aligned} &SC_6(x, y, z; x_0, z_0, L, H) \\ &= g(x - x_0, y, z_0 + H - z) - g(x - x_0 - L, y, z_0 + H - z) \\ &\quad - g(x - x_0, y, z_0 - z) + g(x - x_0 - L, y, z_0 - z) \end{aligned} \tag{9}$$

If all possible conditions for the window position apply to the wall area, then the equation for the whole condition is as follows:

$$SC(x, y, z; x_0, z_0, L, H) = \begin{cases} SC_1(x, y, z; x_0, z_0, L, H), & \text{if } x_0 < x < x_0 + L,\ z = z_0 \\ SC_2(x, y, z; x_0, z_0, L, H), & \text{if } x < x_0,\ z = z_0 \\ SC_3(x, y, z; x_0, z_0, L, H), & \text{if } x_0 + L < x,\ z = z_0 \\ SC_4(x, y, z; x_0, z_0, L, H), & \text{if } x_0 < x < x_0 + L,\ z < z_0 \\ SC_5(x, y, z; x_0, z_0, L, H), & \text{if } x < x_0,\ z < z_0 \\ SC_6(x, y, z; x_0, z_0, L, H), & \text{if } x_0 + L < x,\ z < z_0 \end{cases} \tag{10}$$

By using room testing criteria in conditions without any reflection factors from the exterior and interior of the building that affect the distribution of DF in the test room, IRC and ERC are zero and can write in Equation (11).

$$Df(x, y, z; x_0, z_0, L, H) = \int_x \int_y SC(x, y, z; x_0, z_0, L, H)dxdy \tag{11}$$

To find the optimal point of window shift in the wall plane, use Equation (12). The DF optimization function of the window position is:

$$\max_{x_0} \int_x \int_y SC(x, y, z; x_0, z_0, L, H)dxdy \tag{12}$$

Table 1. Sky Component (SC) based Daylight Factor (DF) optimization algorithm

Algorithm 1: Sky Component (SC) based Daylight Factor (DF) optimization
Input: $SC(x, y, z; x_0, z_0, L, H)$
Output: $\max_{x_0} \int_x \int_y SC(x, y, z; x_0, z_0, L, H)dxdy$

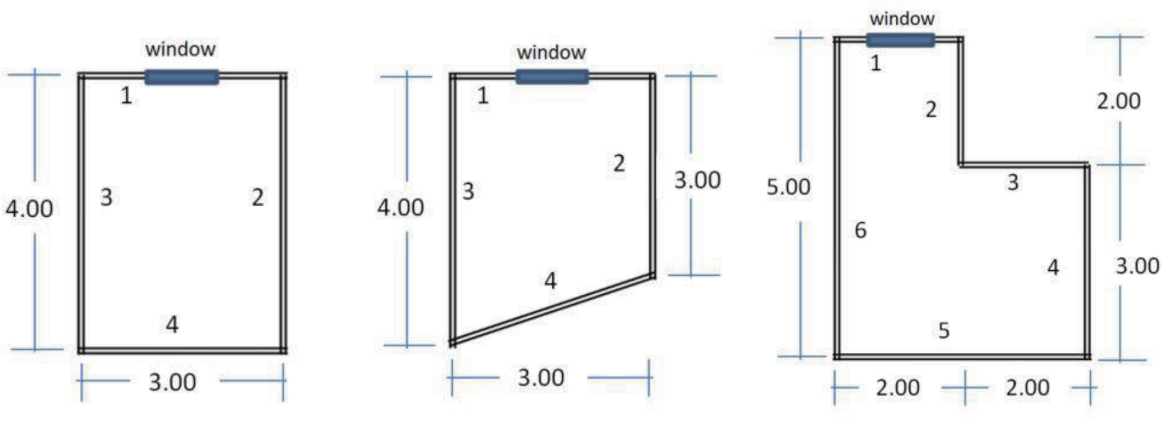
Step 1. Grid division, to determine the measuring point by dividing the room into an $m \times n$ grid.
Step 2. Initialize x_0, z_0 position window, initialization $Df_{\max} = 0$.
Step 3. Position the window in position x_0, z_0 in the window from the left corner of the wall.
Step 4. Calculate the value of DF at the position of the measuring point x, y (Equation (10)).
Step 5. Calculate the value of $Df(x, y, z; x_0, z_0, L, H) = \int_x \int_y SC(x, y, z; x_0, z_0, L, H)dxdy$ where the IRC and ERC value in this research eliminated.
Step 6. If $Df(x, y, z; x_0, z_0, L, H) > Df_{\max}$ then $Df_{\max} = Df(x, y, z; x_0, z_0, L, H)$ $x_{optimal} = x_0$.
Step 7. Slide the position of the window $x_0 = x_0 + Dx$, repeat Step 4.

