JSACE X/X

Design-Driven Daylight Simulation for Lighting Optimization in an Educational Building at YOBU

Sadakat Safiyye Mumcuoglu Turker[1*], **Selahaddin Sezer**[2]

[1]Yozgat Bozok University, Faculty of Engineering and Architecture, Architecture Department, Yozgat, Turkey

[2]Yozgat Bozok University, Yozgat Vocational School, Program of Interior Design, Yozgat, Turkey

*Corresponding author: **ss.mumcuoglu@yobu.edu.tr**

https://doi.org/10.5755/j01.sace.42032

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Received 2025/07/19

Accepted after revision 2025/09/25

Abstract

The aim of this study is to analyze the illumination performance of selected workshops, corridors, and instructor rooms at the Department of Architecture, Yozgat Bozok University (YOBU), and to propose solutions to identified problems. In educational buildings used for most of the day, optimizing daylight and minimizing reliance on electric lighting is crucial for sustainability, energy efficiency, and user comfort. A review of university building studies indicates that glare and insufficient lighting are common issues. In this study, illumination performance was examined using two methods: in-situ measurements and simulation. Light levels were recorded with a lux meter at specific time intervals and then compared with the Velux Daylight Visualizer simulations, verifying the tool's accuracy. Based on these data, design suggestions were developed, and the base case was compared with alternative designs through simulation. The results identified the most effective design suggestion and quantified the annual daylight performance of the existing situation. Findings indicate that the strategic use of simulation tools at the design stage can reduce the need for electric lighting and support energy savings.

Keywords: educational buildings; illumination performance; daylighting; integrated lighting; simulation; Velux Daylight Visualizer.

Introduction

The quality and quantity of illumination in educational settings is of paramount importance for creating an optimal learning environment and ensuring visual comfort for both students and instructors. Inadequate lighting impedes learning, while excessive brightness and glare hinder focus and performance. Consequently, strategies integrating daylight and electric light are employed in the design of educational buildings to enhance energy efficiency and comfort. Optimal use of daylight reduces energy consumption and environmental impact. Educational buildings, comprising classrooms, laboratories, workshops, and offices, play a critical role in individuals' lives and therefore require careful design attention (Baskan Bostancı and Sözen Şerefhanoğlu 2006). In this context, factors such as solar orientation, sunlight availability, climate, and geography must be considered; otherwise, spaces risk suffering from inadequate daylight, glare, overheating, or overcooling (Yıldırım and Yüksek 2024). Lighting is central to learning since visual perception is fundamental to education. Appropriate lighting design enhances user productivity and comfort while significantly affecting energy consumption (Bayram et al. 2020, Günaydın 2022). Simulation systems allow designers to test daylighting strategies, compare design alternatives, and identify optimal solutions before construction (Ulukavak Harputlugil 2010). Given that educational spaces are used throughout the day, ensuring adequate and homogeneous daylight in classrooms and workshops is essential; when daylight is insufficient, electric lighting can be employed (Erlalelitepe et al. 2011). The aim of this study is to analyze the daylighting and integrated lighting conditions of workshops and offices at the Department of Architecture, Yozgat Bozok University (YOBU), using in-situ measurements and simulation tools, and to develop and compare design suggestions for improving visual comfort and energy efficiency. Accordingly, the research addresses the question: How can simulation-based daylight design strategies improve lighting quality and reduce dependence on electric lighting in educational buildings?

Literature review

A plethora of studies on the subject of daylighting and electric lighting in educational buildings can be found in the existing literature. The present study comprised a review of articles dealing with the analysis of lighting in various indoor settings, including classrooms, workshops, laboratories, and offices within university campus buildings. The studies, conducted in various educational facilities in disparate countries, are presented in a table of references with details such as the author's name, the case study and the method of lighting analysis (see Table 1).

Table 1

A review of literature on the analysis of lighting in educational settings, with a focus on classrooms and offices in universities.

