Original Research Article

Simulating the Amount of lighting and Visibility to the Outside of the Space based on Two Parameters: Position and Elongation of the Opening

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Abstract | Problem Statement: Visibility of the surrounding environment for users requires sufficient light within the space, enabling individuals to perform their activities without eye strain. Additionally, natural light significantly impacts human health. Accordingly, openings, as sources of light and thermal comfort, play a pivotal role in architecture. The quality of window design can substantially affect the quality of indoor lighting and the extent of visibility from the interior to the exterior. This research aims to investigate the role of the position and proportions of openings in determining the quality of indoor lighting and the degree of visibility from inside to outside the space. To evaluate the level of illumination, daylight indicators such as the Daylight Factor (DF), Glare Index (Glare), were utilized. For assessing the visibility to the outside, a View Analysis method was employed. A rectangular space measuring 5×3 meters with a single window of 1×1 meters on its southern façade, located in Shiraz, was considered as the base model. A total of 22 case studies with varying positions and proportions of openings were selected as the study samples. Following simulation and analysis of the cases using Honeybee and Ladybug plugins, the results were analyzed to determine the optimal position and proportions for openings on the facade. The findings indicate that utilizing horizontally elongated openings located centrally on the facade provides the optimal conditions for both outdoor visibility and indoor daylighting.

Keywords | Keywords Honeybee and Ladybug, Outdoor Visibility, Lighting, Window proportions, Window position.

Introduction | In recent years, the positive effects of natural light on human mental and physical health, along with its alignment with the human biological rhythm, have drawn the attention of designers to the renewed use of daylight (Newell, 1995). One of the initial and common solutions was increasing the size of openings in spaces. However, this often causes issues, such as increased energy consumption due to the excessive penetration of solar radiation into the interior

(Ruck, 2000). Openings in buildings not only serve to provide indoor lighting but also have a visual function by enabling views of the exterior. Viewing the outside is considered a key indicator of visual quality in buildings, achievable only through appropriately designed openings. Nonetheless, the lack of optimal dimensions for openings can affect both indoor lighting and outdoor visibility (Demirbas & Demirkan, 2000). Thus, using daylight in contemporary architecture is recognized as one of the fundamental principles of sustainable architecture

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(Zare Mahzabie et al., 2016). Daylight utilization for lighting spaces is significant not only in terms of reducing energy consumption but also for its impact on mental and psychological well-being (Heidari & Jahanienuq, 2014). This has led to the recognition of the biological effects of light in medical and psychological sciences under the term "light therapy" (Kianideh & Masoudi Nejad, 2017). The design of openings, in addition to their aesthetic impact on the building's exterior appearance, has functional aspects, particularly in providing interior lighting and views of the outside. Designers often face two challenges when designing openings: the form and position of the openings in the building's external façade. The form of the opening refers to its geometric shape, as well as its horizontal or vertical elongation, while its position refers to its placement within the external façade. Improper positioning and elongation of openings in modern buildings not only reduce the quality of interior lighting but also impact visibility to the outside, significantly lowering the visual quality of interior spaces. This highlights the considerable impact that the quality of opening design can have on indoor lighting and the extent of visibility from inside to outside. Based on this understanding, the present study aims to investigate the role of two parameters, "position" and "elongation" of openings, in the quality of indoor lighting and the extent of outdoor visibility. For this purpose, a 5x3-meter room with a 1x1-meter opening on its southern side in the city of Shiraz was chosen as the base model. Fourteen case studies with different opening positions and eight with varying horizontal and vertical elongations (1×1.5, 1×2, 1×2.5, and 1×3 meters) were selected for analysis. After simulating and analyzing these models using Honeybee and Ladybug plugins, the results were used to determine the optimal position and elongation of openings in facades.

This study seeks to answer the following questions:

How does the position of openings in a building's external façade impact the quality of indoor lighting and the extent of visibility to the outside?

How do the extent and direction of elongation of openings in the external façade impact the quality of indoor lighting and the extent of visibility to the outside?

Research Background

According to the existing literature, the quality of light can be evaluated using indices such as the Daylight Factor (DF), and Glare (Ghiabaklou, 2013). These indices are explained as follows:

•**Daylight factor (DF)**

 This index measures the ratio of the interior illuminance at a specific point to the exterior illuminance under overcast sky conditions. It can be calculated for a single point or as an average across a space. While the Daylight Factor determines the minimum amount of natural light received in a space, it does not account for the quality of light in terms of visual comfort (The SLL Lighting Handbook, 2009, 132).

