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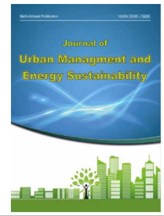

ORGINAL RESEARCH PAPER

Investigation of the Physical Aspects of Openings on Interior Daylight Quality and Exterior Visibility

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ABSTRACT

Daylight and visual connection to the exterior are critical factors in architectural design, directly influencing occupants' comfort, well-being, and energy performance. However, contemporary window design often lacks a systematic understanding of how opening geometry simultaneously affects daylight quality and exterior visibility. This study aims to investigate the combined impact of opening position and elongation on indoor daylight performance and view quality. The research asks how variations in window location and geometric elongation influence daylight metrics and the extent of visual access to the outside. A parametric simulation approach was employed using Honeybee and Ladybug, analyzing 22 scenarios of a reference room model (5×3×3 m) through daylight factor, horizontal illuminance, glare probability, and view analysis indices. The results show that centrally positioned openings with horizontal elongation improved daylight uniformity by approximately [10%] and increased exterior visibility by [36%] compared to vertically elongated configurations. Qualitatively, the findings suggest that balanced horizontal window proportions enhance both visual comfort and spatial perception without excessive glare. Future research should extend the model to multiple climatic contexts and diverse room geometries to improve the generalizability of the conclusions.

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23	19	03

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INTRODUCTION

In recent years, the positive effects of natural light on physical and mental health have become increasingly evident, leading to a renewed focus on daylight use, especially among designers (Newell, 1995). One common initial strategy was to increase the surface area of openings in spaces. However, this approach often resulted in challenges, such as higher energy consumption due to excessive solar radiation entering indoor environments (Ruck, 2000). Beyond providing interior illumination, openings in buildings serve a crucial visual function by offering views to the outside. External visibility is considered a key indicator of visual quality within buildings, achievable only through the proper design of these openings. Unfortunately, poorly sized openings can negatively impact both the quantity of interior lighting and the quality of external views (Demirkan & Demirbas, 2000). Utilizing daylight not only fulfills human physical and psychological needs but also aids in reducing fossil energy consumption (Ghiabaklou, Hashemi Rafsanjani & Heidari, 2018). Existing literature evaluates light quality using several indices such as the Daylight Factor (DF), Illuminance (E), and Glare. These indices are explained as follows:

- Daylight Factor (DF): Due to constant changes in sky conditions, clear, partly cloudy, or fully cloud, throughout the day and across seasons, the quantity of daylight reaching a space varies. Consequently, daylight calculations are complex, requiring consideration of moment-to-moment changes in the sun's angle relative to the receiving surface, as well as sky and atmospheric conditions. The Daylight Factor measures the ratio of interior illuminance at a specific point to exterior illuminance under overcast sky conditions. It can be calculated for an individual point or as an average across a space. While the Daylight Factor indicates the minimum amount of natural light in a space, it does not assess light quality in terms of visual comfort (Ko et al., 2022).

- Illuminance: This index measures the amount of light energy received per unit area (Ruck, 2000). Its unit of measurement is lux, defined as the illuminance received by a one-square-meter area from a standard candle located one meter away (Almusaed, 2011, Berman et al., 2008). Represented by the letter "E," this index is directly or indirectly used in calculating other light-related indices. Illuminance is crucial in lighting engineering, serving as the basis for measuring light on visible surfaces and establishing lighting standards (Zare Mahzabieh et al., 2013, Heydari, 2013).

- Glare Index: This index serves as a functional criterion to predict the undesirability of daylight. It is recommended to remain within an acceptable visual comfort range of 16 to 22 (CIE, 2006, Metrics, 2012). According to LEED standards, the allowable glare level ranges from 30 to 40 (Hesari et al., 2025, Elsadek et al., 2020).

Daylight assessment in a space can be performed through both field measurements and computer simulations (Tahbaz et al., 2014, Goharian et al., 2018, Bedocs, 2010). In evaluating lighting conditions via computer simulation, factors such as the geometry and shape of the space, material properties, and light sources (sun and sky) are considered as input data for the simulation software. A grid of sensors is typically positioned at a specific height (commonly at work surface level). The lighting data gathered from each sensor are then used to calculate the relevant indices. Finally, the simulation results are compared with standards and lighting codes to provide an accurate interpretation of the findings (Heschong, 2021). Tab. 1 presents some standards related to the aforementioned indices. (Tab. 1)

One important aspect of the visual quality of architectural spaces is the availability of views to the outside. A key function of openings in buildings is to provide occupants with these outdoor views. Research indicates that there is a direct correlation between a building's value and the extent of views to the outside from within (Konstantzos et al., 2015). Furthermore, having the ability to see natural landscapes from inside workspaces significantly reduces stress and enhances individual focus (Pilehchian et al., 2020).

Many studies have been conducted on the impact of daylight entering spaces and the views available through openings in building walls. A selection of these studies is presented in Tab. 2:

Table 1: Standard Values for Daylight Indices

Standard Description	Standard System	Index
At least 75% of the space area should have a DF greater than 2%	LEED	Daylight Factor (DF)
At least 75% of the space area should receive illuminance between 300 and 3000 lux during the fall equinox under clear sky conditions	LEED	Illuminance (E)
The allowable glare level according to the LEED standard is between 30 and 40 (DGP)	LEED	Glare (Glare)

Table 2: Research Background on Daylight and Views to the Outside Through Building Openings

Researcher (Year)	Research Title	Objective	Variables	Method	Result
Gouharian et al, (2022)	Standardizing a method for optimizing skylight aperture as a reflector for daylight: A new approach using Honeybee and Ladybug plugins	Configuring the skylight through a hierarchical process of troubleshooting and identifying advantages to prepare an optimal solution for compatibility with direct sunlight rays	Skylight depth Skylight height Daylight reflector	Utilizing the capabilities of Ladybug and Honeybee plugins in the parametric environment of Grasshopper and conducting an in-depth analysis of the sky matrix to determine the main indicators for optimizing daylighting	Each section of the skylight depth exhibits different behavior in reflecting rays. In general, skylight height plays a significant role in altering multiple reflection
Liu et al, (2023)	Modular classroom optimization and combinations to increase daylight performance and open platform space through ANN acceleration in the post-pandemic era	Proposing a new architectural form that ensures overall visual comfort while also enhancing students' learning and physical well-bein	Classroom form Daylighting performance	Four stepped educational buildings are created, and six spatial daylight indices (SDA), Daylight Uniformity (UOD), Annual Sunlight Exposure (ASE), Open Platform Area (OPA), Gable Wall Length (GWL), and Space Utilization (SU) are analyzed	The proposed combination of stepped forms creates a harmonious balance between the building's attractive form and daylight performance. It offers optimal daylight and outdoor spaces, providing students with abundant access to natural light in the post-pandemic period

Tahbaz et al, (2013)	Natural Lighting in Traditional Houses of Kashan - Case Study: Ameriha House	relationship between brightness level and the distribution of natural light with skylight specifications, space geometry, and its surrounding environment	Natural lighting	Using field measurements and computer simulations, this study seeks to demonstrate the distribution and amount of light in different spaces and traditional skylights and aims to reuse these ideas in contemporary architecture.	The natural lighting design in the historical Ameriha House follows precise rules
Shafavi et al, (2018)	Efficiency of Daylight Metrics in Estimating Sufficient Lighting in Spaces Based on User Evaluations - Case Study: Educational Spaces in Architecture Schools of Tehran	The amount of illuminance in lux in the user's perception, which serves as a criterion for determining whether a space is bright or dark	Daylight Visual comfort	The predicted bright zone, defined by horizontal illuminance indices, daylight factor, useful daylight illuminance, and daylight autonomy, was compared with the bright zone perceived by 386 architecture students across 20 design studios in universities in Tehran	Users consider 125 lux as the threshold between dark and semi-bright zones and 350 lux to distinguish between semi-bright and bright zones. For long-term evaluations using the DA climate-based metric, with 300 and 150 lux as the lower thresholds, one can reasonably predict the bright and semi-bright zones perceived by the users
Giraldo et al, (2022)	Occupant Response to Window View, Daylight, and Indoor Lighting: A Critical Review	A critical review of studies addressing the effects of window views, daylight, and lighting on occupants' behavior, perception, performance, and well-being.	Daylight Well-being Perception Behavior	The data were extracted from selected studies and articles to propose a simplified model for predicting occupant performance based on lighting and color temperature.	A preliminary simplified model was proposed to quantify lighting and CCT based on occupant performance. This model, however, is based on limited and scattered data, providing only a rough estimate of the impact of lighting characteristics on performance.