Researcher	Case study	Objective and Methodology of the Study
Erlalelitepe et. Al, 2011	Izmir Institute of Technology	Measure illumination performance in classrooms, labs, offices, and galleries
Tatar, 2013	Eskişehir Anadolu University	Propose daylight-oriented design for two workshops
Kesten Erhart and Tereci, 2015	Stuttgart University of Applied Sciences and KTO Karatay University	To conduct user satisfaction surveys, develop potential lighting scenarios for classroom, and calculate the cost of renovation
Bayram and Kazanasmaz, 2016	Izmir Institute of Technology	Develop improvement suggestions for classrooms based on glazing, shading angle, and fixture type
Rubeis et. al, 2017	University of L'Aquila	Calculate energy use of different fixture and control systems
Kong and Jakubiec, 2019	Singapore Technology and Design University	Identify user satisfaction through surveys, and create simulated brightness maps of classrooms using HDRi technology
Ma'bdeh and Al-Khatatbeh, 2019	Jordan University	Determine optimal classroom illumination with reflectivity, skylights, light shelves, and CIBSE and CEN standards
Bayram et. al, 2020	Ege University	Check compliance of various spaces with TS EN 12464-1 standards.
Chiou et. al, 2020	National Taiwan University	Measure user satisfaction through surveys and identify glare issues through HDRi (High Dynamic Range image) technology
Demir et. al, 2020	Yalova University	Calculate the energy consumption and cost of fluorescent and LED fixtures
Freewan and Al Dalala, 2020	Jordan University	Evaluate daylight, glare, and energy savings with anidolic system and light shelves
Onak and Yıldıran, 2020	Kocaeli University	Simulate LED/fluorescent luminaires and check TS EN 12464-1 compliance
Günaydın, 2022	Niğde Ömer Halisdemir University	Analyze workshop lighting under varying weather per CIBSE Guide
Kong et. al, 2022	Southeast University Nanjing	Measure user satisfaction through surveys and identify glare issues through HDRi (High Dynamic Range image) technology
Qin et. al, 2023	University in Harbin	Control overheating, daylight, and energy with shading design
Budhiyanto and Chiou, 2024	National Taiwan University	Measure satisfaction and glare with HSLDCS (HDRi Surveillance Lighting Control System) technology
Liu et. al,2024	Central South University	Optimiz classroom design for climates using MOO method

Common problems identified include insufficient daylight, glare, non-homogeneous distribution of light, and the overuse of shading devices or low-transmittance glazing. Similarly, several studies propose strategies such as the use of light shelves, reflective materials, LED luminaires, and optimized window-to-wall ratios to enhance visual comfort and energy performance. While these studies provide valuable insights, most adopt a single methodological approach or focus on specific building types, which limits the generalizability of their findings. The novelty of this study lies in its comprehensive dual-method analysis, combining in-situ measurements and advanced daylight simulation techniques to evaluate the daylighting performance of an educational building. Unlike prior research, it develops and compares multiple design scenarios to identify the most effective solutions, linking technical findings with architectural decision-making. The uniqueness of the case building at Yozgat Bozok University, with its distinctive orientation, glass façade proportions, and climatic conditions, provides an opportunity to extend the discussion beyond general guidelines and contribute to the development of transferable strategies for similar educational facilities.

Materials and Methodology

The methodology employed in this study was elucidated in a stepwise manner in Fig. 1. The term integrated lighting in Fig. 1 refers to the combined use of daylight and electric lighting. In the initial phase of the study, an in-depth examination was conducted on the analysis of daylighting and electric lighting in classrooms and office rooms within the Department of Architecture, Yozgat Bozok University (YOBU), encompassing classrooms, offices, and corridors. To identify solutions to inadequate lighting and glare issues, a light analysis was conducted using a luxmeter and a simulation tool.