•**Glare index**

This index is used as a functional criterion to predict the undesirability of daylight and should fall within an acceptable visual comfort range of 16 to 22 (CIE, 2006). Additionally, the allowable glare level according to LEED standards is between 30 and 40 (Wienold & Christoffersen, 2005). Daylight assessment in a space using the aforementioned indices can be performed through both field measurements and computer simulations (Tahbaz et al., 2022). In the evaluation of lighting conditions through computer simulation, factors such as the geometry and form 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 placed at a specific height (commonly at work surface level), and the lighting data obtained from each sensor are used to calculate the relevant indices. Finally, the simulation results are compared with the standards and lighting codes to provide an accurate interpretation of the findings (Heschong, 2014). The view out of the space is one of the other indicators that is significant in the visual quality of architectural spaces. Therefore, one of the most important functions of openings in a building is the possibility of seeing outside spaces for users. According to research, there is a direct relationship between the value of a building and the amount of view from the inside looking out (Konstantzos et al., 2015). Additionally, the ability to observe natural landscapes from within workplace buildings has a substantial impact on stress reduction and individual attentiveness (Vasquez et al., 2019).

The parameters influencing the quality of views can be categorized into quantitative and qualitative factors. Quantitative criteria include width, depth of view, number of layers, fragmentation of the view, vegetation coverage, age and gender of users, and climatic conditions. Aesthetic quality factors involve dominant elements in the view and the composition of landscapes. Three key elements defining window view quality are content, accessibility, and clarity (Ko et al., 2022). Numerous studies have been conducted on the role of openings in bringing daylight into interior spaces and providing views to the outside. Below is a review of some key research:

Yubo Liu et al. (2023) In their research "Optimizing Modular Classroom Design and Combinations for Enhancing Daylight Performance and Open Space Platform through

ANN Acceleration in the Post-Pandemic Era," the authors proposed a new classroom design. The design aimed to enhance visual comfort, learning, and students' physical health while increasing access to natural light in post-pandemic education spaces. By analyzing six daylighting indicators (SDA, UOD, ASE, OPA, GWL, and SU) across four architectural patterns, they concluded that stepped forms create optimal daylight and outdoor spaces, ensuring abundant natural light for students.

Goharian et al. (2022) In their study "Standardizing a Method for Optimizing Skylight Apertures as Reflective Devices," the authors used the Honeybee and Ladybug plugins in Grasshopper to explore the main optimization indicators for skylight configuration. Their findings revealed that different depths of skylights reflect light rays differently, with skylight height playing a significant role in multiple reflections and overall light distribution.

Shafavi-Moghaddam et al. (2018) Their study "Evaluating the Efficiency of Daylight Metrics in Estimating Adequate Lighting Based on User Assessments" examined the predicted lit areas in 20 design studios in Tehran. The results indicated that users perceived 125 lux as the boundary between dim and moderately lit areas and 350 lux for distinguishing moderately lit and well-lit areas. For long-term evaluations using climate-based daylight metrics (DA), the study found that thresholds of 300 and 150 lux could predict user-perceived boundaries with high accuracy.

•**Key insights from previous research**
Most studies on natural lighting in architecture focus on either theoretical daylight calculations or field surveys.

A significant portion of research emphasizes daylighting, with relatively fewer studies addressing the topic of outdoor views.

Studies on outdoor views tend to focus on computational and line-of-sight analysis, with fewer works adopting simulation-based methods. Daylighting and outdoor views are often studied separately, with limited research examining both aspects simultaneously.

Contribution of the Present Study

This study aims to explore the simultaneous role of window position and elongation in enhancing both indoor lighting quality and views to the outside using numerical simulation methods. By integrating these two factors, the research provides a novel approach to optimizing the dual functionality of openings in architectural design.

Research Method

As mentioned earlier, the main goal of this research is to examine the role of the shape characteristics of openings on the amount of daylight and the view from inside to outside the space. The space under study in this study was a room measuring 3×3×5 meters on the ground floor with a southern orientation. Different shapes of openings on the southern facade (as shown in Figs. 1 & 2) are analyzed. The shape characteristics of the openings, including their "position" and "elongation," are considered independent variables, while the amount of "daylight" and "view from inside to outside" are considered dependent variables. n order to measure the level of illumination, the indices of daylight (DF), glare were used, and to measure the
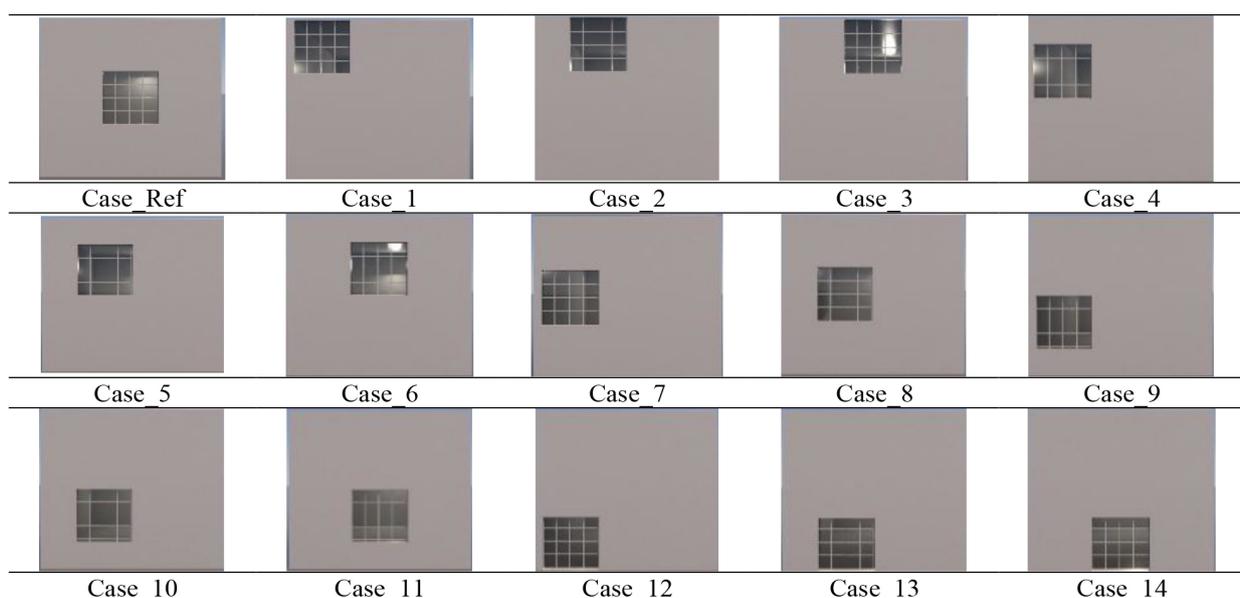