Abboushia et al, (2020)	Assessment of Visual Comfort, Visual Interest in Sunlight Patterns, and Observation Quality Under Different Window Conditions in an Open-Plan Office	This study explores the effects of sunlight patterns on visual comfort and potential impacts on visual interest under different sunlight conditions.	Daylight Visual interest Visual comfort Sunlight patterns	The study used an experimental method where 33 office workers were exposed to three different window and sunlight patterns: fractal pattern, striped pattern, and clear conditions in an office building over three days (one condition per day). Subjective ratings and physical environmental measurements were collected and analyzed to understand the differences between the three conditions	No significant difference in visual comfort or visual interest ratings was observed between fractal, striped, and clear conditions. However, fractal and striped patterns were associated with a significant reduction in view quality compared to clear conditions
Pilechihiha et al, (2022)	Multi-Objective Optimization Framework for Office Window Design: View Quality, Daylight, and Energy Efficiency	A framework is proposed to quantify view quality in office buildings balanced with energy and daylight performance, thus enabling the optimization of office window design	Window design Daylight Building energy consumption	Based on previous research, a multi-objective approach is developed for assessing a reference room parametrically using real climate data.	The optimization model shows that room geometry must be modified to meet the lighting and view requirements specified in building performance standards.

MATERIALS AND METHODS

A critical review of the studies summarized in Table 2 reveals three prominent research trajectories. The first group primarily examines daylight performance through quantitative metrics and parametric or experimental analyses (e.g., Tahbaz et al., 2013; Vasquez et al., 2019; Liu et al., 2023). These studies significantly contribute to understanding daylight distribution and visual comfort; however, they often treat daylight as an isolated environmental parameter, without systematically integrating exterior visibility into their evaluation frameworks.

The second group focuses on visual perception and view quality (e.g., Hopkinson, 2019; Abboushia et al., 2020), frequently emphasizing occupant responses, behavioral aspects, or visual interest under different window conditions. While these studies highlight the psychological and perceptual significance of external views, they seldom establish a direct quantitative link between opening geometry and daylight performance.

The third group attempts to combine multiple performance criteria, including energy, daylight, and view quality (e.g., Pilechiha et al., 2022). Although these approaches advance toward multi-objective optimization, the interaction between the geometric characteristics of opening, specifically their position and elongation, and their simultaneous effects on daylight distribution and visibility remains insufficiently explored. Consequently, despite the increasing body of research on daylight and exterior views, the literature indicates a fragmentation between studies on lighting performance and those on view quality. Few investigations have systematically examined how variations in opening geometry impact both areas within a unified simulation-based framework. This gap restricts designers' ability to make evidence-based decisions regarding window configurations that optimize both daylight and visual connections. This study aims to address this gap by proposing an integrated parametric simulation approach that evaluates the effects of window position and elongation on both daylight performance and exterior visibility within a single controlled model. By linking geometric variables to dual performance outcomes, this research contributes a more comprehensive framework for architectural opening design. Window design plays a dual role in architecture, combining aesthetic expression with essential functional performance related to daylight provision and visual connection to the exterior. In this context, designers primarily face two interrelated variables: the geometric configuration of the opening and its spatial position on the façade. Geometric configuration refers not just to the basic shape of the window but also to its horizontal and vertical elongation, while position pertains to its placement within the enclosing surface. In contemporary buildings, poor decisions regarding these variables may compromise both daylight distribution and exterior visibility, ultimately reducing overall interior visual quality. Despite their importance, the relationship between opening geometry and these dual performance outcomes has often been addressed separately in previous studies. This fragmentation underscores the need for an integrated analytical framework that systematically evaluates how geometric variations influence both daylight performance and visual connection. Accordingly, this study adopts a conceptual framework that links opening geometry to interior visual quality through a combined assessment of daylight metrics and exterior visibility. Figure 1 illustrates this framework and clarifies the analytical structure guiding the research. (Fig. 1)

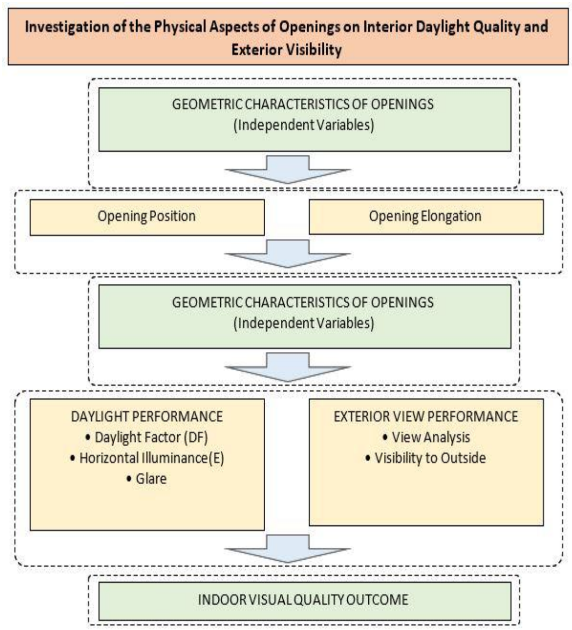


Figure 1: Conceptual model of the relationship between opening geometry and interior visual quality

Methodology

This study investigates how the geometry of openings affects interior daylight performance and exterior visibility, utilizing a controlled reference model. The base case selected for this research is a south-facing ground-floor room measuring 3 × 3 × 5 meters. Variations in opening geometry were examined through two structured sets of scenarios: different opening positions (Fig. 2) and different elongation patterns (Fig. 3). In this framework, the position and elongation of openings are treated as independent variables, while daylight performance and views of the outside are considered dependent variables. Daylight performance was assessed using metrics such as Daylight Factor (DF), glare levels, and horizontal illuminance (E), while exterior visibility was evaluated using the Analysis View metric.