4. **Results and Analysis.** In this paper, there are differences when compared with some studies that have been done. 1) Present the process of finding the best window position by shifting the position of the window opening in the wall plane to produce an optimization of the Daylight Factor distribution; 2) The process of optimization calculations using mathematics, statistical analysis, the value of objects that have the highest average value with the lowest variance value ratio, the object that has optimization will be considered the best. This section will test with three geometric characters commonly found in architectural design; this is to test the optimization of DF distribution calculations.

4.1. **Three character sample rooms.** To test the function of the algorithm, the author uses three types of geometry of space commonly planned by architects.

1) The character of the rectangular shape is the character of the ample room in the room planning.
2) The character of the room in which one side is not perpendicular to the other plane is the character of the room that occurs due to the use of land due to the geometric conditions of the availability of land.
3) The character of a room combined with two geometric rectangles is one of the standard characters to distinguish between two types of room functions. In this research, the characters taken are letter geometric "L".

This study uses three room characters with different geometric shapes. Of the three types of space that have a wall thickness of 0.15 m, the height of the room is 3 meters, and the size of the room depends on the shape of the room, as described in Figure 9. Window dimensions for openings in the sample of 3 characters are based on SNI 03-2396-2001, then the standard window area is 1/6 of the floor area. In this research, the three rooms will use the same window dimension. The window dimensions used for testing the three rooms are 1.5 m × 1.3 m.



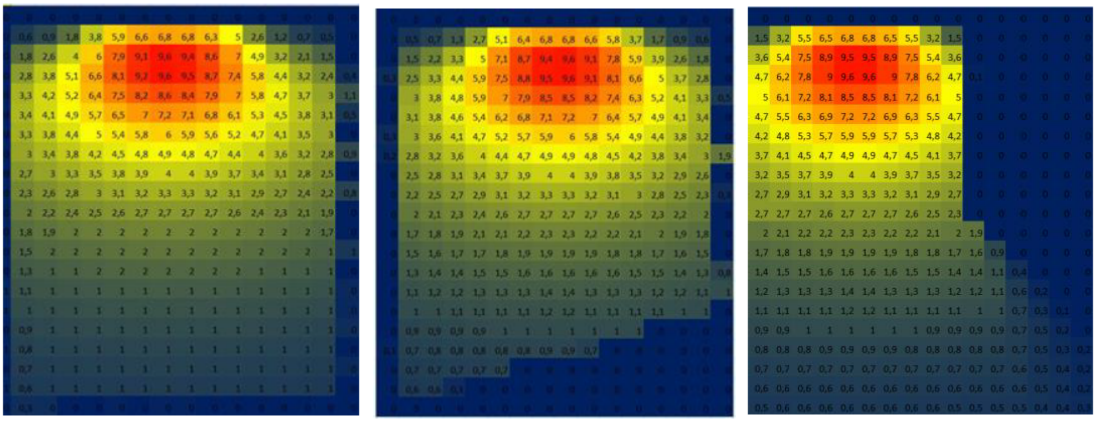
(a) Room 1 (b) Room 2 (c) Room 3

FIGURE 9. Typology of the sample room

1) Room 1, the first room is rectangular. The geometry of a room that commonly applied to buildings, for example, is bedrooms, living rooms, bathrooms, and the like. Room dimensions are 3×4 m^2. Room area is 12 m^2. The position of the window is on the 1st wall. The window area is 1.95 m^2 with dimensions of 1.5 m × 1.3 m.
2) Room 2, the second room is rectangular, where one of the fields is not as long as the other. The shape of a room like this is usually made because of sloping land conditions or architect design concepts. Room size is 10.5 m^2 – the position of the window on the 1st wall. The window area is 1.95 m^2 with dimensions of 1.5 m × 1.3 m.

