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OPTIMIZATION STUDY OF VISUAL COMFORT AND DAYLIGHT AVAILABILITY AT CADL ITB

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ABSTRACT

One way to reduce energy consumption in buildings is to use daylighting. However, daylight can cause visual discomfort in the form of glare. Center of Art, Design, and Language (CADL) Institut Teknologi Bandung is a building that has windows on west and east facades, so the probability of glare occurrence is high. In this research, CADL was optimized so that the percentage of time that Daylight Glare Probability below 0.21 (%DGP<0.21) is more than 50% and spatial daylight autonomy with illuminance 150 lux and 50% (sDA150$_{lux,50\%}$) is more than 30%. In the optimization, vertical blinds, horizontal blinds, and curtains were added. Vertical blinds and horizontal blinds were varied by changing the blade's opening angle and area covering the windows, while curtains were varied only by changing the area covering the windows. The results show that %DGP<0.21 can be increased beyond 50%, but in some rooms, sDA$_{150,50\%}$ also decrease below 30%. The most frequent optimum solutions are vertical blinds 75%-60^o.

Keywords: Daylight; glare; spatial daylight autonomy.

INTRODUCTION

Nowadays, energy saving becomes one of the most important topics because it makes many problems, such as global warming (Ghiaus & Inard, 2004). Buildings consume much energy that is used for lighting. Therefore, one way to reduce energy consumption in buildings is used daylighting. Daylighting has advantages and disadvantages. The advantage of using daylighting is creating a healthy and productive working environment for workers. On the other hand, the disadvantages are thermal and visual discomfort. Visual discomfort occurs in the form of glare and the temperature of buildings will increase because of daylighting (Aries et al., 2010). Visual comfort can be predicted using illuminance and luminance. Prediction using luminance is more accurate than using illuminance because human eyes perception to illumination from an object can be predicted more accurate using luminance (Inanici, 2014). One of the methods to evaluate visual comfort is High Dynamic Range (HDR) technique. The principle of HDR is taking multiple exposures of one object and combine. The combination of those images will have a large range of luminance that called High Dynamic Range image. HDR image can be used to measure Daylight Glare Probability (DGP). Glare occurs because of high intensity of daylight in human's field of view. To reduce glare means reducing the intensity of daylight. Reducing daylight will reduce the daylight availability. This research was conducted to obtain the optimal design for a newly constructed building at a university in Bandung, Indonesia. The optimal criteria for this research are the percentage of time that glare occurred in a year is minimum and daylight availability is maximum.

LITERATURE

Daylight Autonomy

Daylight Autonomy is defined as the percentage of occupied times in the year during which minimum, task specific illuminance levels can be met by daylight alone. The IESNA committee recommends a target illuminance 300 lx for typical offices, class-rooms, and library, and a minimum DA of 50% of the occupied times of the year (in notation: DA$_{300lx}$ 50%).

Spatial Daylight Autonomy

Spatial Daylight Autonomy is a metric that shows daylight availability in a room in a year. sDA is calculated as the percentage of the area which met the minimum criteria of occupied times in the year compared to the total area. Minimum criteria are using DA$_{300lux}$ 50% (in notation: sDA$_{300lux,50\%}$). This research used sDA$_{150,50\%}$ because according to Mangkuto et. al. (2016), Indonesian people may perceive that lower illuminance is sufficient than that prescribed in the standard. According to Greenship Building Council Indonesia, minimum area that should be met minimum criteria is 30%.

Daylight Factor

Daylight Factor (DF) is the ratio between horizontal illuminance on the work plane in a room and horizontal illuminance on an exterior, unobstructed field at the same time under the CIE overcast sky. Daylight factor can be written in equation (1).

$$DF = \frac{E_i}{E_o} \times 100\% \tag{1}$$

where:
E_i = Indoor horizontal illuminance (lux)
E_o = Outdoor horizontal illuminance (lux)

Daylight factor has some limitations, as it does not consider the window orientation and the geographical location of the building.