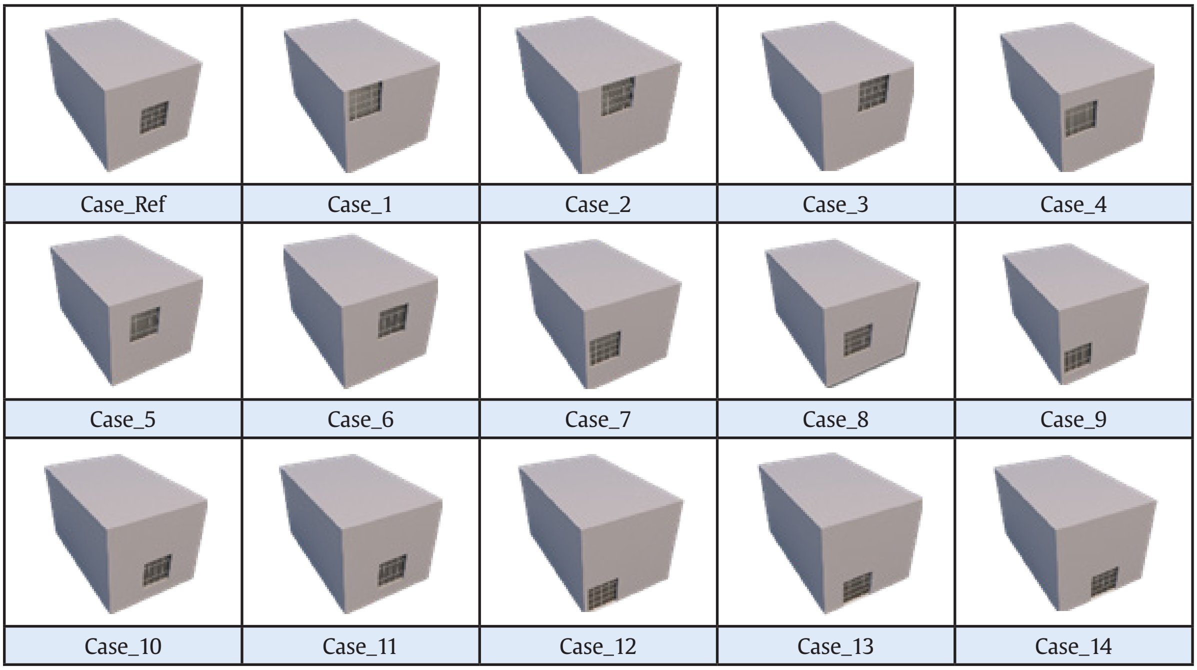


Figure 2: Case Study Samples Based on Opening Position on the Southern Facade

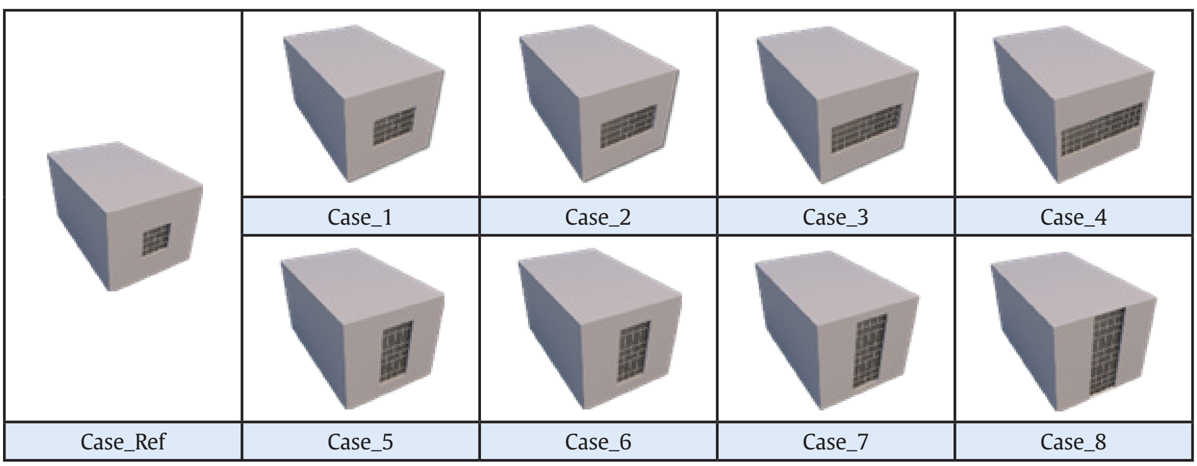


Figure 3: Case Study Samples Based on Opening Elongation on the Southern Facade

Simulations were conducted in the Grasshopper environment utilizing the Honeybee and Ladybug plugins. Three-dimensional models were created using Rhino 6 and analyzed parametrically. The Radiance simulation parameters were configured according to validated references, with the selected settings summarized in Table 3. Climatic data for Tehran were imported using EPW and STAT weather files from Iran's Comprehensive Climate and Meteorology Database (Iran's Comprehensive Climate and Meteorology Website, 2019). The simulations were carried out for January 22 and December 22 to represent daylight conditions. (Tab. 3)

Table 3: Daylight Simulation Parameters for Radiance

ab (ambient bounces)	3
ad (ambient divisions)	2.48
aa(ambient accuracy)	0.10
ar(ambient resolution)	64
dt(Direct Threshold)	0.25

A simplified and controlled reference room was intentionally created to isolate the geometric effects of opening design, allowing for a systematic comparison between different scenarios. Although this approach restricts direct generalization to all architectural contexts, it establishes a clear analytical framework for identifying relative design trends. The results should be viewed as design guidelines that can be further developed in future studies for other spatial configurations and climatic regions.

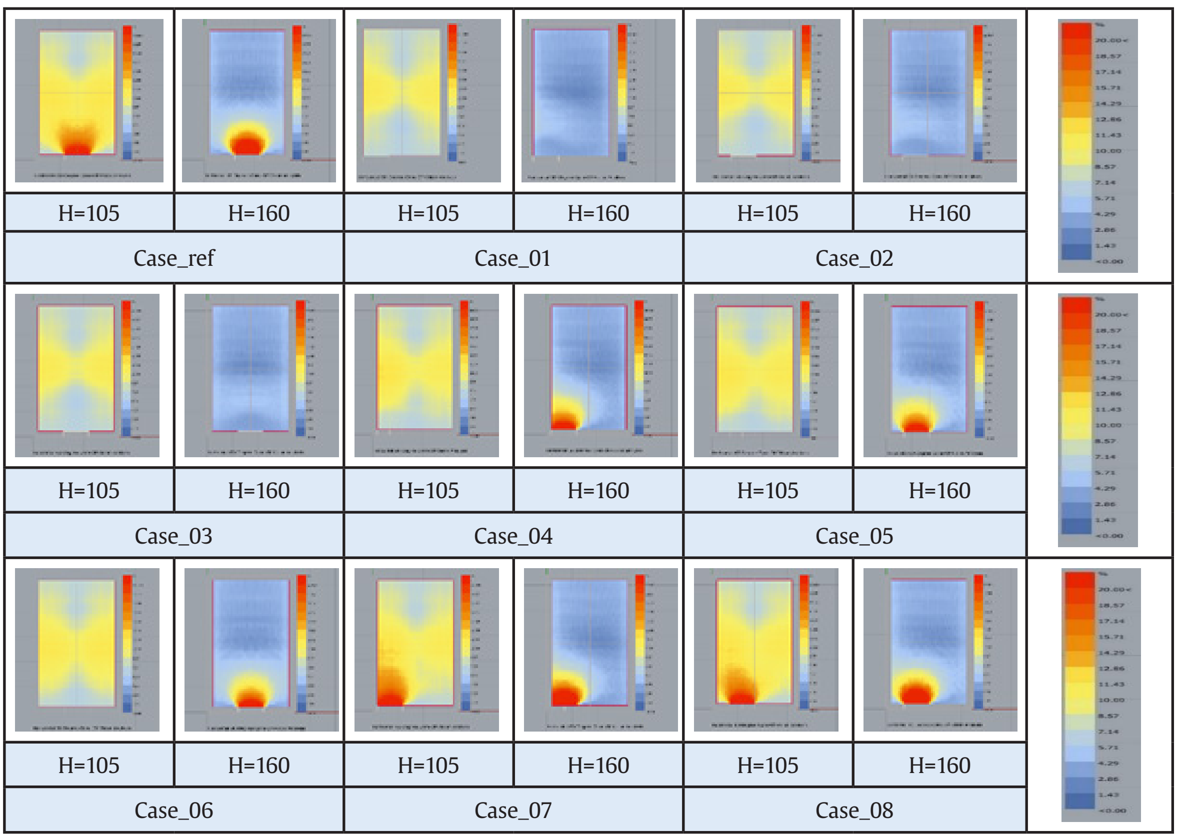
DISCUSSION AND FINDINGS

This section presents the research findings related to the two variables: "view to the outside" and "daylight," discussed separately.