3) Room 3, the third room has a geometric space in the form of an "L" letter. This space, usually in architectural works, often appears in residential building designs. The third room has an area of 16 m^2 – the position of the window on the 1st wall. The window area is 1.95 m^2 with dimensions of 1.5 m $\times$ 1.3 m.

4.2. **Distribution of Daylight Factors.** Testing the three sample rooms is accompanied by shifting the position of the window in the same field in each sample space based on Equations (1) to (11). Shifting the window parallel to the x-axis, then the DF distribution can get a window optimization position, which will show with the graph. Based on the distribution of DF in Figure 10, it analyzed that each direction of the window shift from each space affects the DF distribution value in the room. The process of shifting the window is 0.1 m from the left side of the window to the right side of the window. From the distribution results, the search process calculates using Equations (1) to (11) according to the methodology. The Daylight Factor distribution shown in Figure 10 has colors in each distribution. Dark blue shows the smallest presentation of DF value of 0%, light blue shows presentation of DF value 0.6%-1.2%, green indicates DF value 1.3%-3.1%, yellow indicates presentation of DF value 3.2%-5.3%, and the red shows the presentation of the highest DF value of 5.4% and above. From these colors, it can represent and make it easier to see the distribution of Daylight Factor distributions per space with variations in window shifts.



(a) Room 1 (b) Room 2 (c) Room 3

FIGURE 10. (color online) Daylight Factor distribution in all three sample rooms

4.3. **Results and analysis of Daylight Factor optimization.** After obtaining the Daylight Factor distribution value in each room with different window positions, the next step is to calculate the mean and variance in each room with a different window position. The calculation of the mean and variance has the purpose of analyzing the optimization of the best room in each position where the window placed. The position of the window in the room that has the highest mean value and has a small value of the variance, the position of the placement of the window is considered the most optimal of each space. Of the three spaces, financial analysis is as follows.

1) Room 1. In Figure 11, the window position is 0.80 m from the left wall with a wall width of 3 m, indicating the highest mean value is 2.50%. The lowest variance value is 5.27%. Based on the graphic image in Figure 11, the most optimal window position is located at 0.80 m from the left wall of the window, with the highest mean value of 2.50% and the variance value that approaches the lowest value of 5.27%.

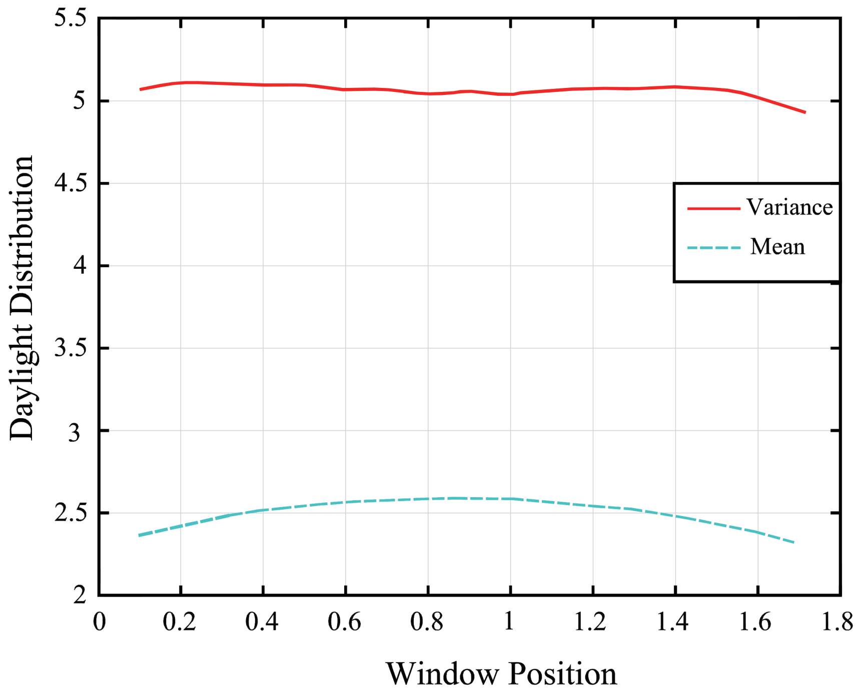


FIGURE 11. Variance and mean graphs, DF distribution in Room 1

2) Room 2. In Figure 12, the position of the window is 0.89 m from the left wall with a wall width of 3 m, indicating the mean is 2.85%. The lowest variant value is 5.33%. Based on the graphic image in Figure 12, the most optimal window position is located at the position of 0.89 m from the left wall of the window, with the highest mean value of 2.85% and the variance value, which is near the smallest value of 5.33%.

