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AN INTEGRATED ASSESSMENT METHOD FOR VIEWS, DAYLIGHTING, AND GLARE IN OFFICE BUILDINGS WITH WINDOWS

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Abstract

Windows in architecture provide daylight and offer visual stimulation, which helps occupants relax and feel refreshed. Previous studies have shown that satisfaction with the view often enhances satisfaction with both daylight and the visual environment. Therefore, when designing office spaces, it is crucial to ensure good views, while achieving appropriate targets for daylighting and glare. In this study, we comprehensively evaluated the visual environments created by windows using quantitative indices related to views, daylighting, and glare. ‘Volume of sight’, proposed in previous studies, is a physical index for quantitatively assessing the openness of views from indoor spaces. Vertical illuminance was used to evaluate daylighting and glare. It was shown that this assessment method could ensure both views and daylighting while minimising glare by devising a window design. However, further analysis is required to determine the appropriate threshold for glare assessment.

Keywords: View, Daylighting, Glare, Window, Volume of sight, Office building

1 Introduction

Daylighting through windows is crucial for promoting occupants’ well-being, and windows also play an important role in ensuring access to views that provide information about the external environment. The view provided by the windows served as a source of visual stimulation, helping the occupants relax and feel refreshed. Previous studies have developed an evaluation framework for the visual environment in office buildings based on subjective impressions of daylighting and views gathered through experiments conducted in actual office buildings (Ohki et al., 2023). The results revealed that increased satisfaction with views enhanced satisfaction with daylight and overall satisfaction with the visual environment. Consequently, ensuring view quality should be a priority in office design. The simplest way to secure daylight and views is to maximise the window area on the walls. However, this approach often leads to an increased glare in the window. Therefore, window designs must balance adequate view and daylight while minimising glare. To achieve these design objectives, it is necessary to establish the physical indices and target values. Ko et al. (2022) indicated that view quality consists of three elements: view content (the sum of the visual features seen in the window view), view access (the amount of views that an occupant can see from their viewing position), and view clarity (how the content appears in the window view). Among these, we propose using 'volume of sight' as a metric to mainly evaluate both view content and view access. For daylight and glare, metrics based on the physical quantity of the annual vertical illuminance in front of occupant’s eyes have been proposed. The vertical–spatial Daylight Autonomy (ver-sDA) metric was introduced for daylighting. Vertical illuminance can also be used to assess daylight glare through DGPs (Simplified Daylight Glare Probability) or PGSV (Predicted Glare Sensation Vote). In this study, we propose a new integrated assessment method that uses these metrics to evaluate views, daylighting, and glare. The key points of this method are: 1) View quality is first assessed in balance with glare, and then daylight quantity is examined to ensure energy-saving performance in buildings. 2) Vertical illuminance is used as an index for both glare and daylighting because it corresponds more closely to the actual visual environment observed by the occupants, such as glare and spatial brightness, than horizontal illuminance. Annual hourly illuminance can be calculated in a practical and realistic time compared to the calculation of luminance. 3)

Widespread BIM (Building Information Modelling) design using computer simulations is required. This study examined an assessment method under various conditions in a hypothetical building model. These conditions include factors such as window orientation, window attachment, and the outdoor environment.

2 Proposed indices for view, glare, and daylighting

2.1 View

The volume of sight (VOS) as an index for evaluating the view quality, was proposed by Arano et al. (2023) based on the Isovist concept (Benedikt, 1979). VOS is a physical metric that incorporates both the solid angle and distance to objects. VOS refers to the spatial volume that is directly observable from a given viewpoint and effectively represents the sense of openness of the view. The calculation method is illustrated in Figure 1. In this study, the VOS which represents the outdoor space observable through a window, is referred to as $VOS_{outside}$. Arano et al. also showed that the view satisfaction of occupants can be estimated using $VOS_{outside}$. As the distance to the sky is physically infinite, it is necessary to set a distance limitation when calculating $VOS_{outside}$. Arano et al. introduced the concept of a "search radius", which defines the maximum distance used in the calculation of $VOS_{outside}$. Arano et al. conducted an analysis using $VOS_{outside}$ calculated with varying search radii and concluded that 400 m was an appropriate value for the search radius.