View to the Outside

Analysis Based on Opening Position on the Southern Facade

To evaluate exterior visibility, two observer positions were considered: standing (height = 160 cm) and sitting (height = 105 cm). The spatial distribution of the view index across the room is illustrated in Figure 4 and 5. (Fig. 4 and 5)



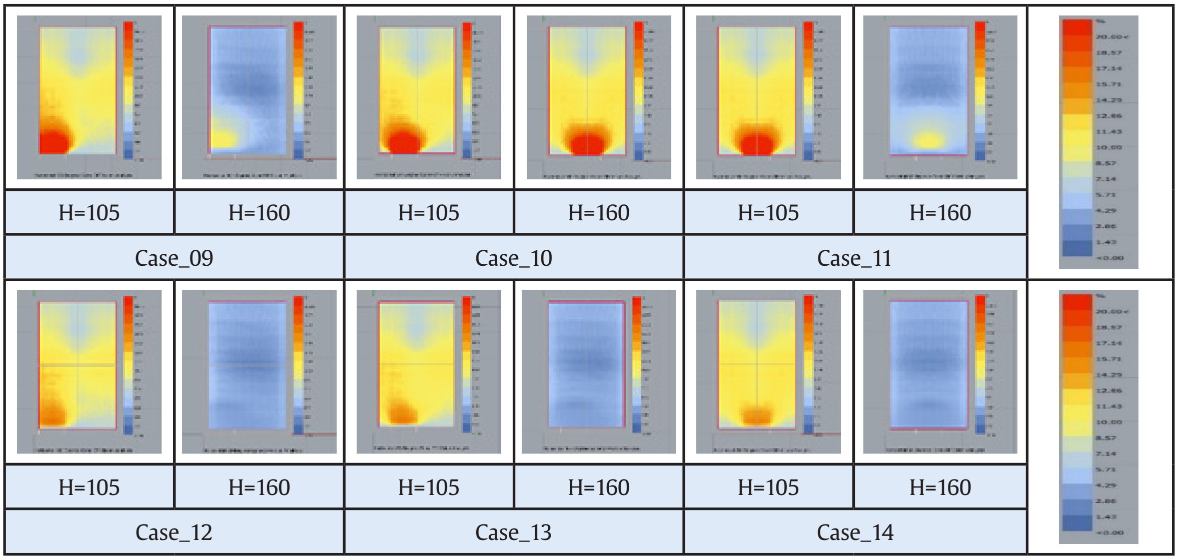


Figure 4: Contour of the View to the Outside in Case Studies with Different Opening Positions

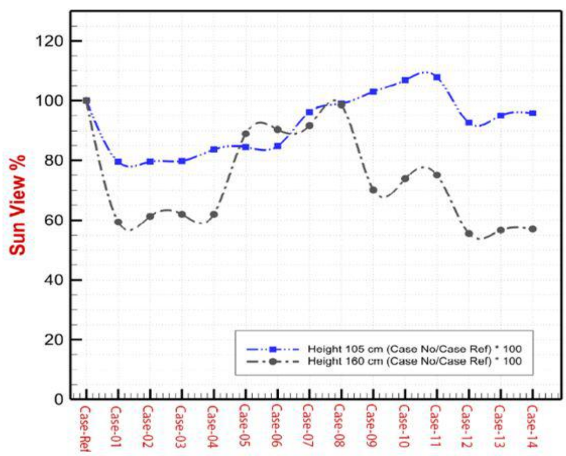


Figure 5: Numerical Results of the View Index in Case Studies with Different Opening Positions (Source: Authors)

The results indicate a consistent effect of observer height on exterior visibility. Across all scenarios, the average visible area of the room was 9% in the sitting position, compared to 4% in the standing position. This represents an approximate 55% reduction in visible area when the observer height increases from 105 cm to 160 cm, highlighting the strong influence of vertical eye level on visual access to the outside. When comparing individual cases, variation in opening position led to measurable differences in view performance. In the sitting position, Case 11 achieved the highest visibility (10.52%), while Case 01 recorded the lowest value (7.75%), indicating a relative difference of approximately 26% between the best and weakest scenarios. In the standing position, Case 08 yielded the highest value (5.48%), whereas Case 12 had the lowest (3.09%), corresponding to a 43% difference between extreme cases. Comparison with the reference case further clarifies the relative performance of positional variations. In the sitting condition, only three configurations (Case 10, Case 11, and Case 12) outperformed the reference model, while the remaining cases showed reduced visibility. In the standing condition, none of the alternative configurations exceeded the reference case, and all scenarios demonstrated a decrease in visible area. Overall, the findings suggest that opening position has a moderate but measurable influence on exterior visibility, with the observer's eye level exerting a stronger impact than positional displacement alone. The data also indicate that only specific positional adjustments can enhance visibility beyond the reference configuration, underscoring the importance of precise geometric calibration in façade design.

Analysis of the View to the Outside Based on Opening Elongation on the Southern Facade

The impact of opening elongation on exterior visibility was assessed for both sitting (H = 105 cm) and standing (H = 160 cm) observer positions. The numerical findings are displayed in Figure 6 and 7.

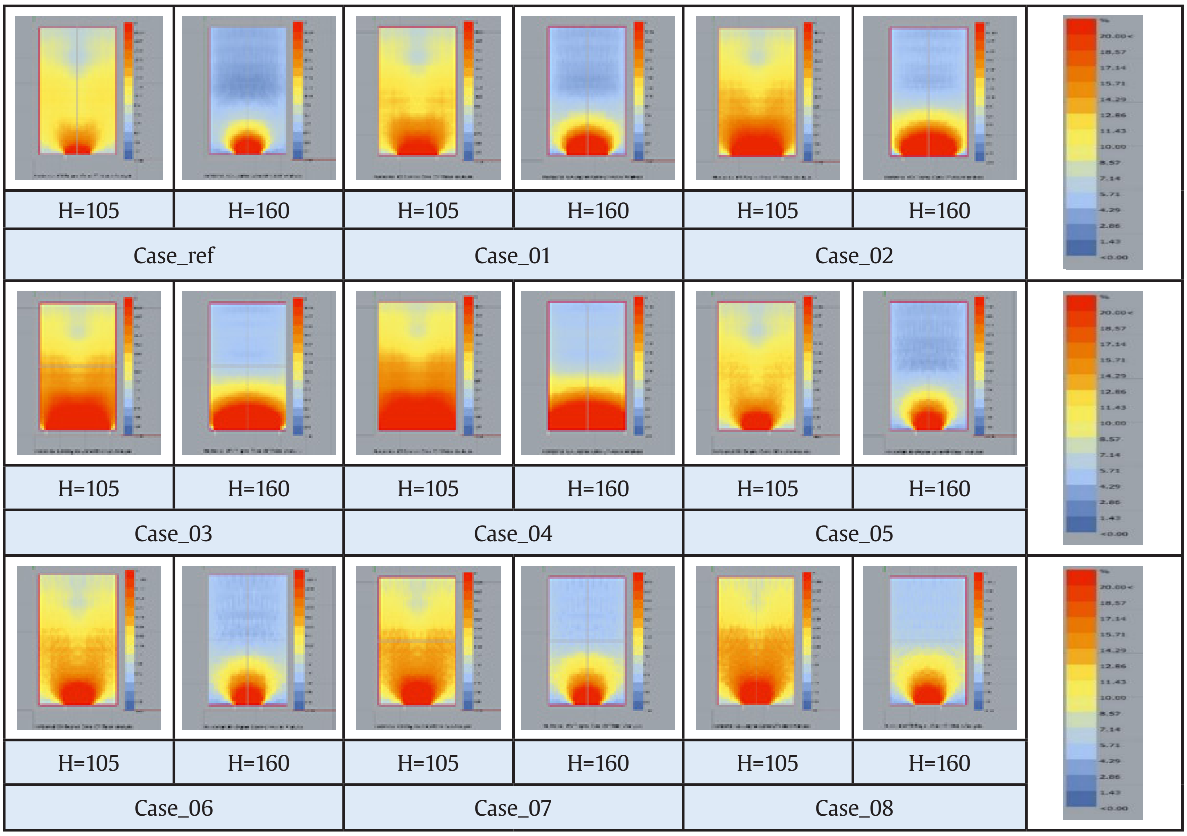


Figure 6: Contour of the View to the Outside in Case Studies with Different Opening Elongations

