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Article

Climate-responsive daylight system design for primary schools in Türkiye

Gökçe ERDEMİR ŞENDUR*, Alpin KÖKNEL YENER

Department of Architecture, Istanbul Technical University, Istanbul, Türkiye

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ABSTRACT

Passive systems are currently the preferred method in architectural design for enhancing energy efficiency in buildings. Utilizing daylight as the primary light source in buildings meets the visual, psychological, and physiological needs of users while avoiding the negative effects of direct sunlight. Therefore, passive systems are widely favored in architectural design to promote energy efficiency. It is essential to use natural lighting as a passive system to reduce a building's energy needs for lighting. Additionally, it creates an appealing visual atmosphere while maintaining comfort requirements.

The daylight criteria for providing sufficient daylight in educational buildings were evaluated in this study related to the TS EN 17037+A1 standard. The study aimed to establish an optimal approach for determining direction, obstruction, and façade design parameters that will ensure sufficient daylight in primary school classrooms in different climatic regions of Türkiye. The study's main focus was to develop a framework for classroom design in educational buildings that takes into account the provision of adequate daylight while avoiding discomfort glare.

"The Minimum Design Guide for Educational Buildings" is a guidebook for constructing educational buildings in Türkiye. However, it lacks detailed specifications for dynamic variables of the environment and interior components. To address this issue, the guide should be improved according to the latest standard of TS-EN 17037-A1, which provides guidelines for daylight design in buildings.

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INTRODUCTION

From the early beginning of building design in history, the aim of utilizing daylight has played an active role in settlement decisions, building shaping, and facade design. In today's world, it has become an accepted fact that conscious consumption is essential due to the depletion of energy resources. Therefore, today's architecture prioritizes the efficient use of daylight and reducing lighting energy consumption as one of its main purposes (Mardaljevic, Heschong, & Lee, 2009).

For an efficient lighting application, in addition to the required illuminance level, it is essential to meet the qualitative needs (Kocagil, 2022), (Türk Standardları Enstitüsü, 2021). Additionally, adequate daylight provision is the primary objective of natural lighting systems.. Achieving the proper distribution of daylight is crucial to fulfill the user's visual performance as well as their psychological and physiological needs, while avoiding the negative consequences of direct sunlight (Illuminating Engineering Society, 2013). Architectural design is

***Corresponding author**
*E-mail adres: gokceerdemir@gmail.com

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significantly influenced by climatic conditions, from the urban to the building scale. Climate-responsive design is an increasingly important consideration in today's architecture (Littlefair, 2011). Presently, passive systems are predominantly favored in the architectural design of buildings to enhance energy efficiency. One of the most prominent passive systems employed is daylighting, which is the primary lighting system for all buildings with daylight openings. Utilizing natural lighting as a passive system is crucial in reducing the building's energy requirements for lighting and creating a desirable visual environment while ensuring comfort requirements (Illuminating Engineering Society, 2013). Furthermore, learning spaces where students spend much of their early life play a crucial role in their cognitive, physiological, and social development (Duyan & Ünver, 2022). Additionally, access to natural daylight benefits human well-being, both physiologically and psychologically, as it positively impacts human health and environmental conditions (Turan, Chegut, Fink, & Reinhart, 2020).

It is highlighted in the TS-EN 17037-A1 standard that giving priority to natural lighting as a passive system is crucial for reducing the energy needed for building lighting, establishing an inviting visual atmosphere, and ensuring comfort. Spaces should be illuminated by daylight for a considerable part of the annual daylight hours (Türk Standartları Enstitüsü, 2022).

The 'TS-EN 17037-A1: Daylight in Buildings' standard, approved by CEN on 29 July 2018 and last updated on 2 March 2022, is a comprehensive and up-to-date guide for evaluating daylight in indoor areas. The standard takes into account various environmental and climatic factors that affect daylight performance. It outlines four main criteria for assessing daylight in interior spaces: 'daylight provision, view out, exposure to sunlight, and protection from glare' (Türk Standartları Enstitüsü, 2022). Additionally, the standard recommends a classification for daylight assessments in three levels: 'minimum, medium, and high'. Moreover, the recommendations for these assessments are mentioned in Table 1.

In this study, the criteria for providing daylight in educational buildings were examined in accordance with the TS-EN 17037-A1 standard. The main purpose was to develop an approach to determine the optimum values of direction, obstruction, and façade design parameters for different climatic regions of Türkiye in the context of providing sufficient daylight in the classroom design of primary school buildings.

Türkiye is located in a wide geography that has a variety of five different climate zones. This article focuses on the optimal conditions for two of these climate zones, with representative provinces of Istanbul and Antalya. Variable scenarios of direction, façade design, and obstruction were assessed according to the criteria of daylight provision and protection from glare recommended in TS-EN 17037-A1. The aim is to create a comprehensive design proposal

Table 1. Assessment of Daylight Performance for indoor areas as defined in TS-EN 17037-A1

Daylight Assessments			**Recommended Levels**		
			Minimum	**Medium**	**High**
	% area	**% Daylight Hours**			
Daylight Provision					
Target Illuminance (lx)	50%	50%	300lx	500lx	750lx
Minimum Target Illuminance (lx)	95%	50%	100lx	300lx	500lx
View Out					
Horizontal sight angle			≥14°	≥28°	≥54°
Outside distance of the view			≥6 m	≥20 m	≥50 m
Number of layers to be seen from at least 75% of utilized area			1 (Landscape)	2 layer	All layers
Exposure to sunlight					
Recommended number of hours (h) for a given reference day (between February 1st - March 21st) that a space should receive sunlight			1.5 h	3 h	4 h
Protection from glare					
DGP-value, that is not exceeded in more than 5 % of the occupation time			0,45	0,4	0,35

that takes into account the climatic conditions and design variables for educational buildings to be built in Türkiye, which will be used from the early beginning of the design process.

METHOD

The classroom model created for this purpose was designed according to the criteria specified for primary school classrooms in the 'Educational Buildings Design Standards Guide', which was prepared by the Ministry of National Education (MEB) for educational buildings in 2013 and revised in 2015 (MEB, 2015).

In order to make an accurate comparison, it is necessary to determine variable and invariable assumptions for analysis. The steps of the method improved within the scope of the study are outlined in Figure 1.

The first step involves making preliminary decisions by identifying design variables and constants. After determining these parameters, a number of 200 classroom models are created and evaluated based on the daylight criteria of daylight provision and protection from glare as recommended in TS-EN 17037-A1. Finally, the optimal combinations of climatic conditions, direction, obstruction, and façade design are determined in order to contribute to the design guide for educational buildings to be built in Türkiye.