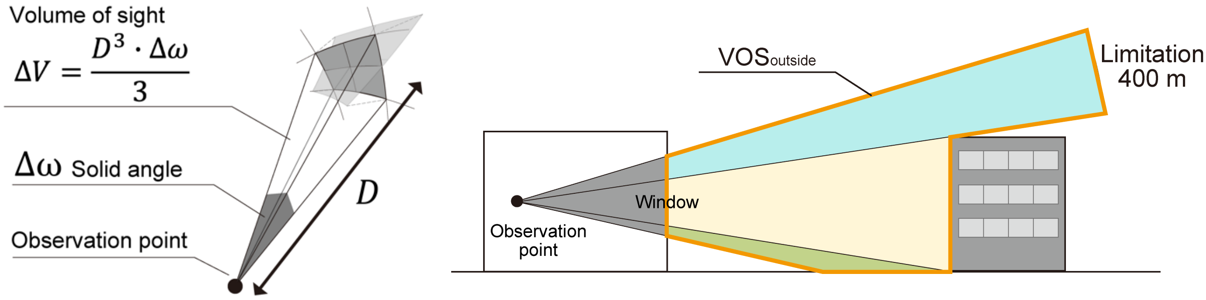

Figure 1 – Volume of Sight

Kashiwaguma et al. (2024) aimed to identify the threshold of $VOS_{outside}$ to ensure sufficient view satisfaction of occupants, based on a questionnaire survey conducted in three real offices. We added data from seven offices and analysed ten buildings (Table 1). Offices with diverse floor and window areas and orientations were surveyed. In this survey, we asked office occupants to evaluate their impressions of the viewing environment from their seats. Occupants were asked to rate their satisfaction with the question, *"Are you satisfied with views through the windows?"* on a five-point Likert scale (*1. Dissatisfied, 2. Somewhat dissatisfied, 3. Neither, 4. Somewhat satisfied, 5. Satisfied*.

Table 1 – Characteristic of Each Surveyed Offices

Building	Site	Survey period	Floor area (m²)	Window-to-floor ratio (%)	Window orientation	Number of valid responses
A	Tokyo, Japan	2019-10-28 to 2019-12-20	2102	10	WSW; ENE	5
B	Tokyo, Japan	2019-10-28 to 2019-12-20	3210	48	NW; SE	12
C	Tokyo, Japan	2019-10-28 to 2019-12-20	609	9	ESE	10
D	Tokyo, Japan	2022-07-08 to 2022-07-22	1251	8	N; W; E	17
E	Kyoto, Japan	2022-10-01 to 2022-10-14	335	21	N; W	13
F	Toyama, Japan	2023-07-24 to 2023-08-04	854	35	W; E	30
G	Hokkaido, Japan	2024-07-10 to 2024-07-24	337	5	SSW; ESE	3
H	Hokkaido, Japan	2024-07-10 to 2024-07-24	356	18	WNW; SSW; ESE	4
I	Hokkaido, Japan	2024-07-10 to 2024-07-24	369	38	SW	14
J	Tokyo, Japan	2024-07-28 to 2024-08-10	535	40	SE	15

We examined the threshold of $VOS_{outside}$ by using logistic regression analysis, with $VOS_{outside}$ as the explanatory variable and satisfaction with the views as the dependent variable. JMP PRO 17 statistical software (SAS Institute, USA) was used for statistical analysis. In this analysis, the search radius was set to 400 m to calculate $VOS_{outside}$. $VOS_{outside}$ was calculated in all directions over 360° from each occupant seat. As shown in Figure 2, the proportion of occupants dissatisfied with the view decreased as the $VOS_{outside}$ increased. The $VOS_{outside}$ corresponding to 50 % and 25 % occupant dissatisfaction are $10^{5,8}$ m³ and $10^{6,5}$ m³, respectively.