Daylight Glare Probability

Daylight Glare Probability (DGP) is a glare index applied to measure glare from daylighting. In DGP, glare sources are determined by comparing areas of bright luminance against the total vertical eye illuminance for a viewing hemisphere of 2π sr. DGP can be written in equation (2)

$$\mathrm{DGP} = 5.87 \times 10^{-5}\,\mathrm{E_v} + 9.18 \times 10^{-2} \log_{10}\left(1 + \sum_i \frac{L_{s,i}^2 \omega_{s,i}}{E_v^{1,87} P_i^2}\right) + 0.16 \tag{2}$$

where:
E_v = Vertical eye illuminance [lux]
L_s = Luminance from sources [cd/m^2]
$\omega_{s,i}$ = Solid angle [sr]
P = Position index

Glare rating based on DGP according to Wienold can be seen in Table 1.

Table 1. Glare Rating Based on DGP

Glare Rating	DGP
Imperceptible	<0.35
Perceptible	0.35-0.4
Disturbing	0.4-0.45
Intolerable	>0.45

Hirning et al. (2014) published the findings of their study in office buildings in Australia with 64 respondents. They found some correlations between the glare index and subjective perception. The result shows that DGP < 0.21 is considered comfort and DGP > 0.21 is discomfort.

High Dynamic Range Image

High Dynamic Range Image (HDR) is an image resulting from the merger of several images with different exposure to produce images with a broad range of luminance. Inanici (2006) has shown that HDR images can be applied as a system to acquire data of the luminance of every pixel. HDR image has a significant advantage to collect luminance data, since one can determine luminance value at a wide field of view, compared to using a handheld luminance-meter that has a small viewing angle (< 2^o). HDR image can also be applied to evaluate visual comfort. The HDR image can be further processed to determine the value of the luminance distribution or glare index.

METHODOLOGY

Overview of the test site

The study was conducted at Center of Art, Design and Language (CADL) Building at Institut Teknologi Bandung (6^{o}55'N and 107^{o}E), which is adjacent to the PAU building, the highest building at ITB. Eight rooms were chosen from the upper floors (6 & 7). These rooms were A&M2, M2, DKV2, MM Laboratory, DP1, DP2, PSDI1, and PSDI2. As shown in Figure 1, four rooms are located on the 6th floor and four rooms are on the 7th floor. There are four rooms located on the west side and four on the east side. In all of these rooms, windows are installed on the west and east façades, except DP1 and PSDI1, which have additional windows on north façade.

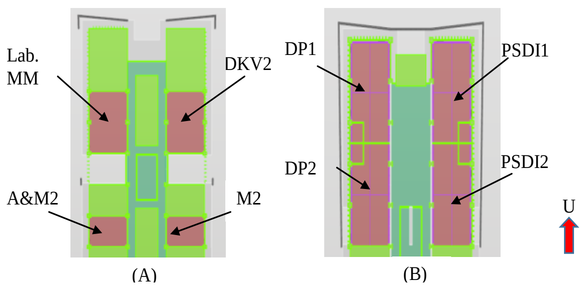


Fig. 1. Floor plan of (A) the 6th floor and (B) the 7th floor

Each room has a different condition. A&M2 and M2 have a window with an area of 5.7 m^2 with no blinds. MM Lab. and DKV2 have a window with an area of 11.5 m^2. At MM Laboratory, venetian blind has been installed while at DKV2 curtains have been set on one of the windows. DP2 and PSDI2 have a window with an area of 11.0 m^2. Curtain have been set at DP2 whereas at PSDI2 no blinds or curtains are found. The north façade windows at DP1and PSDI1 have an area of 7.4 m^2, while the west and east façade windows have an area of 11.0 m^2. At DP1, only the east façade window is provided with a curtain, while at PSDI1 there are no blinds or curtains.

Data Collection

The required data such as material reflectance and transmittance, daylight factor and HDR image were collected on 30th April 2016 at 08.30 until 16.00 western Indonesian time.