Preliminary Design Decisions

The generated model to be analyzed is a primary school classroom designed with optimum dimensions based on the criteria specified for primary school classrooms in the 'Minimum Design Standards Guide' published by the Ministry of National Education (MEB, 2015), which was published in 2013 for educational buildings and revised in 2015.

Based on the specifications outlined in the guide, the classroom model that has been generated possesses a capacity of 30 pupils. The classroom design is intended to provide each student with a minimum of 1.60 square meters of usage area. Additionally, in the 'mechanical installation standards' section of the guide, the internal air quality standard states that the breathable air volume per student in primary education buildings is at least 5m^3 (MEB, 2015). Accordingly, the estimated amount of breathable air per student in a classroom with a total volume of 201.6 m^3 is 6.72 m^3, which exceeds the requirement.

Dimensions of the classroom are 7m x 8m with a height of 3.6 meters. The window is positioned on one side and furnishing of the classroom generated in order to allow daylight to reach the students from the left side. According to the guidelines outlined in the manual, the window area of the generated classroom model has been designed with the recommendations with a minimum transparency ratio (window area/wall area) of 50%. However, alternative design scenarios need to be considered since the current

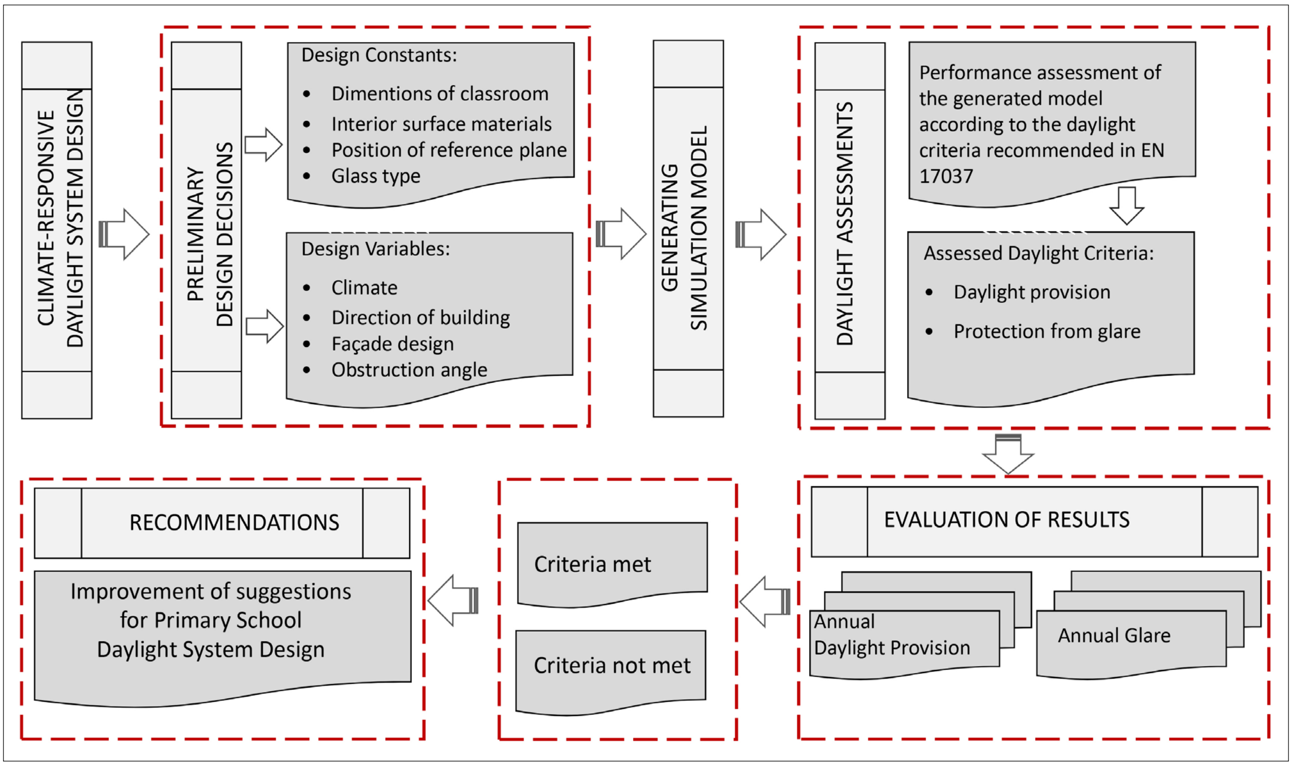


Figure 1. Method of the Study.

guidelines do not provide specific transparency ratios that would be responsive to the variables. Transparency ratios of 40% and 30% were generated to account for different requirements in current calculation methods, which consider variables such as direction, climate characteristics, and obstacle conditions. In addition, a total of 5 façade scenarios were created with attached and separate layout alternatives for 30% and 40% transparency ratios. The detailed window specifications of the classroom model with alternative façade designs appear in Figure 2.

The values of constant design parameters are listed below:

Constant Parameters of Indoor Workspace:

- Number of users of the classroom: 30 pupils
- Dimensions of classroom: 8m length, 7m width, 3.6 m height
- Window location: One side-long wall
- Glazing: 5.8mm - 12.7mm - 5.7mm (outside to inside)
- U value of glazing: 1.81 W/m²K
- Visible transmittance value of glazing (TVIS): 0.804
- Reflectance of interior surfaces: ceiling:0.7, interior walls:0.51, floor: 0.23
- Reference plane: 0.75m from the floor, 0.50m offset from walls

Constant Factors of Exterior Workspace:

- Reflectance of exterior surfaces: exterior walls:0.29, exterior ground: 0.21

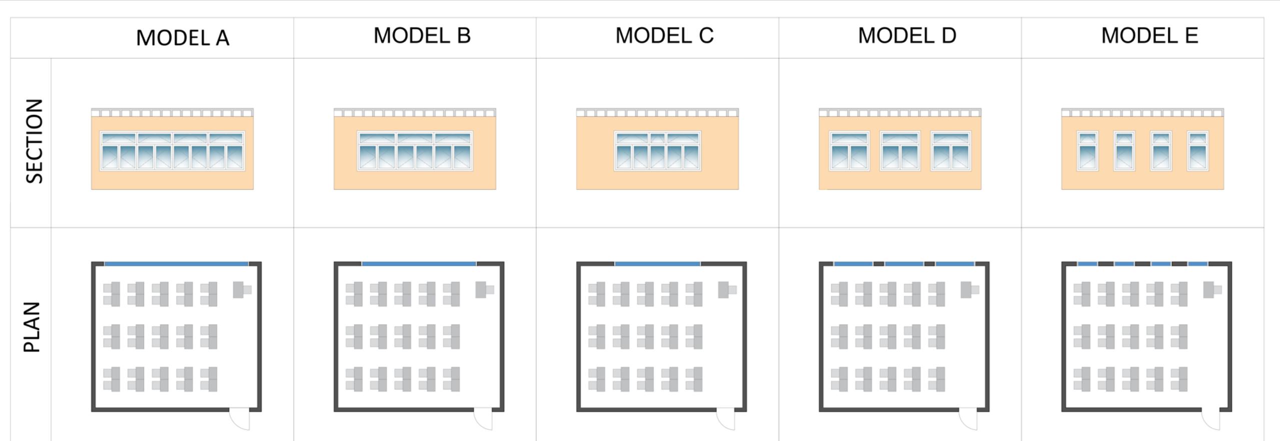
Variable Parameters:

- Location: İstanbul (temperate humid climate), Antalya (hot humid climate zone)
- Direction of window opening: South, North, East, West
- Transparency ratio: 50%, 40%, 30%
- Window orientation: attached, separated
- Obstruction angle: 0°, 20°, 30°, 40°, 50°

A total of 200 simulations were conducted to explore alternative scenarios for variables such as climate, direction, façade design, and obstruction angle.

Because the study aims to produce a guide that takes into consideration different climatic conditions, 2 different cities are chosen for daylight performance assessment. For this purpose, the optimum conditions for Istanbul (temperate humid climate), located on a latitude of 41°00'49"N and longitude of 28°57'18"E; and Antalya (hot humid climate), on a latitude of 36°53'15"N and longitude of 30°42'27"E provinces, are compared. It is aimed to create a design proposal for educational buildings to be built or renovated in Türkiye.

The classroom model was developed with consideration of various orientations: north, south, east, and west. Moreover, 5 different façade designs, which include alternative transparency ratios of 50%, 40%, and 30% in addition to separated and attached arrangements of 40% and 30% alternatives, were considered. It is assumed that the



WINDOW SPECIFICATIONS

MODEL A		MODEL B		MODEL C		MODEL D		MODEL E	
Width (m)	7,2	Width (m)	5,75	Width (m)	4,32	Width (m)	2,02x3	Width (m)	1,08x3
Height (m)	2	Height (m)	2	Height (m)	2	Height (m)	2	Height (m)	2
Parapet Height (m)	0,9	Parapet Height (m)	0,9	Parapet Height (m)	0,9	Parapet Height (m)	0,9	Parapet Height (m)	0,9
Window Area (m2)	14,4	Window Area (m2)	11,5	Window Area (m2)	8,64	Window Area (m2)	11,5	Window Area (m2)	8,64
Transparency ratio	50%	Transparency ratio	40%	Transparency ratio	30%	Transparency ratio	40%	Transparency ratio	30%
Window arrangement	A	Window arrangement	A	Window arrangement	A	Window arrangement	S	Window arrangement	S

Window arrangement types: Attached (A) /Seperated (S)

Figure 2. Classroom plan - section with varied façade designs.

Table 2. Interrelation Between Permitted Road Width and Floor Numbers of Obstacle Buildings According to 'Building Bylaws' published in 2017

Type	Road width (RW) acc. to Building Bylaws	Maximum number of floors allowed	Approximate Obstruction Angle
1	RW ≤ 7.00 m	2	20°
2	7.00m < RW ≤ 10.00 m	30°	30°
3	10.00m < RW ≤ 12.00 m	4	30°
4	12.00m < RW ≤ 15.00 m	5	35°
5	15.00m < RW ≤ 20.00 m	6	40°
6	20.00m < RW ≤ 25.00 m	8	40°
7	25.00m < RW ≤ 35.00 m	10	45°
8	35.00m < RW ≤ 50.00 m	14	50°
9	50.00m < RW	18	55°

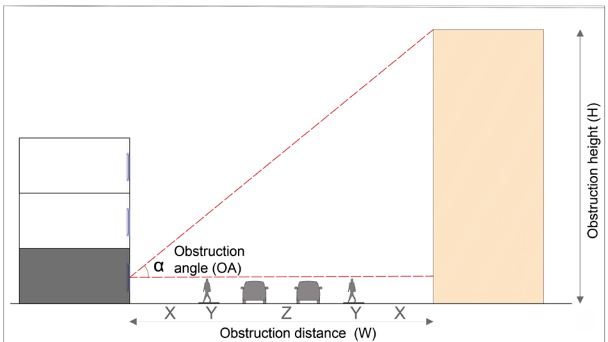
classrooms are located on the ground floor as recommended in the Minimum Design Guide for Educational Buildings, and calculations were made for the ground floor, which is the most negative situation in the simulations. Thereby, a total of 200 alternative classroom models generated according to the parameters mentioned were evaluated according to the criteria of daylight provision and protection from glare.

The building height is determined as 12 meters (3 floors) based on the maximum number of floors allowed for primary education buildings in the 'Educational Buildings Minimum Design Standards Guide' (MEB, 2015). The criteria in the Building Bylaws were accepted as a basis when determining obstruction distances and building heights of obstacles (Resmi Gazete, 2017). Additionally, it is accepted that all obstacles are permanent. The interrelation between permitted road width and the number of floors is given in Table 2.

Within the scope of the study, the scenarios created relating to the interrelation between permitted road width and number of floors according to obstruction angle alternatives of 0°, 20°, 30°, 40°, and 50° were evaluated. For the created classroom models, representative scenarios for obstructions are generated based on the road width - number of floors relationship specified in the 'Building Bylaws Regulation for Planned Areas', which was last published in the Official Journal of Türkiye in 2017. Road width and building height interrelation are represented as type 2 for a 30° obstruction angle, and type 5 for a 40° obstruction angle as mentioned in the Building Bylaws. According to Building Bylaws regulations, an obstruction angle of 0° assumes there are no obstacles in front of the building (Resmi Gazete, 2017). Obstruction angle scenarios to be applied in alternative scenarios are presented in Figure 3.