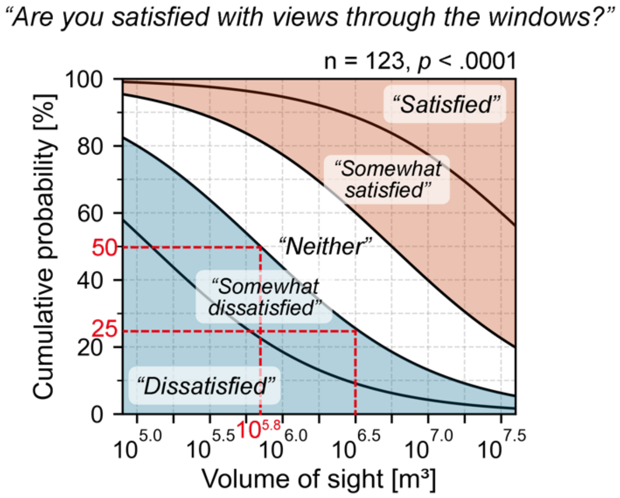

Figure 2 – Logistic Regression Analysis of the Relationship between $VOS_{outside}$ and Satisfaction with Views

In the view evaluation method proposed in this study, the threshold values of $VOS_{outside}$ were defined as shown in Table 2. Level A corresponds to a 25 % occupant dissatisfaction rate with views and Level B to 50 %. This $VOS_{outside}$ is calculated to be over 360° from each calculation point. The calculation points were limited to an area within 3 m of the window, because continuous access to views was not required from every seat or at all times during work. Occupants are expected to engage with views in this perimeter zone during short breaks. Even a brief exposure to views between tasks may provide psychological benefits to occupants. If $VOS_{outside}$ exceeds the threshold value corresponding to each level, the point is considered to satisfy the standard.

Table 2 – View Thresholds

	Level A	Level B
Dissatisfaction rate with views	25 %	50 %
Threshold of $VOS_{outside}$	$10^{6,5}$ m³	$10^{5,8}$ m³
Conditions to satisfy the standard	$VOS_{outside}$ exceeds the threshold.	

2.2 Glare

The typical glare index for windows is the Predicted Glare Sensation Vote (PGSV) in Japan. Scales for the PGSV were as follows; 0-Just perceptible, 1-Just noticeable, 2-Just uncomfortable, 3-Just intolerable. For the discomfort glare caused by daylight, we must consider two types of PGSV: contrast glare and saturation glare. Although the PGSV for contrast glare is typically calculated using luminance, this study employed a threshold based on vertical illuminance, as suggested in previous studies (Ito and Ohki, 2023, Tanaka et al., 2023). Ito et al. proposed two methods for calculating the vertical illuminance thresholds for contrast glare and saturation glare according to optional PGSV values. The calculation process for the illuminance threshold is shown in Equations (1)-(3).

$$Ev_c = Ls_c \left\{ \pi \cdot \varphi + \frac{S_W \cdot \pi \cdot \rho_{ave}}{(1-\rho_{ave}) \cdot S} \right\} \quad (1)$$

$$Ls_c = \left[\left\{ \frac{S_W \cdot \rho_{ave}}{(1-\rho_{ave}) \cdot S} \right\}^{(0.61-0.79 \log \omega)} \cdot 10^{PGSV_c + 8.2} \cdot \omega^{0.64} \right]^{\frac{1}{2.59+0.79 \log \omega}} \quad (2)$$

$$Ev_s = 1270\pi \left(\frac{PGSV_s + 0.57}{-PGSV_s + 3.3} \right)^{\frac{1}{1.7}} \quad (3)$$

where

$PGSV_c$ is PGSV for contrast glare;
$PGSV_s$ is PGSV for saturation glare;
Ev_c is vertical illuminance for contrast glare at the eye (lx);
Ev_s is vertical illuminance for saturation glare at the eye (lx);
Ls_c is the window luminance for contrast glare (cd·m^{-2});
φ is the window configuration factor (-);
S_w is the window area (m^2);
S is the interior surface area (m^2);
ρ_{ave} is the area-weighted average reflectance of all interior surfaces (-);
ω is the window solid angle (sr).

The threshold values for each level used in this study are listed in Table 3. The PGSV threshold was set at 1,2 for both contrast glare and saturation glare, respectively. This value corresponds to the threshold at which 20 % of occupants consider the office environment unacceptable for office work. The vertical illuminance corresponding to the $PGSV_c$ and $PGSV_s$ was calculated for each calculation point using Equations (1)-(3) to determine the vertical illuminance threshold at each point. The vertical illuminance for evaluating the glare was calculated at a point located 3 m from the window in the direction facing the window. This point was considered to meet the standard if the annual time ratio when the vertical illuminance at each point exceeded both thresholds of vertical illuminance based on $PGSV_c$ and $PGSV_s$ was less than the annual time ratio threshold. The threshold of the annual time ratio for Level A was set at 20 % and that for Level B at 40 %.