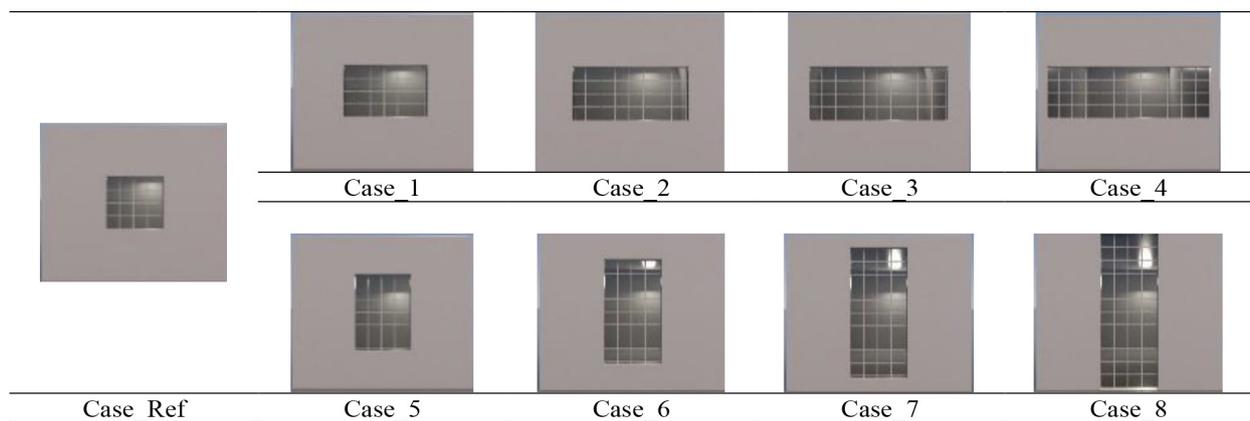Fig. 1. Case Study Samples Based on Opening Position on the Southern Facade. Edited by. Source: Authors.

Fig. 2. Case Study Samples Based on Opening Elongation on the Southern Façade. Source: Authors.

outward visibility index, the visibility of the outdoor space from inside the space in two positions: standing (160 cm from the ground) and sitting (105 cm from the ground). The case studies of the study are introduced in the following figs:

The simulations were conducted in the Grasshopper environment using the Honeybee and Ladybug plugins. First, 3D models of the case studies were drawn in Rhino version 6, and the variables were analyzed in Grasshopper. Then, using the Honeybee and Ladybug plugins, the dependent variables for each of the case studies were measured and analyzed. The case studies were analyzed in the climate of Shiraz on two specific dates: January 22 and December 22. The climatic data for Shiraz was used in the form of an EPW file and a STAT file for the simulation (Iran's Comprehensive Climate and Meteorology Website, 2019).

Research Findings
• Daylight
- Analysis of the daylight factor (DF)
As mentioned earlier, the Daylight Factor represents the ratio of indoor illuminance to outdoor illuminance under overcast conditions (Hopkinson, 1963). The amounts of this index for case studies with different positions and elongations are shown in Figs 1 - 4.

Based on the data presented above, the highest and lowest daylight factor values in case studies with different opening positions were observed in Case-11 and Case_12, with values of 1.08 and 0.46, respectively.