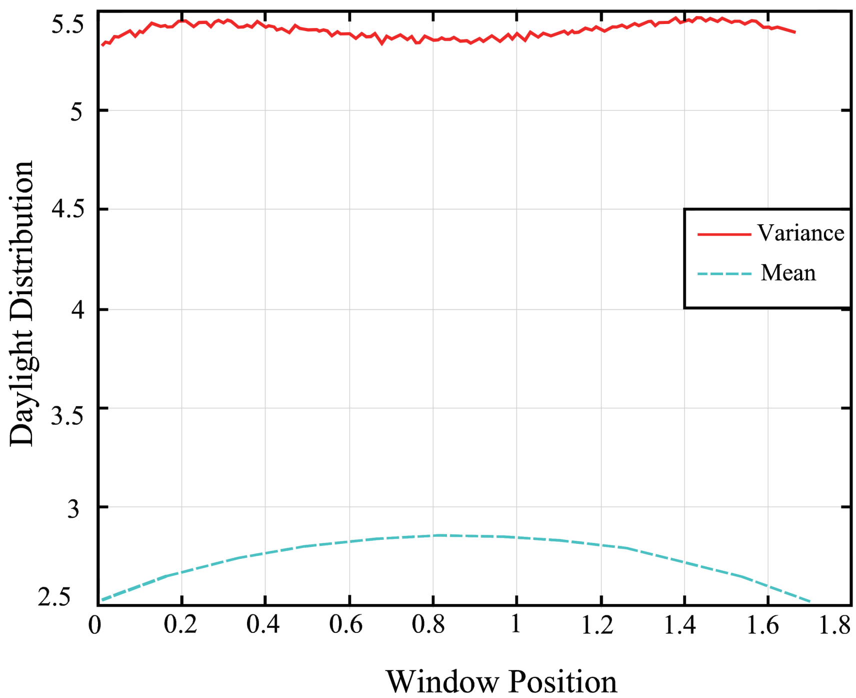


FIGURE 12. Variance and mean graphs, DF distribution in Room 2

3) Room 3. In Figure 13, the position of the window is 0.31 m from the left wall with a wall width of 2 m, indicating the highest mean value is 1.65%. The lowest variant value is 4.89%. Based on the graphic image in Figure 13, the most optimal window position is located at 0.31 m from the wall to the left of the window, with the highest mean value of 1.65% and the variance value close to the lowest value of 4.89%.