Daylight Factor

Daylight factor was measured on 90 points spread in 3 rooms (PSDI2, DP2, and DKV2) with two lux meters Lutron LX-103 and one lux meter HiTester Hioki. The measurement points were located at 80 cm above the floor with the distance between the points of 1.5 m. The result of daylight factor measurement was employed to validate the created model.

HDR Image

Images were taken on 11 capture-points using Canon EOS 5D Mark II DSLR camera with fisheye lens, positioned at 1.2 m above the floor. The camera was set to ISO 100 and f 1/5.6 while the shutter speed was varied. The shutter speed values used were 1/1600 s, 1/400 s, 1/250 s, 1/125 s, 1/100 s, 1/60 s, 1/30 s, 1/15 s and 1/8 s.

The images collecting process was also combined with luminance measurement using Konica Minolta LS-110 that were also positioned at 1.2 m above the floor. The luminance values were measured right before and after the images were taken to minimize difference due to the variation of the sky condition. The measured luminance values were used as a reference to create the HDR images. The obtained images were then processed to create HDR images using *Photosphere*. These HDR images were processed further to yield information about glare indices.

Modeling and Simulation

The building model was made using *Rhino* and simulated using *DIVA-for-Rhino*, while the daylight simulation was performed using *Daysim*. The constructed model consisted of CADL and PAU buildings. The PAU building was modeled too because it is higher than the CADL building. Therefore its height may affect the simulation result. The material properties used in the simulation are displayed in Table 2.

Table 2. Material Used in Simulation

Object	R	G	B	Spe-cular	Rough-ness
Ceiling	0.8	0.8	0.8	0	0
CADL inner wall: green	0.652	0.9	0.329	0	0
CADL inner wall: white	0.6	0.6	0.6	0	0
PAU outer wall	0.69	0.527	0.328	0	0
Window frame: black	0.136	0.102	0.083	0.3	0.2
Window frame: white	0.487	0.481	0.436	0.3	0.2
Wooden door	0.54	0.7	0.162	0	0
Railing	0.259	0.276	0.27	0.3	0.2
Inner room floor	0.76	0.411	0.084	0.045	0
Outer room floor	0.35	0.35	0.35	0.045	0

Before simulating the model, the specific location, simulation points and parameters need to be determined first. Location of the building determines the choice of specific weather or climate data file as simulation input. In this research, the weather data of Bandung was used. Simulation points were the same with measurement points, 80 cm above the floor and at 1.5 m distance between points to calculate the daylight factor. Additional points were introduced to calculate sDA, so that the result is more accurate. For calculating sDA, the simulation points were 80 cm above the floor and at 1 m distance between points. The simulation parameters in *Daysim* were set as shown in Table 3.

Table 3. Simulation Parameters Setting

Parameter	Simulation
Ambient bounce (ab)	5
Ambient division (ad)	1000
Ambient super samples (as)	20
Ambient resolution (ar)	300
Ambient accuracy (aa)	0.1

Optimization

Optimization was done by adding curtains, venetian blinds or vertical blinds to the windows. Variations of vertical and horizontal blinds were realized by varying the blade's opening angle and the area covering the windows, while those of the curtains were realized by varying only the surface area covering the windows. Blade's opening angle used in the optimization were 15°, 30°, 45°, 60°, 75° and 90°. Variations of the surface area covering the window both horizontally and vertically were 25%, 50%, 75% and 100%. Illustration of these variations can be seen in Figure 2. Moreover, the material properties used for the curtains, vertical blinds, and venetian blinds are displayed in Table 4.

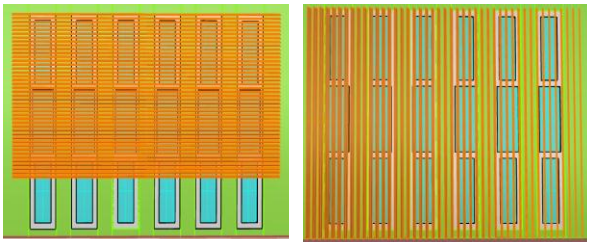


Fig. 2. (A) Venetian Blinds 75%-60°, (B) Vertical Blinds 100%-60°

Table 4. Curtain and Blinds Material

Object	R	G	B	Spe-cular	Rough-ness	Trans missivity	Specular Trans-mittance
Venetian blinds	0.52	0.52	0.52	0.15	0.05	0	0
Curtains	0.033	0.042	0.158	0	0	0	0
Vertical Blinds	0.53	0.53	0.53	0	0	0.15	1