Additionally, based on the numerical results obtained (Fig. 3), a noticeable increase in Df values is observed from Case 02 to Case_12. However, in Case_13 to Case_15, there is a sudden and significant decrease in the values of this index. This indicates an increase in the daylight factor due to the placement of the window in the central part of the facade. In simpler terms, the closer the window is to the center of the facade, the higher the amount of daylight inside the room.

In the case studies based on different window elongations (Fig. 4), the highest and lowest daylight levels were recorded in Case- 04 and Case_ref with values of 2.74 and 0.86, respectively. Additionally, by observing the trend of the graph in Case_02 to Case_05 (horizontal window elongation) and Case_06 to Case_09 (vertical window elongation), it is evident that the numerical value of the daylight factor increases, which is due to the increased window surface area in these cases. However, comparing the horizontal and vertical cases with the same surface area indicates that, in general, horizontal window elongation leads to a greater increase in the daylight factor within the space. This index represents the ratio between the illuminance inside the space and the illuminance outside the space in an unobstructed environment under overcast sky conditions. It is calculated separately for each specific point on the work surface; however, it is generally averaged into a single number for evaluating the entire space, and its threshold varies from 2% to 5% depending on the type of activity (Nabil & Mardaljevic).

- Glare Index Analysis
The glare index in this study was evaluated based on data extracted from case samples on the first two days of July (June 22) and December 1 (December 22). The data related to this section are presented in Figs 7 and 8. Based on the data presented above, the highest and lowest levels of glare in the case studies with different window positions in both December and January were observed in Case-02 and Case-12, respectively. Additionally, the highest and lowest levels of this index in the mentioned months, in the case studies with different window elongations, were related to Case-04 and Case-01, respectively. Given that
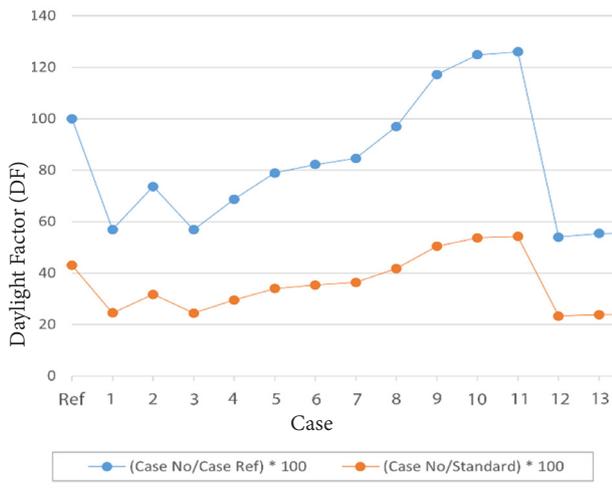
Fig. 3. Numerical Results of the Daylight Factor in Case Studies with Different Opening Positions. Source: Authors.
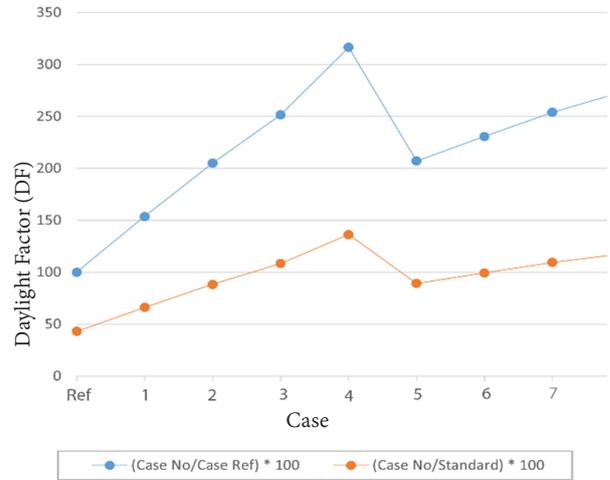
Fig. 4. Numerical Results of the Daylight Factor in Case Studies with Different Opening Elongations. Source: Authors.

the permissible glare level according to LEED standards is between 30 and 40 (DGP), except for Case-04 (in the case studies with different window elongations), the other case studies fall below the standard limit. Furthermore, the data from Figs 7 & 8 show that the glare levels in the case studies in December were closer to the standard limit compared to January.