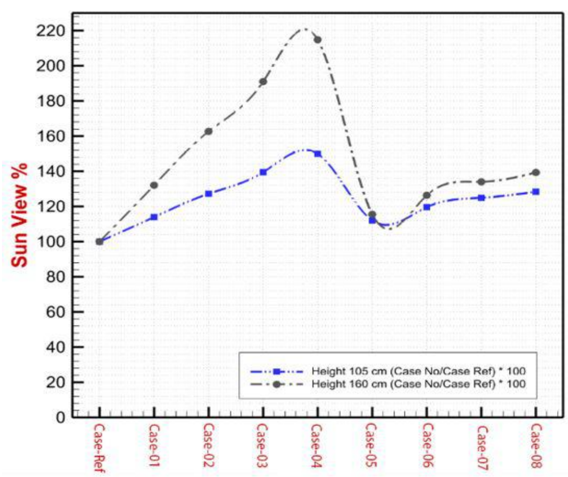


Figure 7: Numerical Results of the View Index in Case Studies with Different Opening Elongations (Source: Authors)

Consistent with the previous analysis, the sitting position yielded higher visibility values than the standing position across all scenarios. However, in contrast to positional variations, elongation of the opening produced a systematic improvement in exterior visibility in all cases relative to the reference model. In the sitting condition, the highest visibility was recorded in Case 04 (14.63%), while the reference case showed the lowest value (9.76%). This corresponds to an approximate 50% increase in visible area compared to the reference configuration. In the standing condition, Case 04 again demonstrated the highest value (11.95%), whereas the reference case recorded 5.56%, representing an increase of approximately 115%. This substantial difference indicates that opening elongation has a stronger relative impact on visibility when the observer is standing. Unlike positional adjustments, where only limited cases outperformed the reference model, elongation scenarios consistently enhanced the view index in both observer positions. This suggests a strong positive relationship between increased opening dimensions and exterior visibility. Moreover, the magnitude of improvement in standing conditions implies that vertical or horizontal extension of the opening can compensate for reduced eye-level alignment. Overall, the results demonstrate that opening elongation exerts a more significant influence on exterior visibility than mere positional displacement. The findings highlight elongation as a dominant geometric factor in improving visual connection to the outside environment.

Daylight

Analysis of the Daylight Factor (DF)

The Daylight Factor (DF) is the ratio of indoor illuminance to the simultaneous outdoor illuminance during overcast sky conditions (Hopkinson, 1963). The calculated DF values for various opening positions and elongation scenarios are illustrated in Figures 8, 9, 10, and 11. (Fig. 8 to 11)

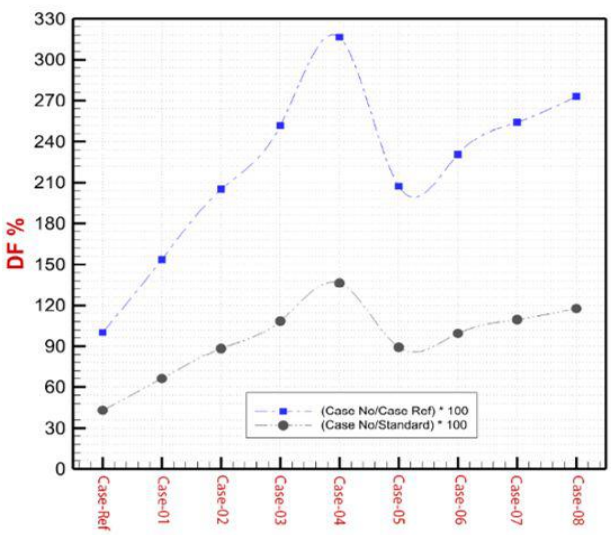


Figure 8: Numerical Results of the Daylight Factor in Case Studies with Different Opening Elongations (Source: Authors)

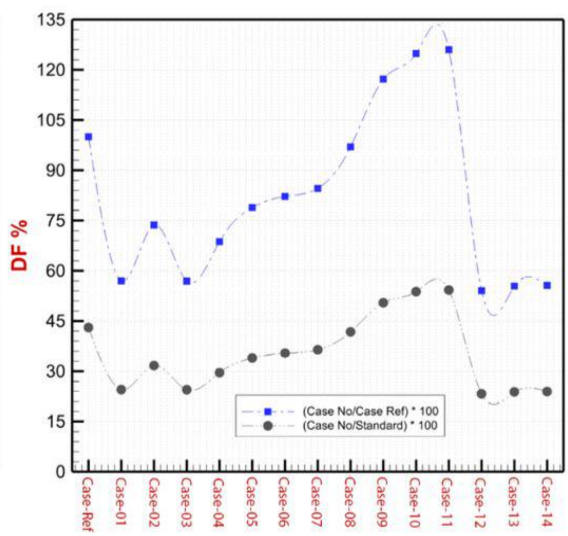
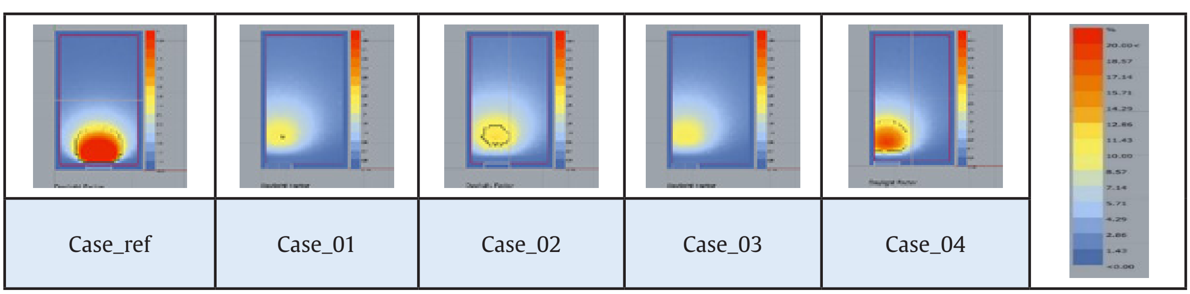


Figure 9: Numerical Results of the Daylight Factor in Case Studies with Different Opening Positions (Source: Authors)