Daylight Assessment

As stated in the daylight provision criteria, daylight illumination must be provided for a significant part of the year for daylight hours. The daylight illumination provided depends primarily on the climatic conditions, then on the neighboring structures surrounding the building, building openings, surrounding building elements, and the configuration of indoor spaces (Türk Standartları Enstitüsü, 2022). In order to provide the required daylight illumination within the indoor space, the target illuminance level (ET) should be provided with daylight for 50% of the space and at least half of the annual daylight hours, while the minimum target illuminance level is desired to be achieved with daylight for at least half of the annual daylight hours in 95% of the space (Türk Standartları Enstitüsü, 2022), (Mardaljevic & Christoffersen, 2017). The standard also recommends that the reference plane height should be taken as 0.85m unless otherwise specified. As the study focuses on elementary school classrooms, the reference plane is taken to be at a height of 0.75m, which is due to the desk height suitable for primary school students.



Obstruction angle (OA)	50°	40°	30°	20°	0°
Obstruction distance (W)	39m	29m	24m	16m	-
Obstruction height (H)	56m	24m	16m	8m	-
H/W	1,43	0,82	0,66	0,5	
X distance	5m	5m	5m	3m	-
Y distance	1,5m	1,5m	1,5m	1,5m	-
Z distance	26m	16m	11m	7m	-

Figure 3. Obstruction angle scenarios.

In this article, two criteria for daylight are assessed, which are daylight provision and protection from glare. Table 1 provides a classification of these criteria. The target illuminance level was accepted as 300 lux, which is the recommended threshold level for primary school classrooms (MEB, 2015). A minimum illumination level of 100 lx is needed to ensure optimal visual comfort for students.

Calculation Method

The classroom was modeled with the 'Rhino 7' software, and daylight simulations were conducted using Climate Studio, which is a plug-in that employs validated simulation engines Energy Plus and Radiance to assess dynamic visual performance parameters. Additionally, the created models are assessed in terms of annual daylight performance using daylight criteria according to the TS EN 17037 standard included in the software. The daylight performances throughout the year have been determined by means of the daylight autonomy method. The daylight autonomy method was utilized to compute the potential of achieving the desired illuminance levels for half of the daylight hours in a year (Reinhart, Mardaljevic, & Rogers, 2013). The calculations were based on the climate data of Istanbul and Antalya provinces gathered from Energy Plus.

CALCULATION RESULTS

A total of 200 simulations were conducted for the alternative scenarios for climate, direction, façade design, and obstruction angle variables. The results are assessed according to two of the assessments mentioned in the TS-EN 17037 standard: daylight provision and protection from glare. The results are evaluated under subheadings of direction, façade design, obstruction angle, and climate.

Assessments for Daylight Availability

The main objective of the study is to determine the optimum visual performance parameters for the user to maintain their work tasks and activities in classrooms. For this purpose, evaluations for the sufficiency of daylight are completed for variations of climate, direction, façade design, transparency ratio, and obstruction angle in order to prepare a detailed guide for the daylight design of primary schools in Türkiye. Rhino 7 was used to create classroom models, which were then analyzed using 'Climate Studio' software. The simulation results were generated using the EN 17037 workflow within the Climate Studio plug-in.

An annual climate-based simulation is used to calculate compliance for interior illuminance distributions (IES Daylight Metrics Committee, 2012). The criteria for compliance measure the percentage of the floor area that achieves minimum and target illuminance level thresholds for each hour of the year. To meet compliance, the target illuminance of 300 lux should be achieved over 50% of the floor area for at least 50% of daylight hours, while the minimum illuminance of 100 lux should be met over 95% of the floor area for at least 50% of daylight hours (Mardaljevic & Christoffersen, 2017). Daylight hours are defined as 4380 hours, and the climatic data of locations are taken from Energy Plus.

For daylight provision assessments according to the TS-EN 17037 standard, the alternative scenarios classified as medium and high also meet the requirement of the minimum level. Because of providing a minimum level of 300 lux illumination for at least 50% of daylight hours over 50% of the reference plane, which is sufficient for primary school classrooms, all three classifications were taken as having passed the requirement. The same acceptance is valid for meeting minimum illuminance requirements which is sufficient for assessments, as the classroom can achieve compliance with medium and high levels by satisfying higher illuminance thresholds. For the evaluation of alternative scenarios, the ones that meet the requirement of providing target and minimum target illumination levels for defined hours of the year and percentage of the floor area are both accepted as prevalent conditions.

• Direction

Based on the assessments conducted on the direction parameter, it has been observed that the south and east directions exhibit superior daylight performance compared to the other directions. Despite the common expectation that the South direction would offer better daylight sufficiency in all circumstances, the East direction is found to have higher annual daylight performance in some alternative scenarios. Upon analyzing the relationship between direction and façade design, it can be concluded that changing the direction does not have a significant impact on achieving the target illuminance for at least 50% of the floor area for 50% of the time. However, there is a significant difference in providing the minimum target illuminance for 95% of the floor area for 50% of the time. Figure 4 illustrates the correlation between direction and façade model through a graph for the fraction of daylight hours (Ftime,%). The graph displays the percentage of daylight hours that provide target illuminance of at least 50% of the floor area and minimum target illuminance in at least 95% of the floor area separately, based on changes in direction and façade model. According to the assessments, the values obtained from the east and west directions in most of the options appear to be quite similar.

The D and E models, which are separated window layout alternatives for different transparency ratios, show a sharper change according to the direction change. Especially for the north orientation, daylight performance has a sharp decrease in daylight illuminance.

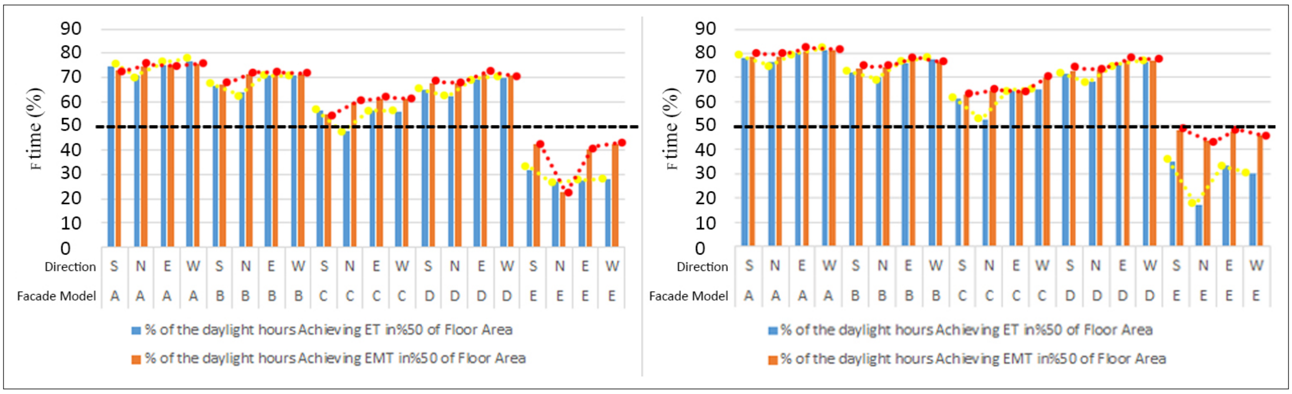


Figure 4. Daylight Provision Changes by Direction Variables for Alternative Façade Designs of 20° Obstruction Angle for Istanbul (Left) and Antalya (Right).