• **View**
- **Position of the opening**
In the analysis of the view to the outside, the observer's position, whether standing or sitting, was analyzed in various parts of the room. The results are presented in Figs. 9 & 10.
The results show that, in general, the amount of view to
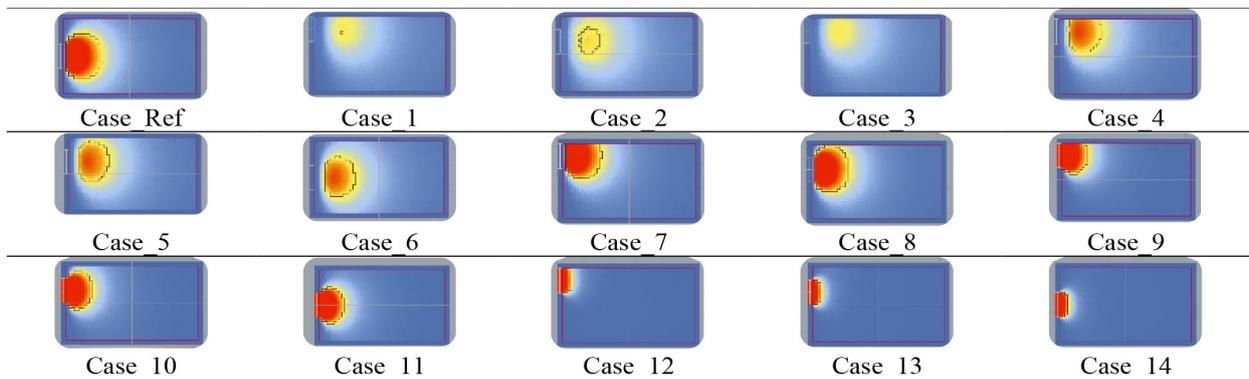

Fig. 5. Contour of the Daylight Factor in Case Studies with Different Opening Positions. Source: Authors.
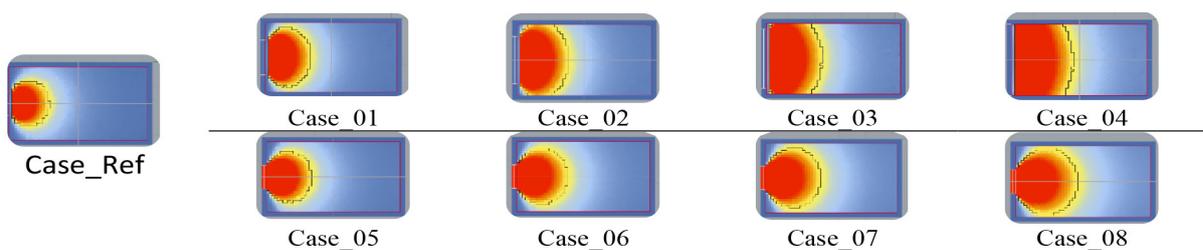

Fig. 6. Contour of the Daylight Factor in Case Studies with Different Opening Elongations. Source: Authors.
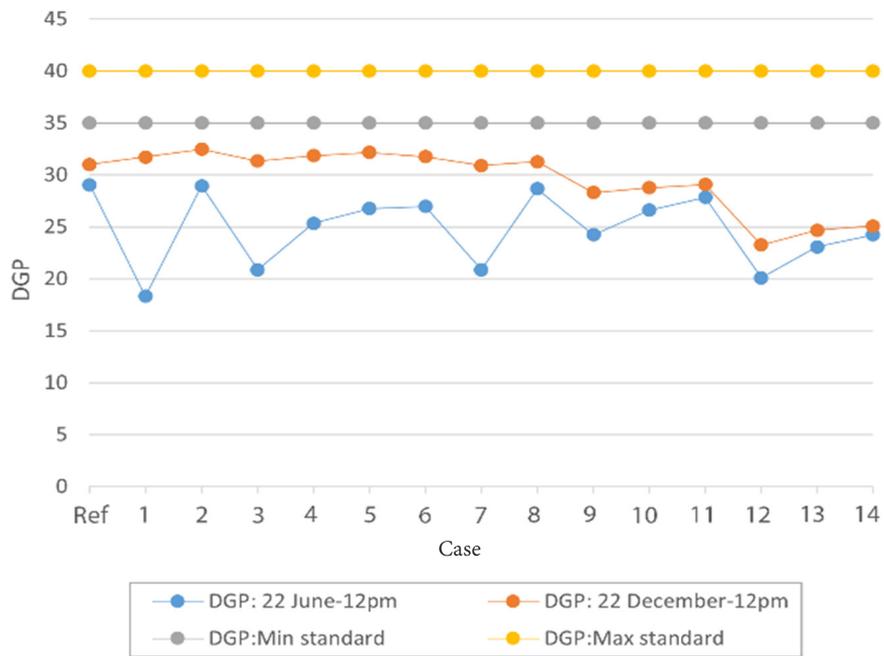
Fig. 7. Numerical results of the glare index in case studies with different window positions. Source: Authors.
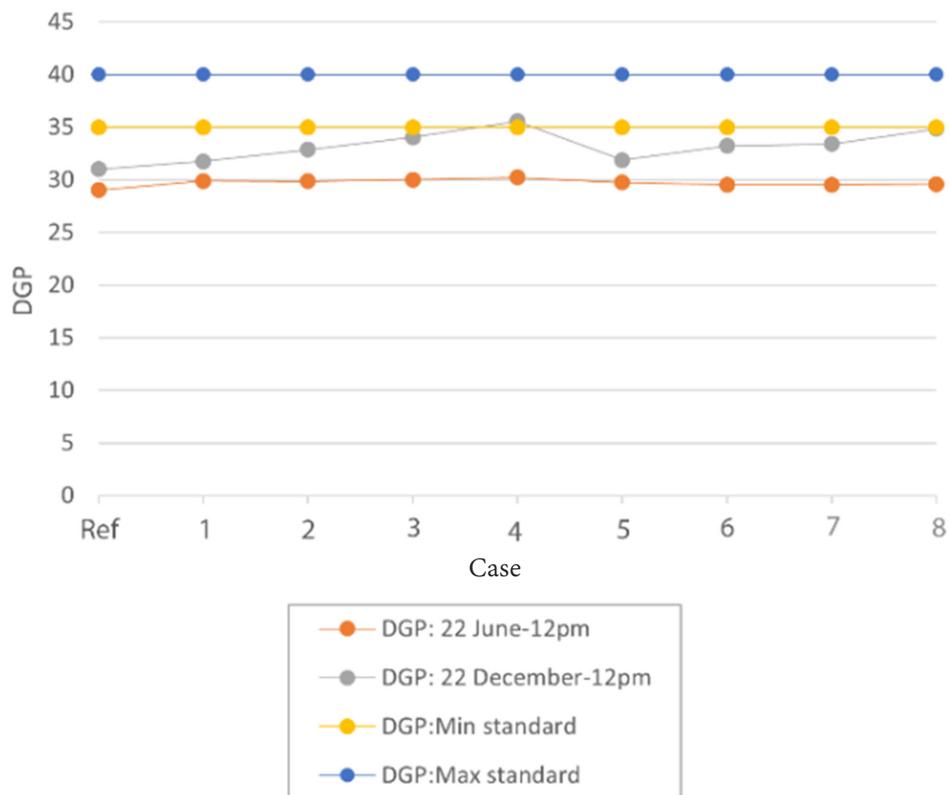