Optimization was done on the eight rooms with ten optimization points. Each point was placed in each room to calculate the percentage of glare that occurs within one year. DP 1 and PSDI 1 had two optimization-points to calculate the percentage of glare that occurs within one year since both rooms had windows on two facades. The location of optimization points in the rooms are displayed in Table 5.

Table 5. Location of the optimization point

Optimization-point 1	M2	Optimization-point 6	DP1
Optimization-point 2	A&M2	Optimization-point 7	DP1
Optimization-point 3	DKV2	Optimization-point 8	PSDI1
Optimization-point 4	MM laboratory	Optimization-point 9	PSDI1
Optimization-point 5	DP2	Optimization-point 10	PSDI2

RESULTS and DISCUSSION

Glare Identification

Figure 3 shows the DGP results at 11 HDR capture-points. The graph indicates that all of the points have DGP > 0.23. According to Hirning et al. (2013), subjects perceive visual discomfort when average DGP value is more than 0.23.

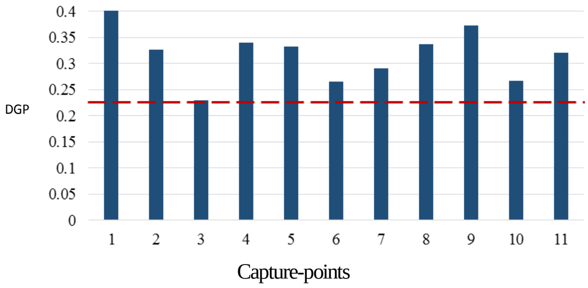


Fig. 3. DGP at the HDR capture-points

Model Validation

The model was validated by comparing daylight factors from the measurement and simulation. There are 90 points to be compared. Daylight fight factor was chosen as validating metric because it is relatively static, as long as the assumption of CIE overcast sky holds. Moreover, daylight factor also considers the internally and externally reflected components. The measurement of daylight factor has an average value 1.3%, with a maximum of 4.4% and a minimum of 0.4%. Meanwhile, the simulated daylight factor has an average value of 1.2%, with a maximum of 3.8% and a minimum of 0.5%.

The statistical *t*-test was applied to validate the model. The result shows that *t*-critical (1.97) > *t*-stat (0.63) so that the model is deemed valid and can be used for further analysis.

Table 6. Statistical *t*-test result

	Measurement	Simulation
Average	1.3	1.2
Variance	0.7	0.6
Observation	90	90
Df	178	
t-stat	0.63	
P(T<=t)	0.53	
t-critical	1.97	

Initial Glare and Daylight Availability Condition

Initial glare condition was evaluated by simulating every room without any curtains or blinds.

Table 7. Initial Glare and Daylight Availability Condition by Simulation

Optimization point	$\%DGP_{<0,21}$ (%)	$sDA_{150,50\%}$ (%)	Optimization point	$\%DGP_{<0,21}$ (%)	$sDA_{150,50\%}$ (%)
1 (M2)	21.0	60	6 (DP1)	27.9	64.3
2 (A&M2)	29.1	40	7 (DP1)	27.9	64.3
3 (DKV)	41.5	55.6	8 (PSDI1)	33.7	60.3
4 (Lab. MM)	26.5	100	9 (PSDI1)	33.7	60.3
5 (DP2)	28.9	37.8	10 (PSDI2)	37.6	25.2

Table 7 shows that every room has a risk of visual discomfort, because their $\%DGP_{<0.21}$ is lower than 50%. $sDA_{150,50\%}$ value for every room fulfill the criteria because the value is higher than 30%, except for one room (PSDI2). The conclusion is that daylight condition in every room needs to be optimized so that $\%DGP_{<0.21} > 50\%$.