Additionally, for higher obstruction angles, it is observed that buildings with facades facing east and west exhibit better daylight efficiency in comparison to the south direction. Furthermore, it can be understood that Model E cannot provide the criteria for a 20° obstruction angle in any direction variables in Istanbul, while Antalya provides the criteria for South orientation.

• Façade Design

The Educational Buildings Design Guide has a description of the transparent area-to-floor area ratio suggestion that is approximately equal to a transparency ratio of 50%. There is no other description for alternative façade designs responsive to interior and exterior environmental parameters. The alternative transparency ratios of 30%, 40%, and 50%, and window layout variables of separated and attached arrangement for 30% and 40% transparency ratios are evaluated as Model A, B, C, D, and E facades, which are displayed in Figure 2.

The required daylight illuminance for all façade models can be provided if the obstruction angle remains below 20°, except for façade model E. Furthermore, for obstacle angles of 20° and below, it can be observed from the scenarios that both the minimum target illuminance level and the target illuminance level criteria are fulfilled for all window direction variables. After analyzing the simulation outcomes of options featuring a 30° obstacle angle, it appears that facades models A, B, and D satisfy the target illuminance level and minimum target illuminance level. However, the C and E models do not meet the required criteria for all directions. The graphics presented in Figure 5 indicate the fraction of time that meets the target and minimum target illuminance requirements. These graphics are generated for the façade variations with the constant direction of the south window orientation. In Istanbul and Antalya provinces, the transparency ratio has a linear effect on daylight performance, as shown in the separate graphics created for each province. It can be observed that the increase in performance is smoother for obstruction angles of 20° or less, while the increase becomes more pronounced as the obstruction angle increases. Upon closer examination of the graphic, it becomes evident that the percentage of increase becomes sharper as the obstruction angle increases.

The Model B facades in the attached window arrangement with 40% transparency, and the Model D facades in the separate layout with obstruction angles of 0°, 20°, and 30 degrees, all fulfill the daylight requirement. However, the Model C alternative with a 30% transparency ratio in the

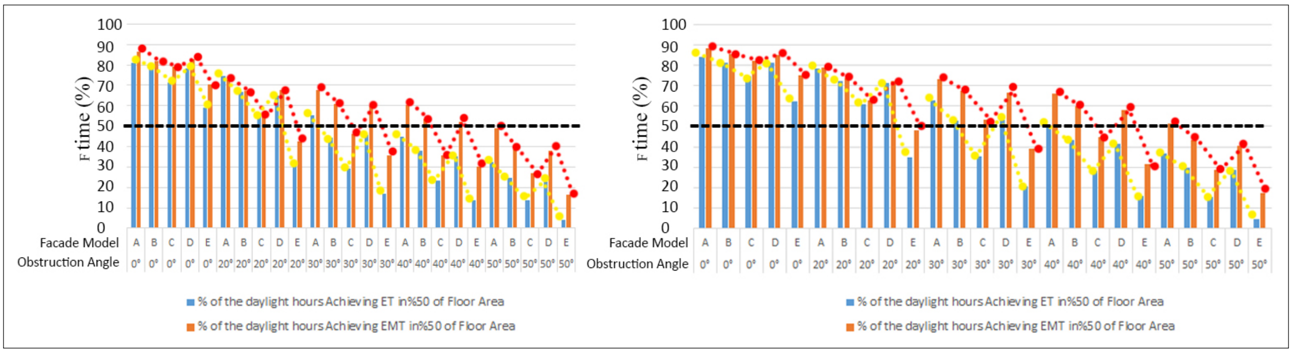


Figure 5. Daylight Provision Graphic for Façade Design Variables for Provinces of Istanbul (left) and Antalya (right) for South Orientation.

attached facade shows better daylight performance than the separated Model E. In the attached window arrangement with 30% transparency, 0° and 20° obstruction angles demonstrate positive daylight performance. Nevertheless, the daylight criteria are not met except for the south facade with a 0° obstruction angle in the separated layout. According to the graph, the attached window orientation has a positive effect on daylight performance. The difference between attached and separated window orientations is significant, leading to a direct decrease in performance, primarily for a 30% transparency ratio. This indicates that window configuration changes have a more significant impact on daylight performance as the transparency ratio drops.

• Obstruction Angle

Upon analyzing all the alternative scenarios, it becomes apparent that the alternatives with lower obstruction angles perform better in terms of daylight provision. As the obstruction angle increases to 30° and beyond, it becomes impossible to meet the daylight provision criterion, particularly at 40% and 30% transparency rates. Especially in Istanbul, it is evident that the daylight criteria cannot be met except for some direction alternatives when the obstruction angle exceeds 40°. It is observed that Antalya province receives an adequate amount of daylight, even with the highest obstruction angle, particularly in the option with a 50% transparency ratio. On the other hand, the option with 40% transparency and a 40° obstruction angle does not offer enough daylight for Istanbul, but it is sufficient for Antalya province. Furthermore, Antalya cannot receive sufficient daylight when the obstruction angle goes beyond 40°. When the façade design has 30% transparency, it produces unfavorable outcomes for both climate zones when the obstacle angle is above 20°. However, the sensitivity to the obstruction angle is less significant in Antalya province, which represents hot and humid climates. Figure 6 displays a graphic that shows the obstruction angle variables for the provinces of Istanbul and Antalya for the south orientation changes by façade models. As per the graph, there is a significant decrease between changes in the obstruction angle. It can be inferred that obstruction angle variables have a greater impact on achieving the required target illuminance level performance throughout the year compared to the minimum target illuminance level.