Fig. 8. Numerical results of the glare index in case studies with different window elongations. Source: Authors.
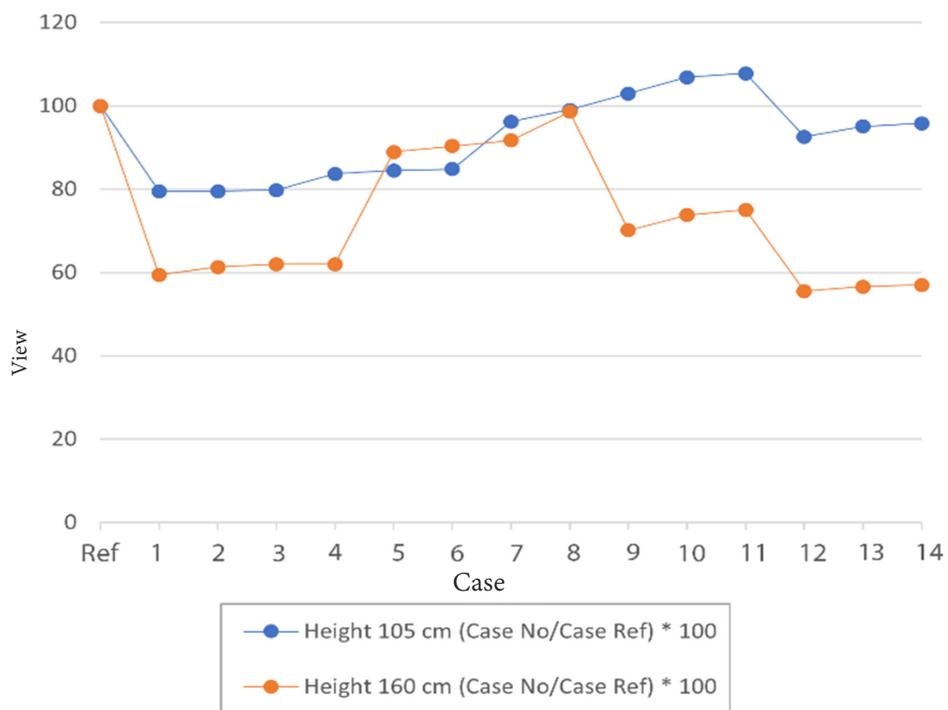
Fig. 9. Contour of the View to the Outside in Case Studies with Different Opening Positions. Source: Authors.
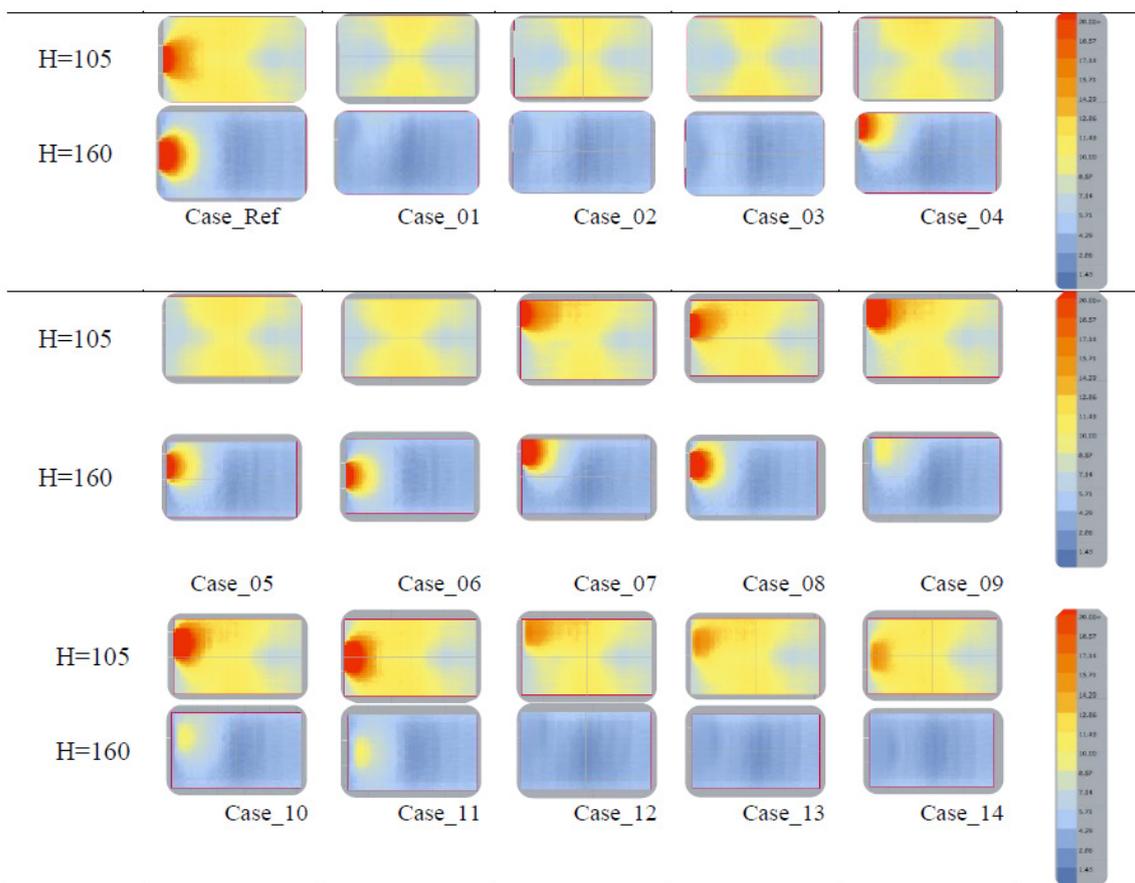