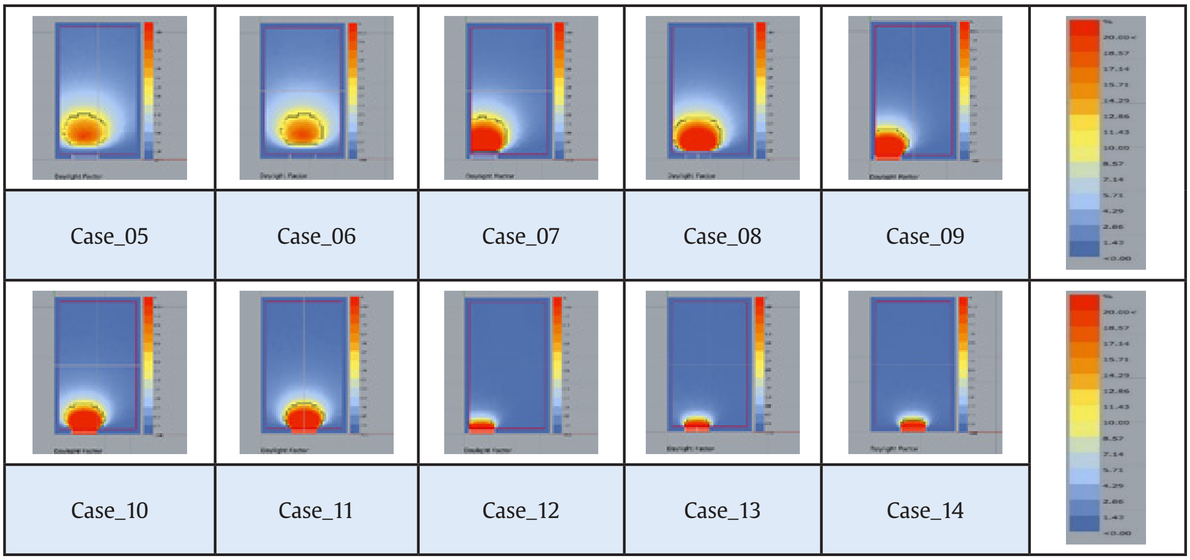


Figure 10: Contour of the Daylight Factor in Case Studies with Different Opening Positions

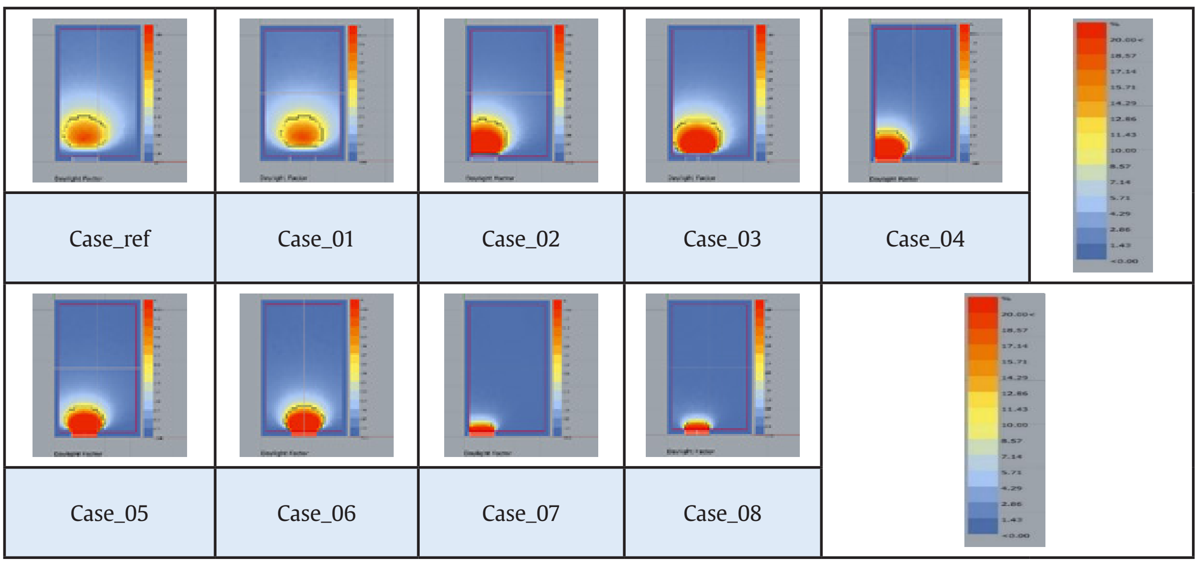


Figure 11: Contour of the Daylight Factor in Case Studies with Different Opening Elongations

DF Based on Opening Position

Among the different positional scenarios, the highest daylight factor (DF) value was recorded in Case 11 at 1.08, while the lowest value was observed in Case 12 at 0.46. This represents a difference of approximately 57% between the best and weakest configurations, indicating a moderate sensitivity of daylight performance to window placement along the facade. A progressive increase in the DF is noted from Case 02 to Case 12, followed by a sharp decline in Values for Cases 13 to 15. This non-linear trend suggests that daylight penetration improves as the window approaches the central area of the facade but decreases when the window is positioned at extreme lateral ends. The results indicate that central placement of the window enhances the efficiency of daylight distribution within the room. However, even in the best-performing case (DF = 1.08), the value remains below the commonly recommended thresholds for adequate daylight provision, which range from 2% to 5% depending on the type of activity. This indicates that simply modifying the window's position is insufficient to achieve optimal daylight performance in the studied configuration.

DF Based on Opening Elongation

In contrast to positional variations, elongation scenarios produced substantially higher DF values. The maximum DF was observed in Case_04 (2.72), while the reference case recorded 0.86. This corresponds to an approximate 216% increase relative to the reference configuration, demonstrating a significantly stronger impact of opening elongation compared to positional adjustment. A consistent upward trend is observed across both horizontal elongation cases (Case_02 to Case_05) and vertical elongation cases (Case_06 to Case_09), reflecting the direct relationship between increased opening area and daylight penetration. However, when comparing horizontal and vertical elongations with equivalent surface areas, horizontal elongation generally resulted in higher DF values. This suggests that widening the opening enhances lateral light distribution more effectively than increasing vertical extension alone. Overall, the data indicate that opening elongation exerts a substantially greater influence on daylight performance than positional displacement. While central positioning improves DF moderately, geometric expansion, particularly in the horizontal direction, produces more pronounced quantitative gains.

Glare Index Analysis

The glare index, measured using the Daylight Glare Probability (DGP), was assessed for June 22 and December 22 (Figs. 12, 13, 14, and 15).

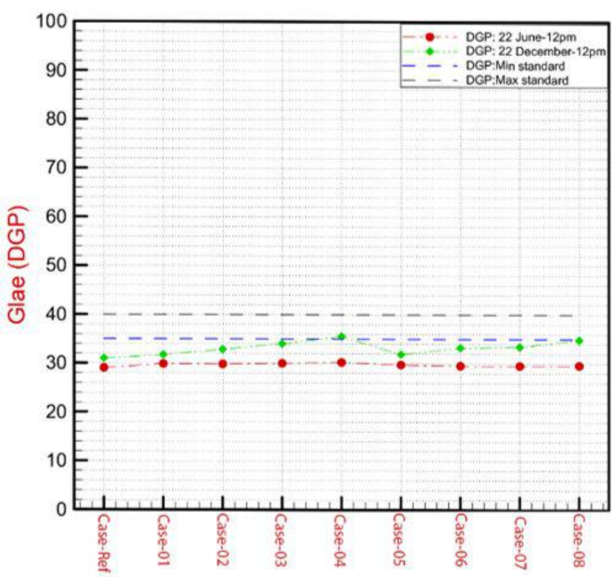


Figure 12: Numerical results of the glare index in case studies with different window elongations (Source: Authors)