Table 3 – Glare Thresholds

	Level A	Level B
Dissatisfaction rate with the space caused by glare	20 %	
Threshold of the annual time ratio	20 %	40 %
Thresholds of vertical illuminance	Calculated based on $PGSV_c$ (= 1,2) and $PGSV_s$ (= 1,2)	
Conditions to satisfy the standard	The annual time ratio when the vertical illuminance in the direction facing window exceeds both illuminance thresholds, is less than the annual time ratio threshold.	

2.3 Daylighting

An index for evaluating daylighting, the vertical–spatial Daylight Autonomy (ver-sDA), was proposed (Budoh et al., 2024). This index uses the average vertical illuminance from the four surrounding directions. Budoh et al. (2024) aimed to determine the threshold of vertical illuminance to ensure sufficient daylight satisfaction of occupants, based on a questionnaire survey conducted in six real offices (Buildings A, B, C, D, E, F in Table 1). Occupants were asked to rate their satisfaction with the question, *"How do you feel about the amount of natural light entering your workspace?"* on a five-point Likert scale (*1. Too little, 2. Somewhat too little, 3. Just right, 4. Somewhat too much, 5. Too much*. We surveyed and analysed four more offices

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(Buildings, G, H, I, J in Table 1). We used data obtained from these ten buildings. To examine the threshold of vertical illuminance, logistic regression analysis was conducted with vertical illuminance as the explanatory variable and satisfaction with daylight as the dependent variable. JMP PRO 17 statistical software (SAS Institute, USA) was used for statistical analysis. Figure 3 shows the results of logistic regression analysis and the relationship between vertical illuminance by daylight and the probability of occupants who answered *"Just right"* for daylight. The proportion of occupants satisfied with the daylight increased with increasing vertical illuminance up to approximately 500 lx, after which it decreased. The proportion of occupants satisfied with daylight reached 50 % at a vertical illuminance of 169 lx, and increased to 63 % when the vertical illuminance exceeded 300 lx.

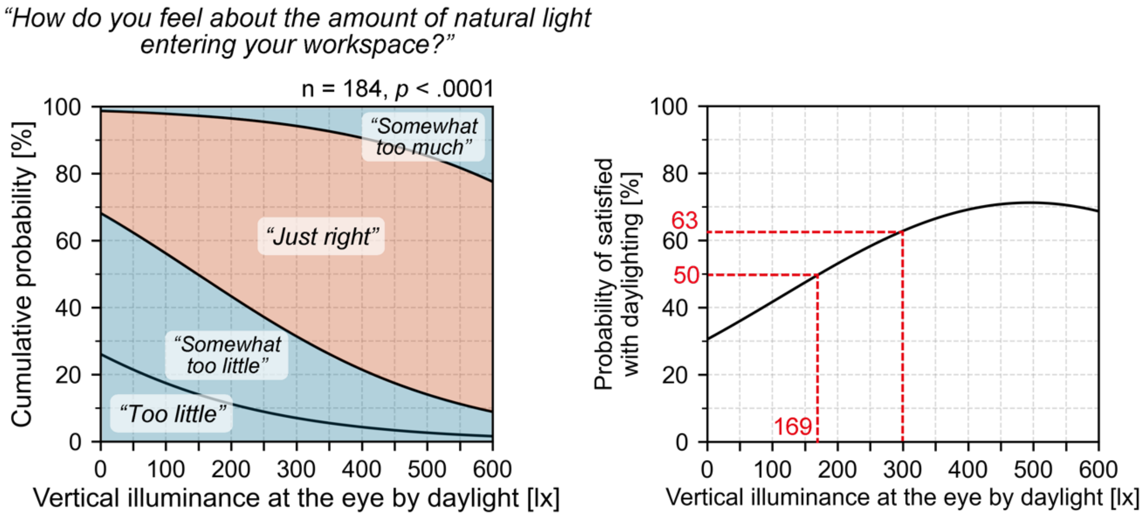

Figure 3 – (Left) Logistic Regression Analysis of the Relationship between the Vertical Illuminance and Satisfaction with Daylight. (Right) Relationship between the Vertical Illuminance and Probability of Satisfied with Daylighting.