Pareto Front

The optimal solution is determined by considering the $sDA150_{lux,50\%}$ and $\%DGP_{<0.21}$. In a multi-objective problem, there will be no unique solution that satisfies all criteria, so that the optimization needs to be performed by finding the solution set that is not dominated by other solutions, which is known as the Pareto front. Based on the criteria of optimization, the optimization function can be written as follows:

- max $sDA_{150,50\%}$
- max $\%DGP_{<0.21}$

s.t.: $sDA_{150,50\%} \geq 30\%$ and $\%\ DGP_{<0.21} \geq 50\%$ (3)

Some results showing the Pareto front are displayed in Figure 4.

From the Pareto fronts, three best solutions were then determined. The Pareto Front are selected by seeking the optimum solution that meets the criteria of optimization. If there is more than one optimum solution that satisfies the criteria of optimization, the optimal solutions were sorted according to the distance to the point of utopia (x_{utopia}), after which three solutions with the smallest x_{utopia} were taken. Conceptually, utopia point is the location of the ideal solution to be achieved, but cannot be achieved in reality because of the conflicting objectives. In this case, the utopia point is defined by $sDA_{150lux,50\%}$ = 100% and $\%\ DGP_{<0.21}$ = 100%. The equation of x_{utopia} is:

$$x_{utopia} = \sqrt{(100 - \mathrm{sDA}_{150\mathrm{lux},50\%})^2 + (100 - \%\mathrm{DGP}_{<0.21})^2} \quad (4)$$

At the optimization point 6, 7, 8, and 9, the selection of the three best optimum solutions is different from the other optimization point. This is because the optimization points 6 and seven are located in one room, as well as the optimization points 8 and 9. If the optimization point is shown in Figure 4 (c) and (d) which illustrates the results of the simulation optimization point 6 and 7, the distribution of the solution is slightly different. This difference occurs because the allocation of both windows influences the simulation results. As an illustration, if the window in front of optimization-point 6 is entirely covered by curtains and the window in front of the optimization point 7 is varied by the surface area covering the window, then the value $\%\ DGP_{<0.21}$ at optimization-point 6 is maximum and $sDA_{150lux,50\%}$ varies in accordance with the window opening of the window in front of optimization-point 7. Determination of the top three Pareto front at these optimization-points was done to find an intersection between the two optimization points on the Pareto front. The results of these intersections were then sorted to obtain a better result.

The top three Pareto front solutions can be seen in Table 8. The optimum solution is the horizontal blinds 100%-60°, which occurs five times. Among 30 optimum solutions at ten points, eighteen use horizontal blinds. However, horizontal blinds only emerge as the best solution at four points.

Comparison After and Before Optimization

Curtains or blinds addition will affect the value $sDA_{150lux,50\%}$ and $\%\ DGP_{<0.21}$. This can be seen in Table 9 which shows the comparison before and after the optimization simulation. The results indicate that the addition of curtains or blinds will increase the value of $\%\ DGP_{<0.21}$ as well as lower the value of $sDA_{150lux,50\%}$.

From Table 9, it can be seen that the optimum solution achieved for all optimization-points has the percentage of time $\%DGP_{<0.21}$ greater than 50%. However, there are two optimization-points (5 and 10) which have $sDA_{150,50\%}$ smaller than 30%. These points already have $sDA_{150,50\%}$ below the criteria before the optimization. Optimization-point 10 has a value $sDA_{150.50\%}$ below 30% and the 5 point $sDA_{150,50\%}$ optimization has a value close to 30% (37.8%).