• Climate

Istanbul and Antalya were taken as representative provinces from the temperate humid and hot humid climate regions evaluated in the study. Within the scope of the variables evaluated in the study, it can be said that the hot humid climate region allows more flexible designs in terms of window design, building orientation, and obstacle status.

For instance, it has been observed that a 50% transparent façade may not offer adequate daylight for Istanbul when the obstruction angle exceeds 40°. However, a required illuminance level of 300 lux is achieved in at least 50% of the space and daylight hours, while a minimum illumination level of 100 lux is achieved in over 95% of the space and more than 50% of the daylight hours in Antalya province. It was also established that the comparable scenario was applicable for the option with a transparency ratio of 40%. However, for a 30% transparency ratio, sufficient daylight cannot be provided in both climate zones when the obstruction angle exceeds 30° or more.

After evaluating the daylight performance of various scenarios created for Istanbul and Antalya based on direction, façade model, and obstacle variables, it has been observed that 49 out of 100 scenarios created for Istanbul, and 69 out of 100 scenarios created for Antalya meet the required illuminance level criteria. These scenarios fulfilled both the target illuminance level and minimum illuminance level criteria. Thus, it can be concluded that Antalya has a more favorable daylight performance as compared to Istanbul. Based on all the findings, it is determined that

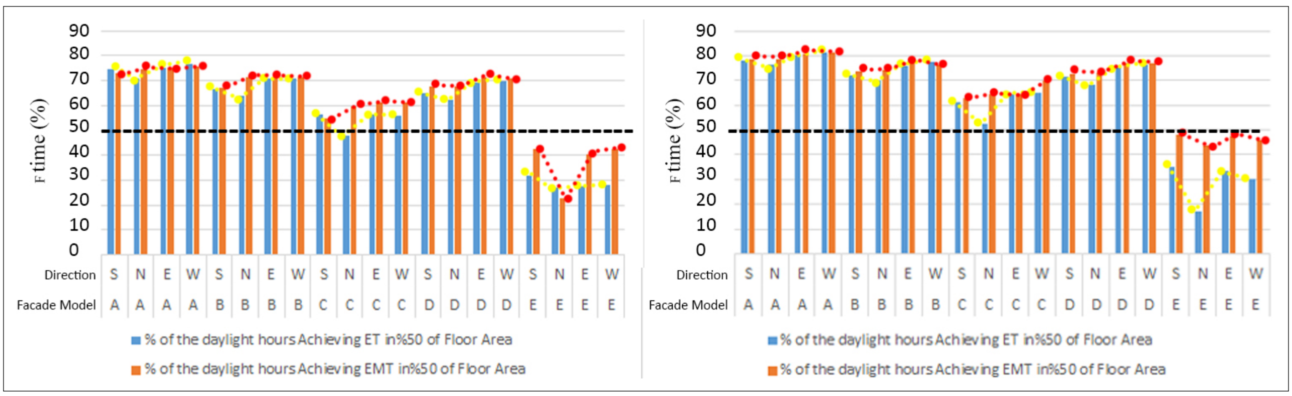


Figure 6. Daylight Provision Graphic for Obstruction Angle Variables for Provinces of Istanbul (left) and Antalya (right) for South Orientation.

having the highest level of transparency and the least amount of obstruction is positive for daylight provision. However, it is important to consider the protection against glare as well, which is one of the daylight criteria mentioned in EN 17037 (Türk Standartları Enstitüsü, 2022), (Walkenhorst, Luther, Reinhart, & Timmer, 2002). During the study, the most favorable scenarios were those where the area received enough natural light, and glare protection was provided.

Assessment of Protection From Glare

Glare can happen due to several design factors, such as the optical properties of the material, the location, the direction of view, the orientation of the façade, the transparency ratio of the façade, the glazing transmittance, and the user's distance from the window.

To evaluate daylight glare, one must consider the complex luminance distribution within the field of view as well as the size, intensity, and location of the glare sources in relation to the line of sight (Türk Standartları Enstitüsü, 2022), (Sepúlveda, Luca, Varjas, & Kurnitski, 2022).

Daylight Glare Probability (DGP) is a dynamic metric used to assess the level of protection from glare in spaces where activities like reading, writing, or using display devices take place. DGP is particularly important in cases where occupants have limited ability to choose their position or viewing direction (Türk Standartları Enstitüsü, 2022). It is important to ensure that the FDGP exceed, which represents a certain fraction of the reference usage time, does not surpass the DGP-threshold values (Türk Standartları Enstitüsü, 2022).

Spatial Disturbing Glare (sDG) refers to the percentage of occupied hours where at least 5% of views across the regularly occupied floor area experience Disturbing or Intolerable Glare (Solemma, 2020).

In this part, alternatives of direction; façade model, and obstruction angle are evaluated for annual glare by means of the sDG (spatial disturbing glare) metric. The number of 200 models evaluated with a reference plane with 0.5m distance from the wall and 1.20m height off the finish floor, which represents the eye level of the seated observer. Additionally, according to TS-EN 17037-A1, the maximum grid size of reference for calculation is evaluated as 1.8m. However, for a more accurate assessment, the grid size is determined as 0.8m (Türk Standartları Enstitüsü, 2022). The frequency of glare is displayed with eight directional pie slices for view nodes on the reference plane, which are color-coded to indicate frequency from intolerable to tolerable glare.

TS-EN 17037 states that in situations where there are multiple potential locations for activities, it is suggested to investigate the position with the worst expected outcome. These positions are defined as near the building's façade or where there is a possibility of a low sun position.

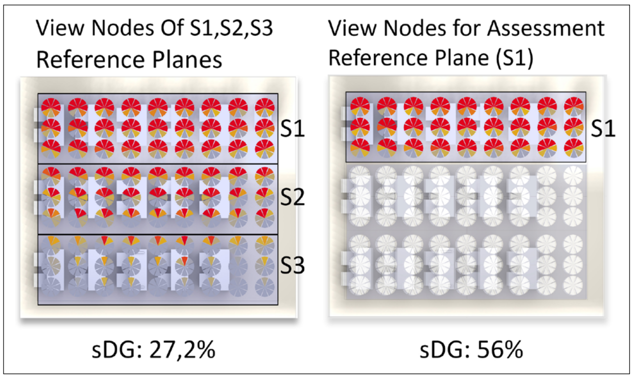


Figure 7. The Reference plane displays view pie slices for the entire classroom (left) and calculation area (right).