The threshold values for each level are listed in Table 4. If the annual time ratio, during which the average vertical illuminance from four surrounding directions exceeded the threshold is greater than 50 %. In this study, the calculation area was set to regions located more than 3 m from the window to assess daylighting in the deeper parts of the room in terms of energy performance.

Table 4 – Daylighting Thresholds

	Level A	Level B
Satisfaction rate with daylighting	63 %	50 %
Threshold of the annual time ratio	50 %	
Threshold of vertical illuminance	300 lx	169 lx
Conditions to satisfy the standard	The annual time ratio when the average vertical illuminance from four surrounding directions exceeds the threshold, is over 50 %.	

3 Case study using simulations

This case study examined how windows affect indoor visual environments in terms of views, glare, and daylighting by varying the geometry and properties of the interior (including windows) and outdoor environments. We used the building model which can be thought of one of the typical architectural shapes for open offices in Japan (hereinafter referred to as the "standard model"). The plan and section of the standard model are illustrated in Figure 4. As explained previously, views were evaluated in the perimeter zone within 3 m of the window, glare was evaluated at points 3 m from the window, and daylighting was evaluated in the interior zone located more than 3 m away from the window. The calculation points were set at 1-m intervals at a height of 1,2 m above the floor, representing the typical viewing height of the occupants. The evaluation was carried out under the assumption that no venetian blinds were settled, which are sometimes left closed and hinder view and daylighting in actual offices.

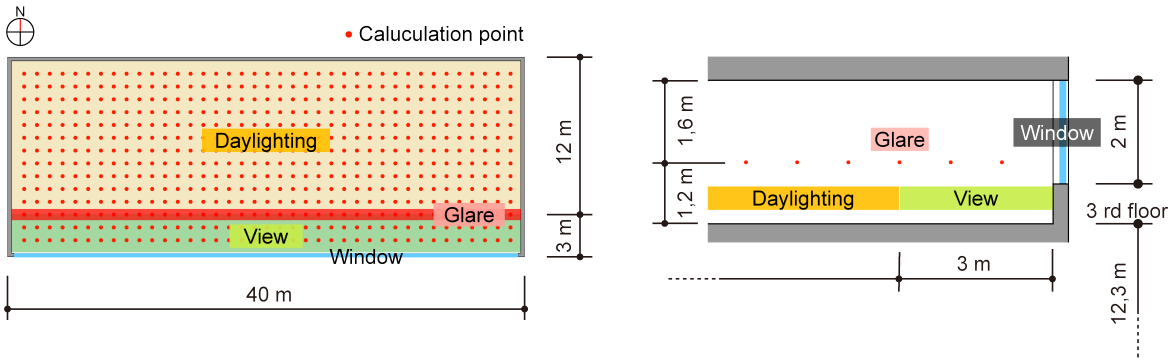

Figure 4 – (Left) Plan and (Right) Section of the Standard Model

Daylight was used as the light source in the standard model with no artificial light. Each index was calculated for all points using the light environment simulation program RADIANCE. The sky conditions used for the calculations were based on the 2020 version of the standard year Expanded AMeDAS (EA) meteorological data for Tokyo, Japan, provided by the MetDS Corporation. In this analysis, it was assumed that the occupants were present from 9:00 to 17:00, and calculations were performed on an hourly basis throughout the year.

The conditions were defined by identifying the factors that could potentially influence the daylighting environment and assigning multiple levels to each factor. These conditions are listed in Table 5. The material properties assigned to each geometry are listed in Table 6. Evaluating all the levels would require considerable computation; therefore, one level from each factor was chosen as the baseline. When the levels of a specific factor varied, those of all the other factors were fixed at their baseline levels. The baseline condition consisted of baseline levels. The sky view factor was calculated at the ground contact point of the south facade based on the horizontal projected solid angle of the sky. A building model was placed 30 m in front of the standard model to vary the sky view factor by changing the height of the building. When the sky view factor was 50 %, there were no surrounding buildings around the standard model, and only the sky and ground were visible outside the window. The depths of the horizontal louvres were set to 20 cm and 30 cm, and the spacing was set to 20 cm. The louvre angle was varied at 0°, 10°, and 20° for the calculation. Regarding the light shelf, the depths on the interior side were set to 1 m and 1,5 m, while the depths on the exterior side was fixed at 0,6 m.