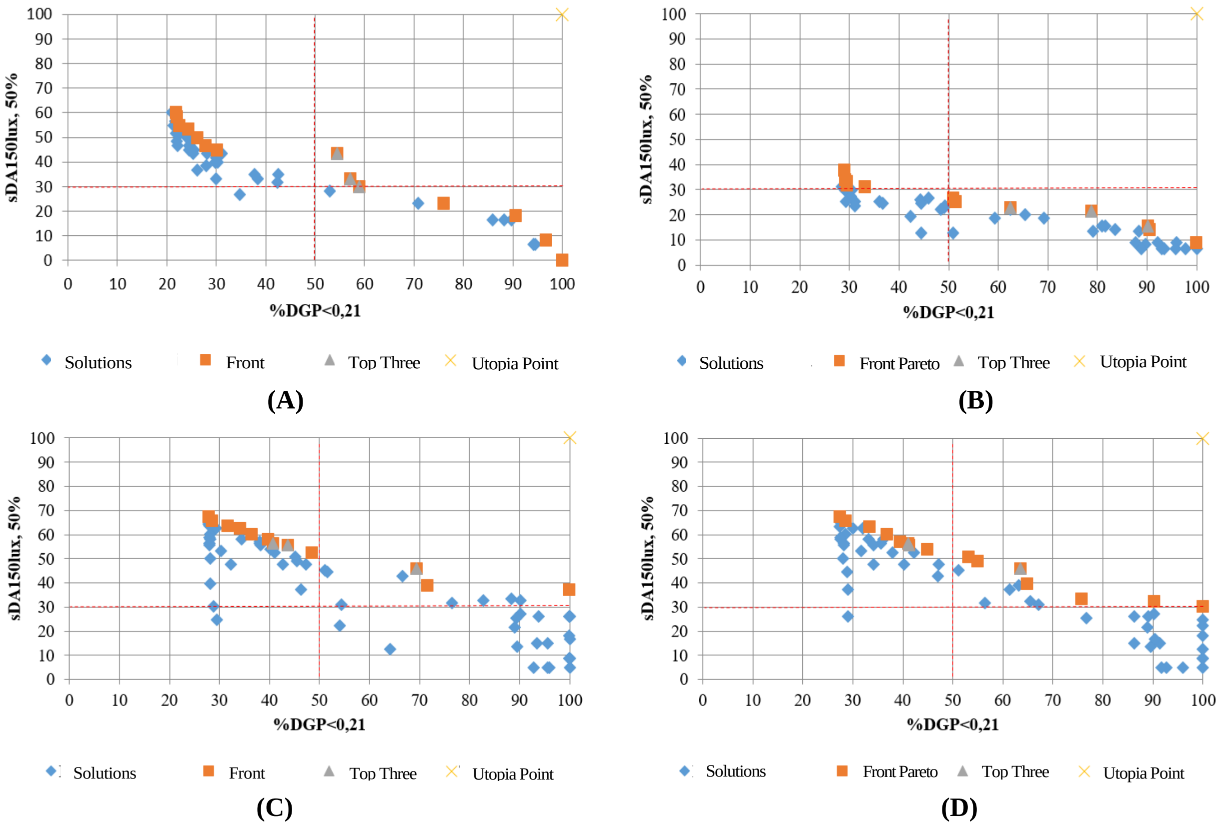


Fig. 4. (A) Pareto Front at Optimization-point 1 (B) Upper Right: Pareto Front at Optimization-point 5 (C) Lower Left: Pareto Front at Optimization-point 6 (D) Lower Right: Pareto Front at Optimization-point 7