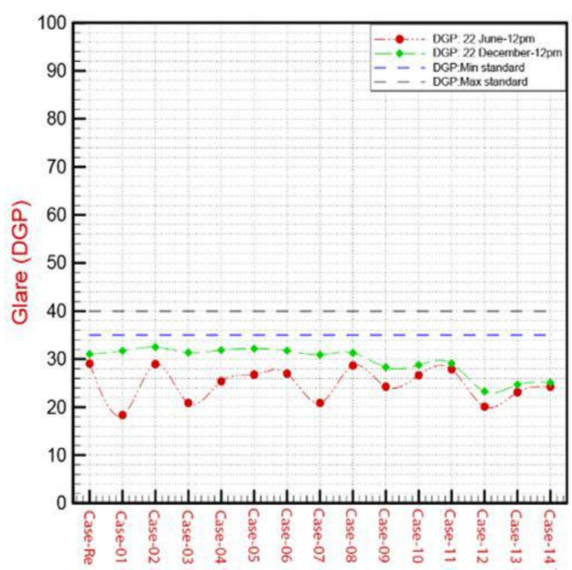
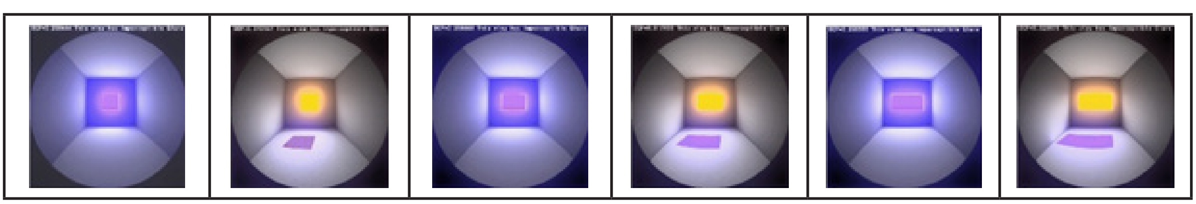


Figure 13: Numerical results of the glare index in case studies with different window positions (Source: Authors)

Figure 14: Graphical output in case studies with different window positions



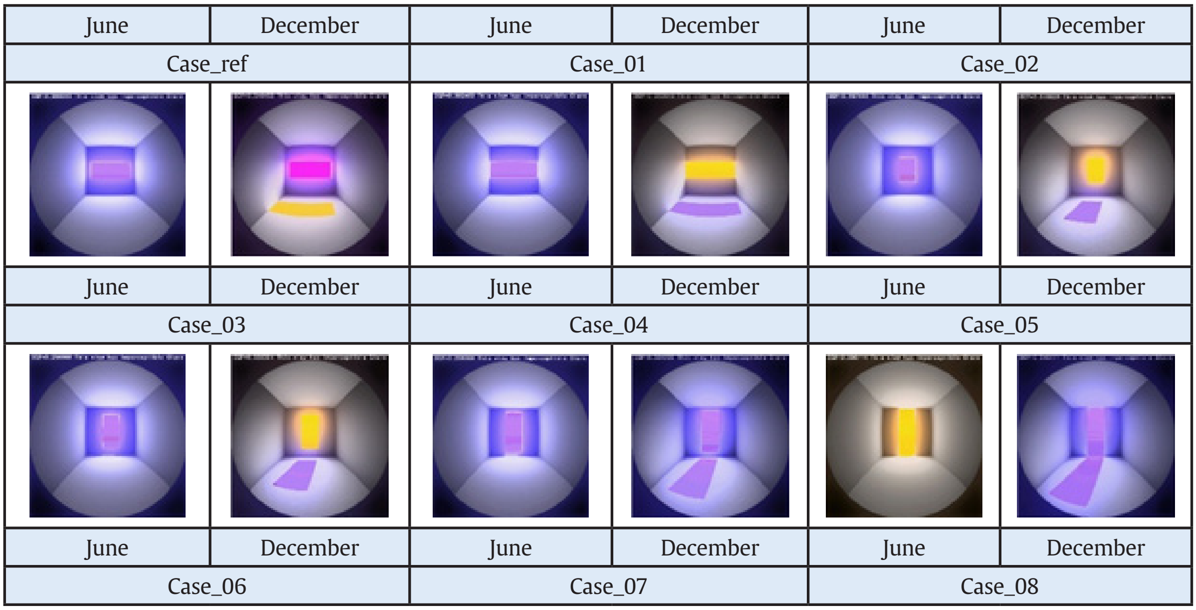


Figure 15: Graphical output in case studies with different window elongations

In the positional scenarios, glare values ranged from 20 (Case-12) to 32 (Case-02), indicating a variation of 37.5% between the extreme cases. All positional configurations remained within or below the acceptable LEED range of 30–40, suggesting that simply displacing windows does not lead to critical glare conditions. In the elongation scenarios, glare values varied from 29 (Case-01) to 35 (Case-04), reflecting a difference of 17%. Case-04 approached the upper threshold for LEED standards, indicating that while increasing the dimensions of openings enhances daylight, it also raises glare levels towards a discomfort boundary. Overall, elongation has a greater impact on glare than positional adjustments. This highlights a measurable trade-off between improving daylight and maintaining visual comfort.

Horizontal Illuminance (E) Index Analysis

Horizontal illuminance was evaluated for June 22 and December 22 (Figs. 16, 17, 18, and 19).

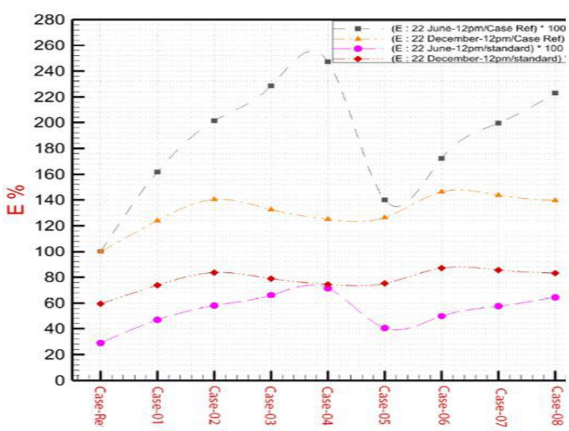


Figure 16: Numerical results of the horizontal illuminance index in case studies with different window elongations (Source: Authors)

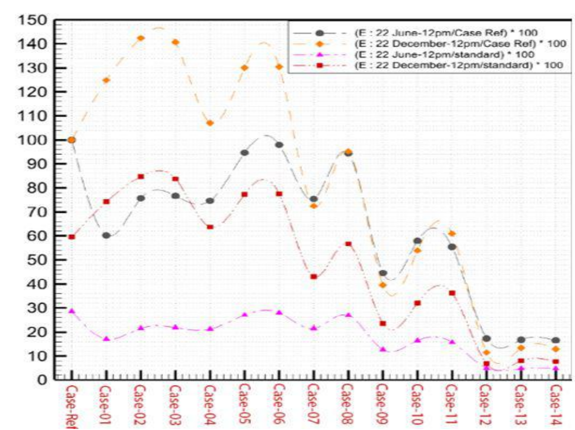


Figure 17: Numerical results of the horizontal illuminance index in case studies with different window positions (Source: Authors)