Table 5 – Conditions of Case Study

Factor	Level
Outside	
Sky view factor (%)	10 / 20 / 30 / 40 / 50
Ground reflectance (%)	10 / 20 / 30
Room	
Reflectance (Ceiling, Wall, Floor) (%)	50, 30, 10 / 70, 50, 20 / 70, 70, 40
Overhang depth (m)	No overhang / 0,6 / 1,8
Window	
Window orientation	East / West / South / North
Window-to-wall ratio (%)	10 / 20 / 30 / 40 / 50
Window solar control devices	None / Horizontal louvre / Light shelf

The red text indicates the baseline level.

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Table 6 – Material Setting

Geometry	Material	R	G	B	Specularity (%)	Roughness (%)
		Reflectance (%)				
Surrounding building	Plastic	50	50	50	0	0
Overhang	Plastic	20	20	20	0	0
Horizontal louvre	Plastic	70	70	70	0	0
Light shelf (upper surface)	Mirror	90	90	90	-	-
Light shelf (lower surface)	Plastic	70	70	70	0	0
		Transmissivity (%)				
Window glass	Glass	87	87	87	-	-

4 Results

The proportion of areas that met each threshold within the target regions for each index was calculated, and the results are listed in Table 7. To visually clarify the results for view, glare, and daylighting, radar charts were created for the selected conditions. In this study, areas exceeding a 50 % proportion were provisionally considered to satisfy these standards. The baseline condition demonstrated that both views and daylighting were sufficiently ensured at 100 %; however, glare was not achieved at all.

Table 7 – Case Study Results

			View		Glare		Daylighting	
			Level A	Level B	Level A	Level B	Level A	Level B
Baseline condition			100 %	100 %	0 %	0 %	100 %	100 %
Sky view factor (%)	40		100 %	100 %	100 %	100 %	18 %	34 %
	30		33 %	33 %	100 %	100 %	0 %	7 %
	20		0 %	0 %	100 %	100 %	0 %	0 %
	10		0 %	0 %	100 %	100 %	0 %	0 %
Ground reflectance (%)	30		100 %	100 %	0 %	0 %	100 %	100 %
	10		100 %	100 %	0 %	0 %	0 %	0 %
Reflectance (Ceiling, Wall, Floor) (%)	50, 30, 10		100 %	100 %	0 %	0 %	100 %	100 %
	70, 70, 40		100 %	100 %	0 %	0 %	100 %	100 %
Overhang depth (m)	0,6		100 %	100 %	0 %	0 %	100 %	100 %
	1,8		100 %	100 %	0 %	0 %	100 %	100 %
Window orientation	East		100 %	100 %	0 %	0 %	90 %	100 %
	West		100 %	100 %	0 %	0 %	93 %	100 %
	North		100 %	100 %	0 %	0 %	85 %	100 %
Window-to-wall ratio (%)	40		100 %	100 %	0 %	0 %	82 %	100 %
	30		100 %	100 %	0 %	0 %	48 %	89 %
	20		100 %	100 %	0 %	0 %	42 %	73 %
	10		0 %	100 %	0 %	0 %	0 %	8 %
Light shelf depth on the interior side (m)	1		100 %	100 %	0 %	0 %	93 %	100 %
	1,5		100 %	100 %	0 %	0 %	91 %	100 %
	Slat depth (cm)	Slat angle (°)						
Horizontal louvre	20	0	100 %	100 %	0 %	0 %	71 %	100 %
		10	100 %	100 %	0 %	0 %	48 %	89 %
		20	98 %	100 %	0 %	95 %	31 %	63 %
	30	0	100 %	100 %	0 %	0 %	61 %	97 %
		10	100 %	100 %	0 %	100 %	31 %	67 %
		20	0 %	100 %	100 %	100 %	0 %	16 %

As shown in Figure 5, glare was significantly suppressed when the sky view factor was decreased by 10 %, from 50 % to 40 %. While a lower sky view factor helps reduce glare, it also leads to a reduction in both views and daylighting. The results of varying the ground reflectance showed that reducing it neither effectively suppressed glare nor preserved daylighting.