Table 8. Top Three Solutions

Optimization point	Explanation	$\%DGP_{<0,21}$ (%)	$sDA_{150,50\%}$ (%)	x_{utopia}(%)
1 (M2)	Horizontal blinds 75%-60°	54,4	43,33	72,7
	Horizontal blinds 100%-45°	57,1	33,3	79,3
	Horizontal blinds 50%-15°	59,0	30	81,12
2 (A&M2)	Horizontal blinds 100%-60°	51,4	30	85,2
	Horizontal blinds 100%-45°	74,0	25	79,4
	Horizontal blinds 75%-30°	79,5	21,7	81,0
3 (DKV2)	Vertical blinds 100%-90°	77,2	33,3	70,5
	Horizontal blinds 100%-60°	66,9	37,0	71,1
	Vertical blinds 100%-75°	79,8	31,5	71,4
4 (MM Lab.)	Vertical blinds 100%-90°	80,2	70,4	35,6
	Horizontal blinds 50%-30°	87,2	56,5	45,4
	Horizontal blinds 50%-15°	87,3	48,2	53,4
5 (DP2)	Vertical blinds 75%-60°	78,8	21,5	81,3
	Horizontal blinds 50%-30°	90,1	15,6	85,0
	Horizontal blinds 100%-60°	62,5	23,0	85,7
6 (DP1)	Vertical blinds 75%-60°	69,4	46,0	81,3
	Vertical blinds 75%-75°	43,7	55,6	71,7
	Horizontal blinds 50%-60°	40,6	56,4	73,7
7 (DP1)	Vertical blinds 75%-60°	63,5	46,0	62,0
	Vertical blinds 75%-75°	41,2	55,6	73,7
	Horizontal blinds 50%-60°	41,0	56,4	77,8
8 (PSDI1)	Horizontal blinds 100%-60°	57,6	39,7	73,7
	Horizontal blinds 50%-60°	44,3	47,6	76,5
	Vertical blinds 50%-75°	37,2	51,6	79,3
9 (PSDI1)	Horizontal blinds 100%-60°	64,7	39,7	73,7
	Horizontal blinds 50%-60°	57,9	47,6	67,2
	Vertical blinds 50%-75°	54,2	51,6	66,6
10 (PSDI2)	Vertical blinds 75%-60°	72,6	14,8	89,5
	Vertical blinds 75%-90°	61,2	18,5	90,3
	Horizontal blinds 50%-30°	76,2	12,6	90,6

Table 9. Comparison After and Before Optimization

Optimization Point	Explanation	%DGP$_{<0.21}$ (%)	sDA$_{150,50\%}$ (%)
Point 1 (M2)	Nothing Installed	21	60.0
	Horizontal Blinds 75%-60^o	54.4	43.3
Point 2 (A&M2)	Nothing Installed	29.1	40.0
	Horizontal Blinds 100%-60^o	51.4	30
Point 3 (DKV)	Nothing Installed	41.5	55.6
	Vertical blinds 100%-90^o	77.2	33.3
Point 4 (MM Lab.)	Nothing Installed	26.5	100
	Vertical blinds 100%-90^o	80.2	70.4
Point 5 (DP2)	Nothing Installed	28.9	37.8
	Vertical blinds 75%-60^o	78.8	21.5
Point 6 (DP1)	Nothing Installed	27.9	64.3
	Vertical blinds 75%-60^o	69.4	46.0
Point 7 (DP1)	Nothing Installed	27.9	64.3
	Vertical blinds 75%-60^o	63.5	46.0
Point 8 (PSDI1)	Nothing Installed	33.7	60.3
	Horizontal Blinds 100%-60^o	57.6	39.7
Point 9 (PSDI1)	Nothing Installed	33.7	60.3
	Horizontal Blinds 100%-60^o	57.6	39.7
Point 10 (PSDI2)	Nothing Installed	37.6	25.2
	Vertical blinds 75%-60^o	72.6	14.8

From the ten optimization-points, the results show that the most optimum solution is vertical blinds 75%-60^o, which becomes an optimum solution for four optimization-points.

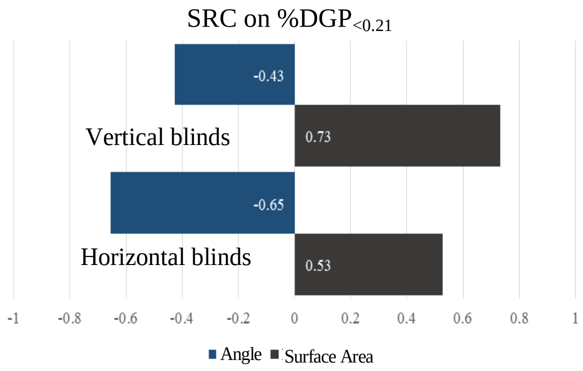
Multilinear Regression

Multi-linear regression was applied to analyze the effect of input variable x to output variable y, in this case using the vertical and horizontal blinds. In this case, x_{i1} is the blade's opening angle and x_{i2} is a surface area covering the window; while the y values are evaluated for %DGP $_{<0.21}$ and sDA$_{150lux,50\%}$. For each y value, there are 24 combinations of x_{i1} and x_{i2}.