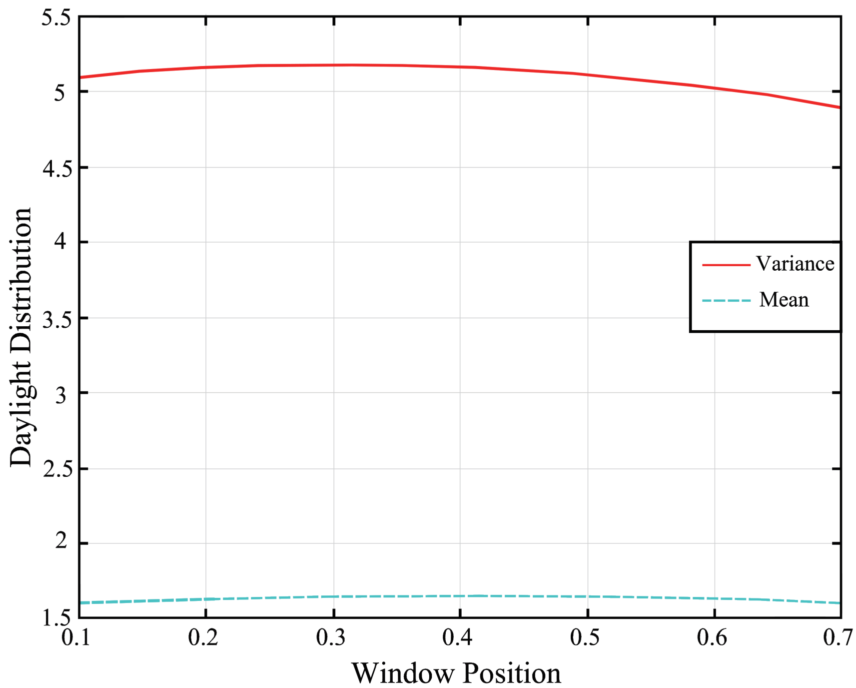


FIGURE 13. Variance and mean graphs, DF distribution in Room 3

From the results of the optimization analysis of Daylight Factor distribution on the position of the window, it can illustrate the position of the distance of the window from the left wall of each space in Figure 14.

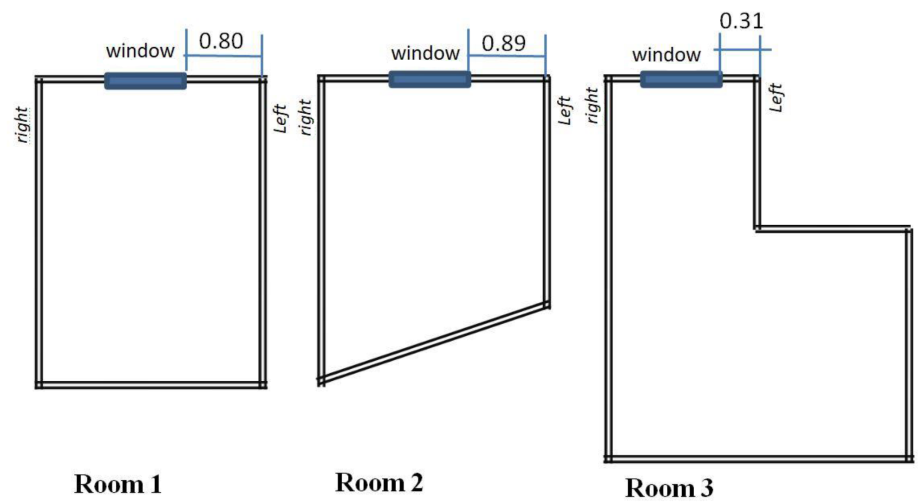


FIGURE 14. Position of the window in each sample room

5. **Conclusion.** It is concluded that the shifting position of the window could affect the distribution value of DF in the room. As was done in the experiment above that the position of the window horizontally changed from each room and the most optimal value is based on the average value and variance based on Daylight Factor distribution in each room. The room that has the highest mean value and the smallest variance value is considered the most optimal daylight distribution room and has the best window position in each room. In this study, the factor used to look for DF is only on Sky Component (SC) because other factors are ignored or considered 0. Moreover, the results of this study concluded that in each room, the optimal positioning position is as follows.

1) In the optimal room 1, window position is based on the mean value, and the variance located at the position of 0.80 m from the left wall with a wall width of 3 m, with a mean of 2.50% and the lowest variance value of 5.27%.
2) In the optimal room 2, window position is based on the mean value and the variance located at the position of 0.89 m from the left wall with a wall width of 3 m, with a mean value of 2.85% and the lowest variance value of 5.33%.
3) In the optimal room 3, window position is based on the mean value and the variance located at the position of 0.31 m from the left wall with a wall width of 2 m, with a mean value of 1.65% and the lowest variance value of 4.89%.

From the results of this study, the search for the optimization value of the positioning of this window can continue to develop into further research on the characteristics of the room and the number of window openings. This research can also be used as a reference for architects in making or designing window positions to get the most optimal or best distribution value.

Acknowledgment. This research is fully funded by the Indonesian Ministry of Research, Technology, and Higher Education with Postgraduate Domestic Education Scholarships (BPP-DN).