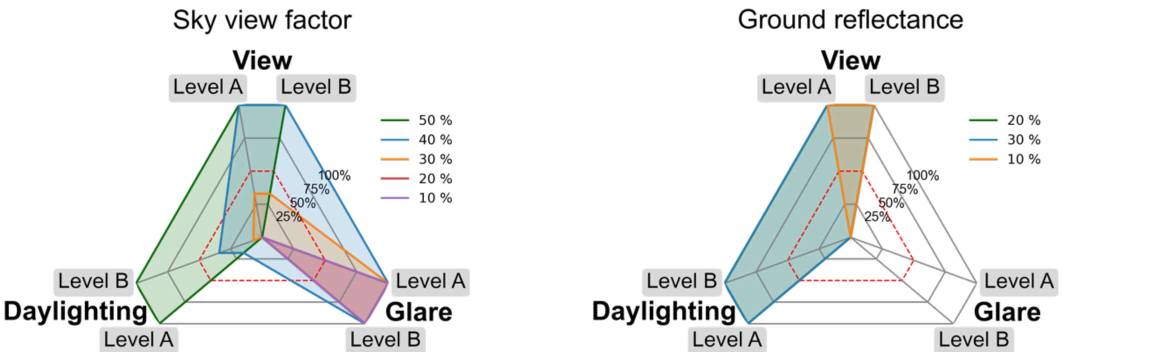

Figure 5 – Radar Charts (Left) Varying Sky View Factor. (Right) Varying Ground Reflectance.

Figure 6 shows that as the window-to-wall ratio was reduced by 10 % increments from the baseline condition, it became increasingly difficult to ensure sufficient daylighting and views, whereas glare was still not effectively suppressed.

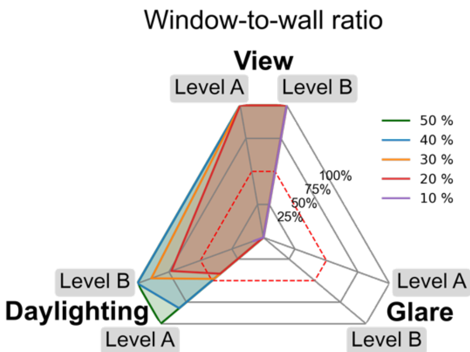

Figure 6 – Radar Chart Varying Window-to-Wall Ratio

For the horizontal louvres, several variations in the depth and angle were tested. Increasing the louvre angle reduced glare; however, it also led to decreased views and daylighting. A slat depth of 20 cm and a slat angle of 20° were identified as potential balance points for views, glare and daylighting, as all three elements exceeded 50 % at Level B. For the window design, even minor design adjustments, such as changing the slat angle of horizontal louvres, substantially influenced these three visual factors.

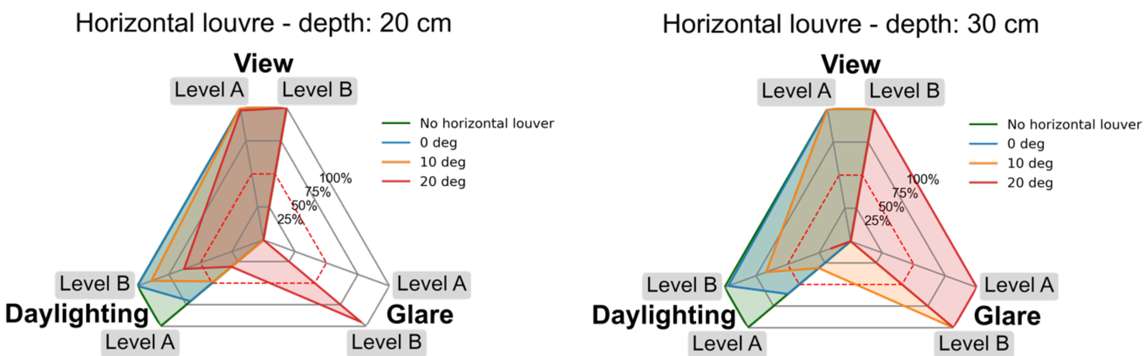

Figure 7 – Radar Charts for Horizontal Louvre (Left) Depth: 20 cm. (Right) Depth: 30 cm.