Moreover, if the glare requirements are met for the worst-case positions within a given space, then they are also accepted to meet throughout the entire occupied area (Türk Standartları Enstitüsü, 2022). According to this admission; in order to make a sensitive evaluation, the calculation points are determined for this study as the area occupied by the group of desks through the window. Figure 7 shows the sDG values for the entire area (left) and the calculation area to be used for evaluation (right). Based on Figure 7, it can be inferred that the desks aligned near the window pose the highest risk of glare. Therefore, evaluating the entire classroom area for the entire year would not be a realistic approach. This is why for this study, annual evaluations for glare are conducted specifically for the desks aligned with the window, as illustrated in Figure 7 as S1.

Direction

Based on the simulation results, it has been determined that the highest probability of glare occurs when a building is oriented toward the South. The East and West directions follow this trend. However, there is no risk of glare from the North direction for any building model or obstruction angle alternatives. The facades of models A, B, and C pose no risk of glare in any direction when the obstruction angle is 50°. For models C and D, with an obstruction angle of 40°, there is no probability of glare in the North, East, and West directions. As for model E, there is no risk of glare in any direction for obstruction angles of 20°, 30°, 40°, and 50°, except for the South direction at a 20° obstruction angle. Figure 8 represents sDG (%) values for alternative scenarios of directions for Istanbul and Antalya provinces, changing by façade and obstruction angle variables.

Based on the graph, it can be inferred that the South orientation poses the highest glare risk in all circumstances. On the other hand, the North orientation has no glare risk. It is recommended to take glare control precautions for buildings facing South, East, and West, particularly when the obstruction angle is 30° or more.

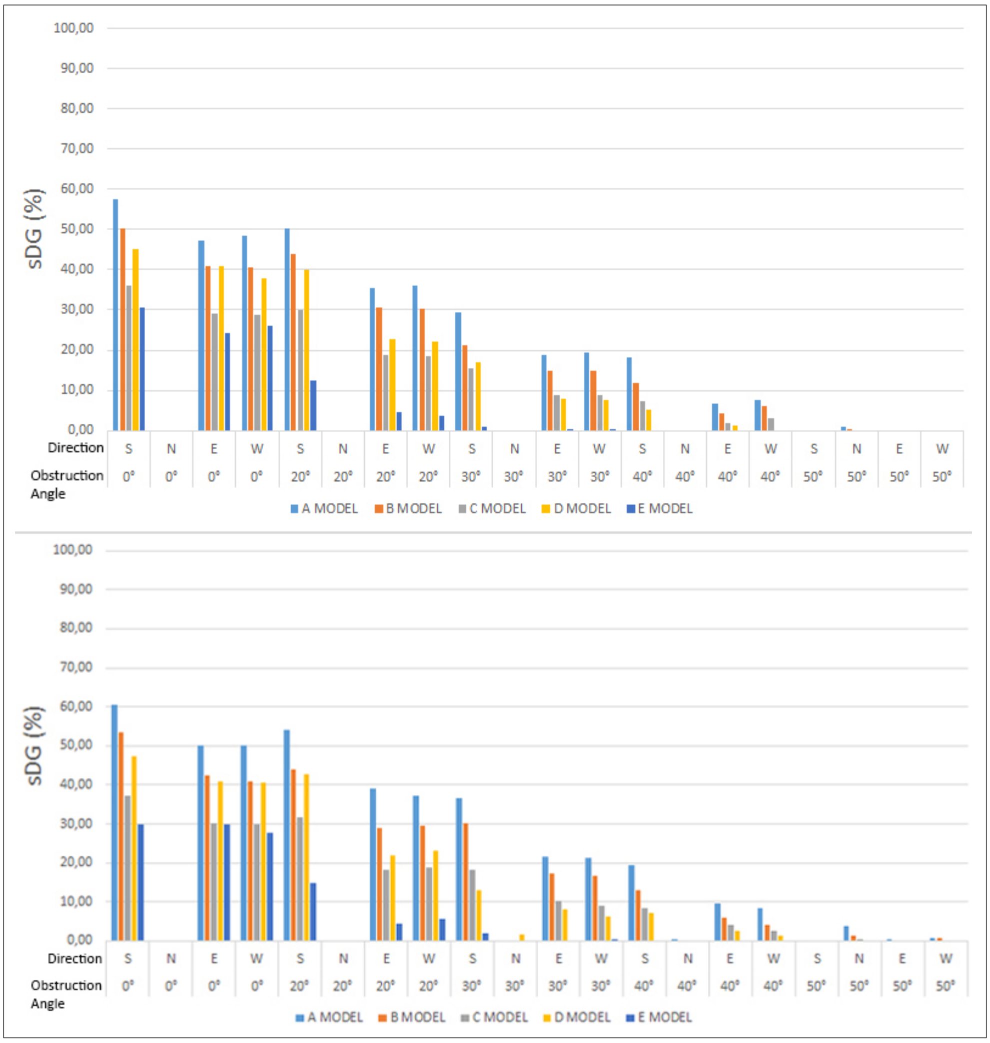


Figure 8. Graphics for sDG (%) value for alternative scenarios of Directions for Istanbul (up) and Antalya (down).

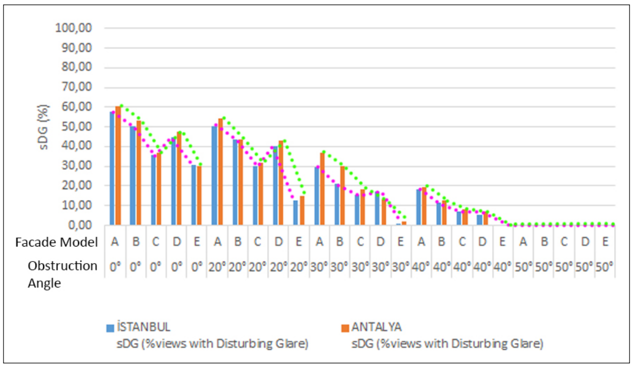


Figure 9. Graphics for sDG (%) value according to Façade Model in South orientation for provinces of Istanbul and Antalya.

Façade Design

The design of a building's façade should be carefully considered as it can significantly affect the occurrence of glare. Upon closer examination, it has been noticed that façade models A and B do not cause any glare issues except for a 50° obstruction angle in both provinces. However, models C and D have a risk of causing glare for 40° and 50° obstruction angles. Finally, model E has no risk of glare, except for an obstruction angle of 0. Figure 9 displays sDG (%) values according to Façade Model in the South orientation for the provinces of Istanbul and Antalya. It can be said that Models A, B, and C exhibit a linear decrease in effect with changes in transparency ratio, while Models D and E exhibit the same ratio of decrease in comparison.