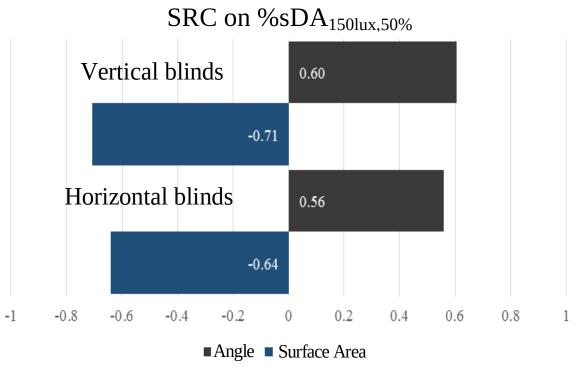
The standardized regression coefficient (SRC) may be positive or negative. A positive coefficient means that the value of the output variable will be larger if the value of the input variable increases, while a negative coefficient indicates that the value of the output variable will be smaller if the value of the variable input increases.

For output % DGP$_{<0.21}$, in the case of using vertical blinds, the SRC of blade's opening angle is -0.43, while the SRC of a surface area covering the window is 0.73. For the case of using horizontal blinds, the SRC of blade's opening angle is -0.65 and the SRC of the surface area covering the window is 0.53.

The most influential input variable using vertical blinds and horizontal blinds are different. This difference may be due to the materials used in the vertical and horizontal blinds and opening direction. For output %sDA$_{<150lux,50\%}$, in the case of using vertical blinds, blade's opening angle coefficient is 0.60 and the surface area covering the window coefficient is -0.71. For the case of using horizontal blinds, blade's opening angle coefficient is 0.55 and the surface area covering the window coefficient is -0.64.



(A)



(B)

Fig. 5. (A) Standard Regression Coefficient for %DGP$_{<0.21}$ (B) Right: Standard Regression Coefficient for %sDA$_{<150lux,50\%}$

Both cases show that the surface area covering the window variable is more influential to the output, compared to the blade's opening angle. This suggests that to increase the sDA, the most influential thing is not to put barriers on the windows.

Improvement Recommendation

Table 10 shows improvement recommendation for every room. This recommendation can be realized by installing or changing curtains or blinds that have been installed before.

Table 10. Improvement Recommendation

Room	Current Condition	Optimum Condition
M2	Nothing installed	Horizontal blinds 75%-60°
A&M2	Nothing installed	Horizontal blinds 100%-60°
DKV2	Curtains	Vertical blinds 100%-90°
MM Laboratory	Horizontal blinds	Vertical blinds 100%-90°
DP2	Curtains	Vertical blinds 75%-60°
DP1	Curtains on west facade	Vertical blinds 75%-60°
PSDI1	Nothing installed	Horizontal blinds 100%-60°
PSDI2	Nothing installed	Vertical blinds 75%-60°

CONCLUSION

1. Current daylighting visual comfort condition at the CADL building in Institute Technology Bandung has been evaluated using DGP as metric. All of the 11 capture points have DGP of larger than 0.23. According to Hirning et al. (2014), subjects may perceive visual discomfort from daylighting when the average DGP value is greater than 0.23.
2. The constructed simulation model has been validated with t-test by comparing daylight factor from the measurement and simulation. The result shows that *t*-critical (1.97) > *t*-stat (0.63) so that the model is deemed valid.

   Visual discomfort may be experienced in the CADL building so that window optimization needs to be performed. The recommended solution is installing blinds or curtains at certain opening angles or opening areas. This recommendation improves visual comfort at CADL by increasing $\%DGP_{<0.21}$ more than 50% while reducing $sDA_{150lux,50\%}$ below 30%. Using the concept of Pareto front, the most frequently occurring optimum solution is vertical blinds 75%-60°.

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