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Additional analyses were conducted to explore the window designs that could guide daylight deep into a room while suppressing glare. As shown in Figure 7, in designs using only horizontal louvres, increasing the slat angle to suppress glare resulted in a reduction in the view and daylighting, particularly daylighting. To guide daylight deep into the room while suppressing glare with horizontal louvres, additional analyses were conducted under new conditions combining horizontal louvres and light shelves.

As shown in Figure 8, when the interior-side depth of the light shelf was 1 m, increasing the slat angle of the horizontal louvres did not effectively contribute to glare reduction. By contrast, when the interior-side depth was extended to 1,5 m, setting the slat angle of the horizontal louvres to 10° or 20° (Figure 9) enabled glare to achieve Level B while maintaining both view and daylighting.

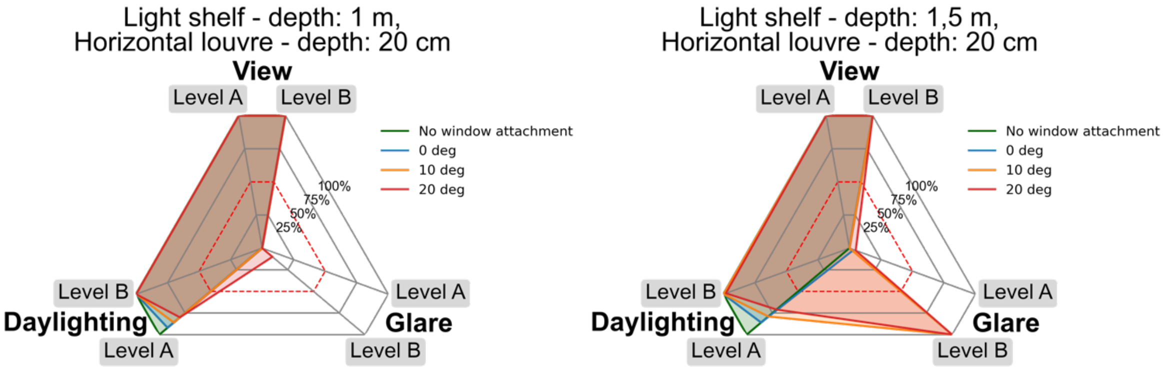

Figure 8 – Radar Charts for Light Shelf and Horizontal Louvre. (Left) Light Shelf Depth: 1 m. (Right) Light Shelf Depth: 1,5 m.

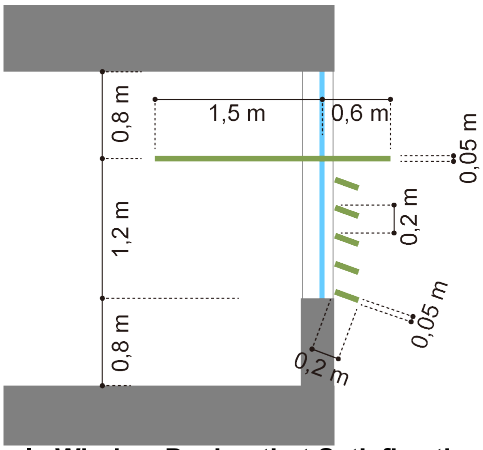

Figure 9 – The Section of an Example Window Design that Satisfies the Criteria for View, Glare, and Daylighting.

5 Conclusion

This study introduced an integrated simulation-based method that assesses views, glare, and daylighting in offices. In the case study, we first tested horizontal louvres and light shelves separately using the standard model. After comparing these results, we analysed combined cases. Through this process, we were able to identify window designs that satisfied each threshold without venetian blinds. The case study demonstrated that the proposed assessment method is effective for exploring window designs that achieve an appropriate balance among these three visual factors.

This step-by-step approach for using the proposed assessment method can be useful in actual design practice for offices and help designers understand the visual environment from the occupant's viewpoints in the early design phase, thereby supporting more effective design modifications.

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