Obstruction Angle

Glare can be significantly affected by obstruction. Among all the façade models assessed, those with 0° and 20° obstruction angles are at the highest risk of glare. As the angle of obstruction increases, the risk of glare also increases in a linear manner. It is especially important to take precautions against glare for façade models A, B, and D with obstruction angles of 0° and 20°. Figure 10 shows the

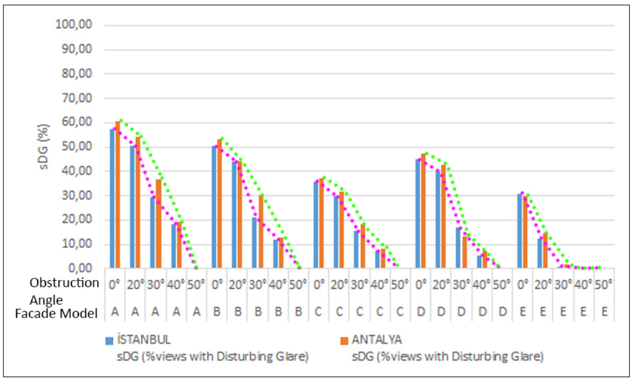


Figure 10. Graphics for sDG (%) Value Change According to Obstruction Angle Alternatives in South orientation for provinces of Istanbul and Antalya.

change in sDG (%) values according to obstruction angle alternatives in the South orientation for the provinces of Istanbul and Antalya.

Climate

The role of climate is crucial in protecting against glare. However, the Design Guides for educational buildings in Türkiye lack detailed alternative façade scenarios for different climate zones. Figure 11 shows the changes in sDG (%) values for the Model A façade in the Istanbul and Antalya provinces.

It is important to note that the Antalya province is at a higher risk of glare than Istanbul under all circumstances. Precautions against glare are particularly important for south-facing buildings. Additionally, glare protection should be considered for buildings facing east and west with obstruction angles of 30° or greater. A closer look reveals that the Istanbul province has more flexible design alternatives when it comes to façade models and obstruction angles compared to Antalya. Therefore, it is recommended to use solar control components when there is a high possibility of glare during the necessary days and hours of the year.

DISCUSSION

As displayed on the flow chart in Figure 1, several alternative scenarios varying climate, direction of the building, façade design, and obstruction angle parameters have been generated in order to assess the daylight performance of primary school buildings in Türkiye regarding the recommendations outlined in TS-EN 17037-A1 standard. The generated models were assessed according to the daylight provision and protection from glare criteria as explained in the standard. Out of the total number of 200 models, those that met and those that did not meet the criteria were determined. According to these outputs: recommendations were generated in order to improve primary school daylight system design.

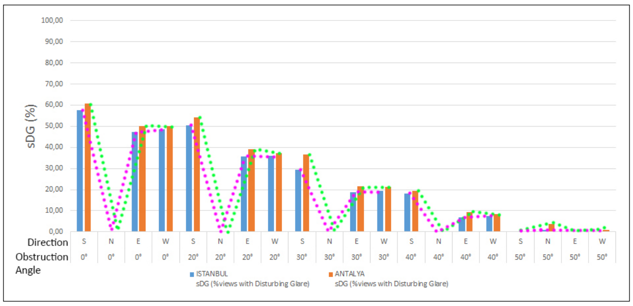


Figure 11. Graphics for sDG (%) Value Changes of Istanbul and Antalya Provinces for Model A Façade.

In the first part of the study, daylight provision was assessed according to the criteria given in TS-EN 17037. From the number of 200 alternative scenarios, 110 of them provided the target illuminance of 300 lux in 50% of daylight hours at least for 50% of floor area and 100 lux of minimum target illuminance in 50% of daylight hours minimum for 95% of the daylit area both. Antalya has a total of 61 models that meet the criteria, whereas Istanbul only has 49 models available. It's important to have plenty of natural light in a space, but it's also crucial to limit the possibility of glare, which is caused by higher illuminance levels.

Glare assessments indicate that the risk of glare is higher for smaller obstruction angles, which emphasizes the need for solar control components. Additionally, for higher transparency ratios, specific times of the year may require glare control more than other options. Furthermore, a south-facing orientation carries the highest risk of glare. Designers are advised to use solar control elements integrated into façade design or, in some cases, if they are not sufficient, user-controlled systems such as curtains, roller blinds, and blinds, to protect against glare in negative alternatives. Within the 200 alternative models analyzed, 31 models pose a risk of disturbing glare, and 94 models have a probability of causing glare throughout the year. Glare protection precautions should be implemented from the initial design phase, especially for the 31 models that cause a decline in visual performance.

When assessing alternatives based on both daylight provision and protection from glare, models that meet target and minimum illuminance levels in identified circumstances while avoiding disturbing glare are considered positive. Out of 200 models evaluated for meeting the criteria of providing adequate daylight and avoiding glare, 79 models were found to have efficient daylight performance.

CONCLUSION

Passive systems are preferred in building design to enhance energy efficiency and visual comfort. Natural lighting is a crucial passive system for reducing a building's energy requirements for lighting while creating a desirable visual environment and ensuring comfort requirements (Kocagil & Oral, , 2021). For educational buildings, a natural lighting system is vital for students' visual comfort and performance (Çelik & Ünver, 2019). Furthermore, variables such as climate, direction, and façade design significantly affect daylight performance. Therefore, to design an effective daylight system for educational buildings, it is necessary to make suggestions that are sensitive to environmental and physical parameters.

The purpose of the study is to create a detailed design guide for primary school classrooms in educational buildings by determining positive scenarios according to the façade model, obstruction angle, and direction variables for different climate regions. For that purpose, alternative scenarios are considered positive when daylight provision requirements are met while avoiding glare according to criteria described in TS-EN 17037-A1. In addition, the study can be improved by investigating the effect of solar control elements on daylight performance (Bian, Dai, & Yuan Ma, 2020).

It is necessary to develop a design guide that takes into account the impact of variables on daylight performance in order to create a sensitive artificial environment design. The currently available guidance does not offer detailed alternative scenarios based on environmental and physical variables. The output of the study can be used for the construction or renovation of educational buildings.

In conclusion, the study indicates that it would be beneficial to improve the Minimum Design Guide for Educational Buildings in accordance with the recommendations to create an efficient environment for students. The effect of environmental and interior design parameters should be considered from the early beginning of the building design phase.

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