Fig. 10. Numerical Results of the View Index in Case Studies with Different Opening Positions. Source: Authors.

the outside is greater when sitting (H=105) compared to standing (H=160). On average, in all case studies, 9% of the room's area had a view to the outside when sitting, whereas this figure decreased to 4% when standing. In other words, when sitting, a larger portion of the room's area has a view of the outside.

• **Opening elongation**

In this section, the amount of view to the outside was also analyzed based on the elongation of the opening, both while sitting and standing. The results are presented in Figs. 11 & 12.

According to Fig. 11, the amount of outward visibility in all case samples (both in standing and sitting positions) is greater than that of the reference sample, which is of course due to the increase in the opening area due to the change in its elongation. Also, examining the samples shows that the highest and lowest amount of outward visibility in the sitting position was obtained in sample 4 and the base sample, with percentages of 14.63% and 9.76%, respectively, and in the standing position in sample 4 and the base sample, with percentages of 11.95% and 5.56%, respectively. Also, comparing the case samples with the reference sample in the sitting and standing positions, it is observed that all samples had a greater amount of outward visibility than the reference sample (base sample).

Conclusion

The subject of this research was the analysis of the role of window position and elongation on the amount of outside view and indoor lighting. Accordingly, 22 case studies based on two criteria window position and elongation in a room measuring 5×3 square meters were selected, modeled in Rhino software, and then simulated using the Honeybee and Ladybug plugins. The most important findings of the research are as follows:

• **Window position**

The closer the window is to the central part of the facade, the better the outside view will be.

The closer the window is to the central part of the facade, the greater the amount of daylight inside the room. There is no significant relationship between window position and glare index. However, in general, the glare level in December was closer to the standard compared to January.

• **Window Elongation**

The more horizontal elongation the window has, the better the outside view will be.

The more horizontal elongation the window has, the better the daylight index is.

In horizontal windows, the glare index is in a more appropriate position.