REFERENCES

[1] R. Looman, *Climate-Responsive Design: A Framework for an Energy Concept Design-Decision Support Tool for Architects Using Principles of Climate-Responsive Design*, Technische Universiteit Delft, Delf, 2017.
[2] P. Manurung, *Natural Lighting in Architecture*, C. V. ANDI OFFSET, Yogyakarta, 2012.
[3] N. Shishegar and M. Boubekri, Natural light and productivity: Analyzing the impacts of daylighting on students' and workers' health and alertness, *Int. J. Adv. Chem. Eng. Biol Sci.*, vol.3, no.1, pp.1-6, 2016.
[4] G. Loisos, Daylighting in Schools, *Georg. Loisos Pacific Gas Electr. Co. behalf Calif. Board Energy Effic. Third-Party Progr.*, vol.1999, no.1, p.140, 1999.
[5] A. Sujudi, *Decree of the Minister of Health of the Republic of Indonesia No: 1405/MENKES/SK/XI/2002 Concerning Health Requirements for Office and Industrial Work Environments*, Jakarta, 2002.
[6] D. Phillips, *Daylighting: Natural Light in Architecture*, 1st Edition, Architectural Press, 2004.
[7] IEA, Daylight in buildings, *Task 21/ECBCS Annex 29*, vol.03, no.3, p.262, 2000.
[8] K. Alhagla, A. Mansour and R. Elbassuoni, Optimizing windows for enhancing daylighting performance and energy saving, *Alexandria Eng. J.*, vol.58, no.1, pp.283-290, 2019.
[9] S. Eriksson and L. Waldenström, *Daylight in Existing Buildings a Comparative Study of Calculated Indicators for Daylight*, Chalmers University of Technology, pp.1-64, 2016.
[10] Y. Rizal, I. Robandi and E. M. Yuniarno, Daylight factor estimation based on data sampling using distance weighting, *Energy Procedia*, vol.100, pp.54-64, 2016.
[11] A. Mangione, B. Mattoni, F. Bisegna, D. Iatauro and M. Zinzi, On the validity of daylight factor for evaluating the energy performance of building, *Proc. of 2018 IEEE Int. Conf. Environ. Electr. Eng. and 2018 IEEE Ind. Commer. Power Syst. Eur. EEEIC/I CPS Eur. 2018*, pp.1-4, 2018.

[12] J. Mohelnikova and J. Hirs, Effect of externally and internally reflective components on interior daylighting, *J. Build. Eng.*, vol.7, pp.31-37, 2016.
[13] S. S. A. Krishan, N. Baker and S. Yannas, *Climate Responsive Architecture – A Design Handbook for Energy Efficient Building*, Tata McGraw-Hill Publishing Co. Ltd., New Delhi, 2001.
[14] L. Díaz-Vilariño, S. Lagüela, J. Armesto and P. Arias, Indoor daylight simulation performed on automatically generated as-built 3D models, *Energy Build.*, vol.68, Part A, pp.54-62, 2014.
[15] N. Y. Azmy and R. E. Ashmawy, Effect of the window position in the building envelope on energy consumption, *Int. J. Eng. Technol.*, vol.7, no.3, pp.1861-1868, 2018.
[16] J. Mardaljevic and J. Christoffersen, 'Climate connectivity' in the daylight factor basis of building standards, *Build. Environ.*, vol.113, pp.200-209, 2017.
[17] D. Ananthakrishnan, Daylighting, calculating the daylight factor, *ABS 643*, pp.1-13, 2011.
[18] I. Acosta, C. Varela, J. F. Molina, J. Navarro and J. J. Sendra, Energy efficiency and lighting design in courtyards and atriums: A predictive method for daylight factors, *Appl. Energy*, vol.211, pp.1216-1228, 2018.
[19] CIBSE London, Daylighting and window design, *The Chartered Institution of Building Services Engineers London*, vol.LG10_1999, pp.8-98, 1999.
[20] T. N. Seshadri, Equations of sky components with a "C.I.E. standard overcast sky", *Proceedings of the Indian Academy of Sciences – Section A*, vol.51, no.5, pp.233-242, 1960.
[21] I. Ashdown, *Daylight Factors*, Lighting Analysts. Inc, No. March, pp.1-9, 2014.
[22] P. Nováková and F. Vajkay, Factors influencing the value of daylight factor, *MATEC Web Conf.*, vol.279, p.03009, 2019.