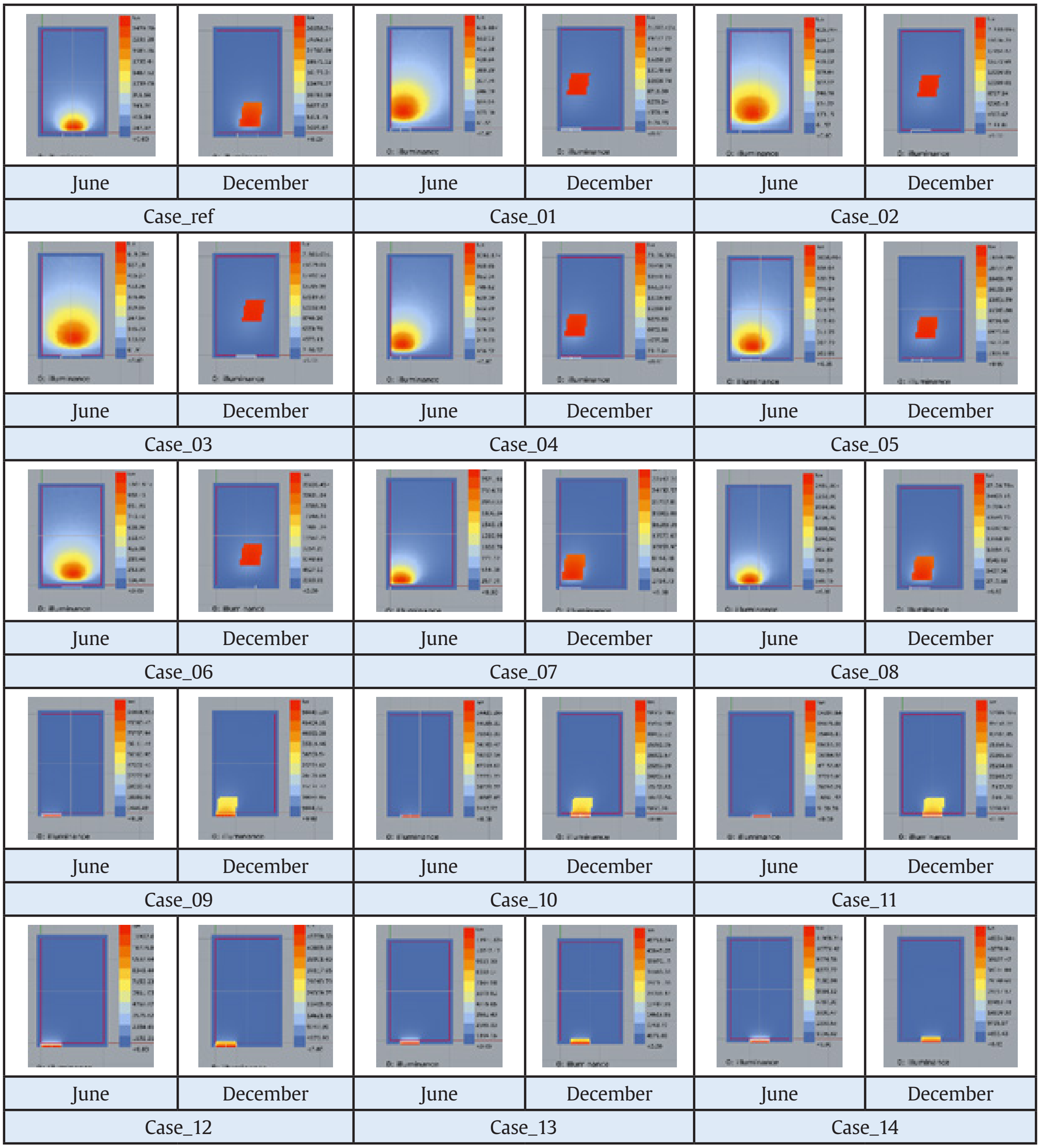
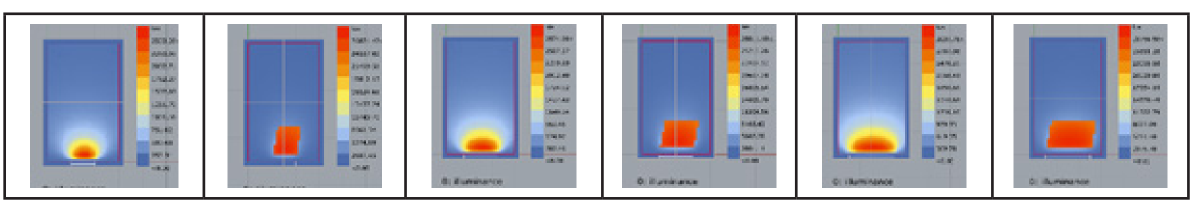


Figure 18: Graphical output in case studies with different window positions



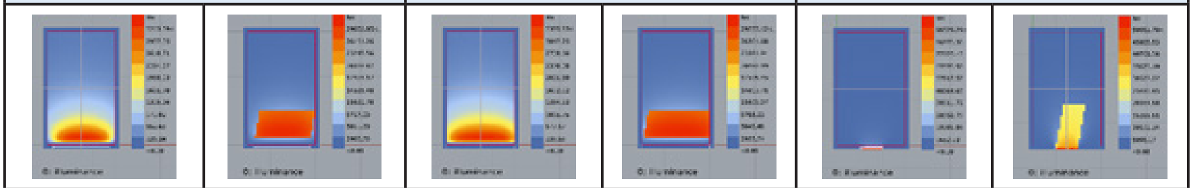
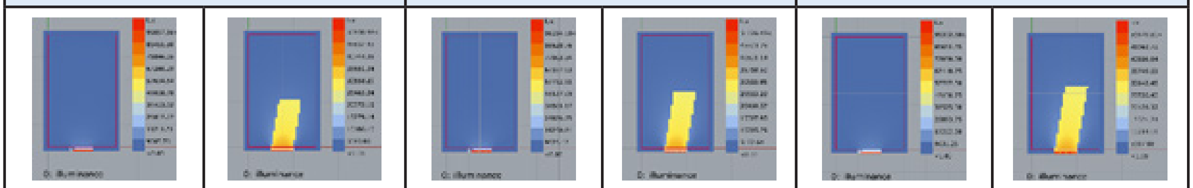
June	December	June	December	June	December
Case_ref		Case_01		Case_02	
					
June	December	June	December	June	December
Case_03		Case_04		Case_05	
					
June	December	June	December	June	December
Case_06		Case_07		Case_08	

Figure 19: Graphical output in case studies with different window elongations

In positional scenarios, illuminance ranged in January from 3.54 (Case 14) to 21 (Case 6), and in December from 5.12 (Case 12) to 63 (Case 2), indicating substantial variation depending on window placement. The December values were consistently higher, reflecting stronger effective daylight penetration under winter conditions.

In elongation scenarios, January values ranged from 35 (Case 5) to 48 (Case 8), while December values ranged from 55 (Case 1) to 65 (Case 6). Compared to positional changes, elongation produced higher and more stable illuminance levels across cases.Despite these variations, all scenarios remained below the LEED threshold requirement (75% spatial compliance), indicating that neither positional nor elongation modifications alone were sufficient to meet standard daylight performance criteria. However, performance in December was consistently closer to the standard compared to January.

CONCLUSION AND RESULTS

This study investigated the influence of window position and elongation on daylight performance and exterior visibility in a south-facing reference room in Tehran. Twenty-two parametric scenarios were simulated using Honeybee and Ladybug to evaluate daylight factor (DF), glare, horizontal illuminance, and view quality. The results were comparatively analyzed to identify relative performance patterns among different geometric configurations. This research examined the relationship between window geometry (position and elongation) and interior visual performance through a controlled parametric simulation framework. The findings indicate that placing the window closer to the central area of the façade tends to improve both exterior visibility and daylight factor values. Additionally, horizontally elongated openings generally demonstrated better overall performance in terms of view quality and daylight distribution compared to vertically elongated configurations. However, no strong or consistent relationship was observed between window position and glare or horizontal illuminance levels. Seasonal variations showed that daylight-related indices were generally closer to recommended thresholds in December compared to January.

It is important to emphasize that the conclusions are derived from simulations conducted on a simplified reference room with a fixed orientation, limited climatic dates, and controlled boundary conditions. The study intentionally isolated geometric variables to identify relative performance trends. Therefore, the findings should be interpreted as comparative design tendencies rather than universally generalizable rules. Future research may extend this framework by incorporating different room proportions, façade orientations, glazing properties, shading devices, and diverse climatic contexts to enhance the robustness and applicability of the results.

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