Based on the findings above, it can be concluded that the optimal position for a window on a facade is its placement in the central part of the wall. In this configuration, the observer inside the space has the best outside view, and the best results are obtained for daylight indices, including glare and illuminance levels. Additionally, horizontally elongated windows perform better in all these indices compared to vertically elongated ones. Thus, it can be generally stated that a horizontally elongated window positioned centrally on the facade creates optimal conditions for an outside view and daylight inside the space. It should be noted that different conditions and results are obtained in different climates, and climatic conditions such as angle of incidence, sunlight intensity, temperature, and humidity can produce different responses.
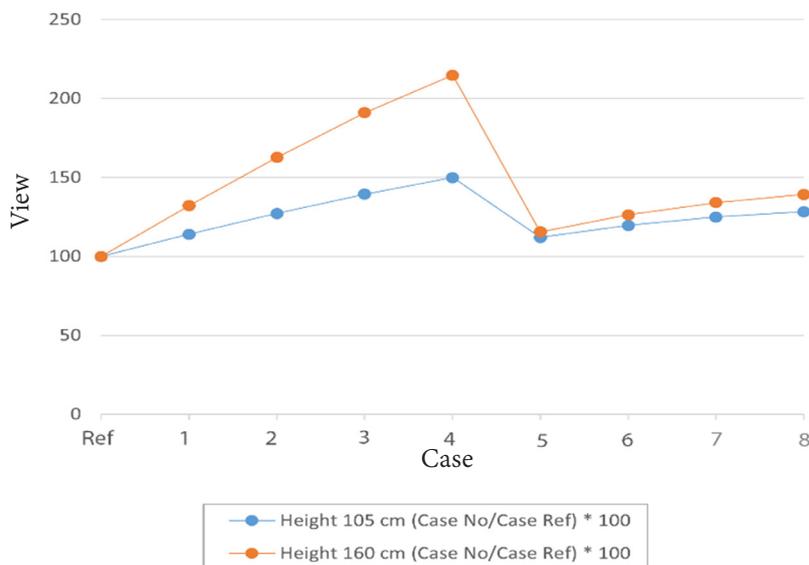

Fig. 11. Contour of the View to the Outside in Case Studies with Different Opening Elongations. Source: Authors.
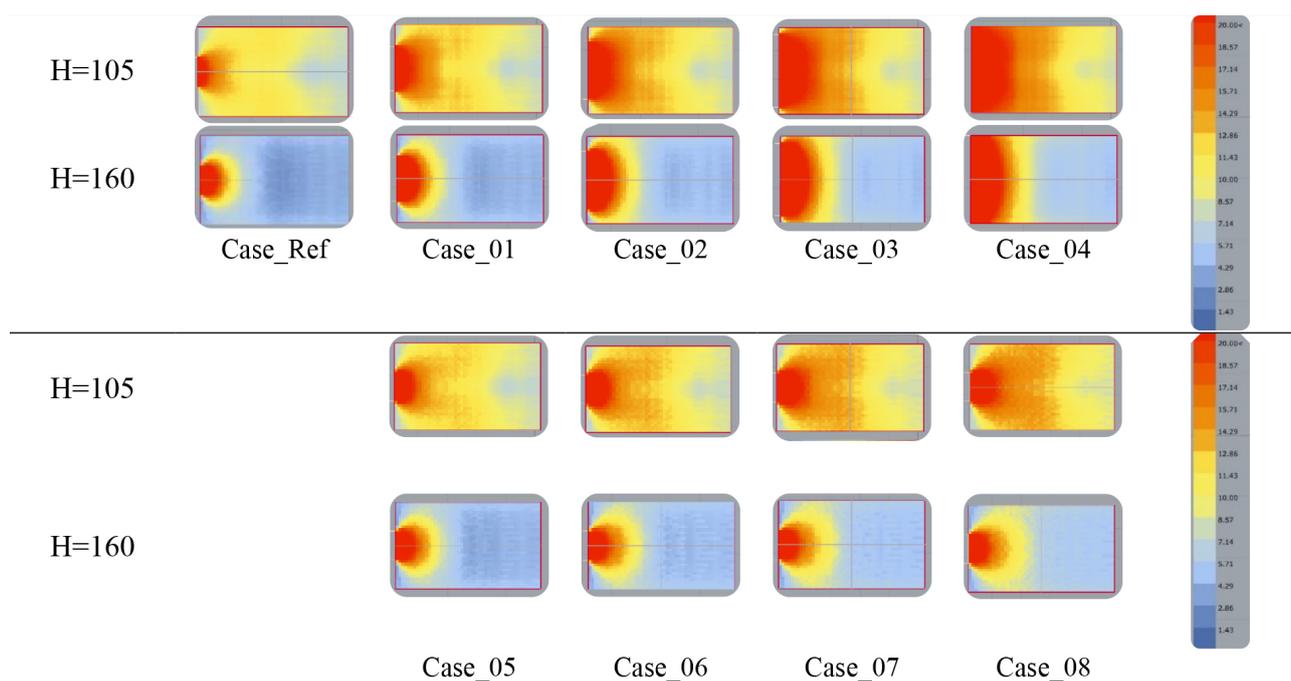
Fig. 12. Numerical Results of the View Index in Case Studies with Different Opening Elongations. Source: Authors.

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