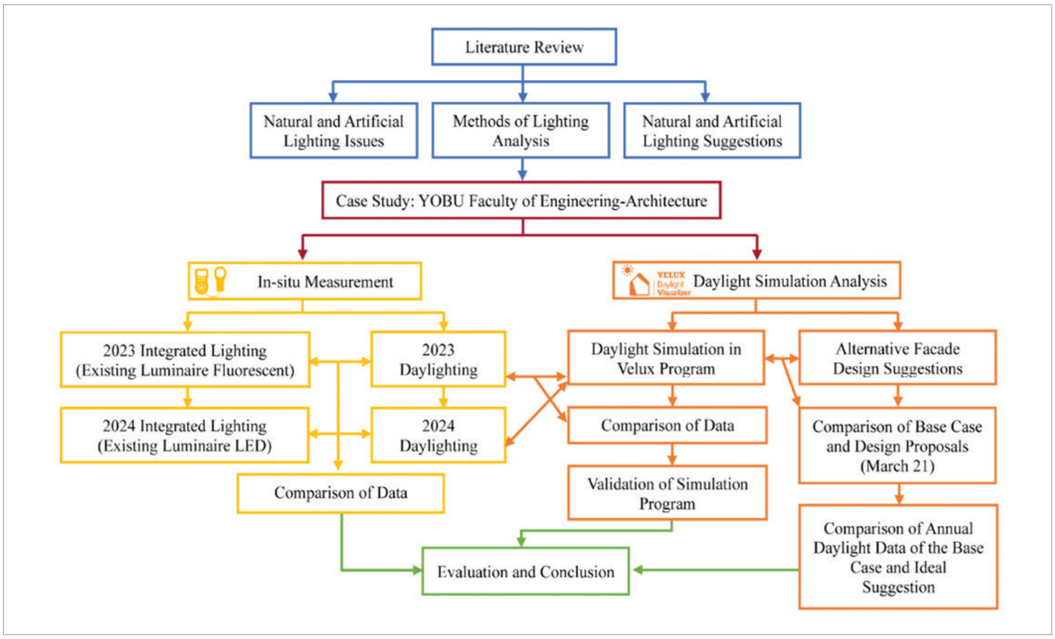


Fig. 1
Phases of the methodology employed in the study

The initial assessment of light values was conducted on March 21, 2023, between 11:30 am and 12:30 pm with the electric lighting fixtures operated in both their on and off states. In late 2023, the existing lighting fixtures in the classrooms were replaced with LED luminaires. To confirm the extent to which the LEDs enhanced illumination, the lux values were measured once more on March 21, 2024, at the same time interval. The daylighting and integrated lighting values of 2023 and 2024 were compared, and the lux changes caused by these two distinct fixture types were identified. To enhance the precision of light distribution analysis, the values obtained from in-situ measurements are presented in the form of plan graphs. In the second phase, the light analysis was conducted using the Velux Daylight Visualizer (VDV). The case study was modelled based on the base case analysis, and simulations were conducted using this model. Data pertaining to the location of the building, the north angle, and the reflectivity and transmittance coefficients of the materials utilized were input into the tool. To verify the simulation, luxmeter measurements were taken on the same day, at the same time, and under the same weather conditions. The mean lux values obtained from the two methods were compared using MSE (mean square error) and RMSE (root mean square error). In the subsequent phase, the daylighting issues within the case study were discerned through an examination of the luxmeter and simulation data. Three alternative solutions were devised to address these issues. The base case setting, along with the three suggestions, and the average lux values and iso contour lines at 12:00 pm on March 21 were evaluated with the simulator, and the most appropriate solution was suggested. In the final stage, the annual daylight performance of the ideal suggestion was analyzed in conjunction with the base case, and the impact of the change in average lux values was expressed through graphs.

Case Study

The subject of this study is the classrooms and offices of the Department of Architecture, Faculty of Engineering and Architecture, within the Erdoğan Akdağ Campus of Yozgat Bozok University. The edifice comprises several buildings referred to as Block(s); A, B, C, D, E, F, G, H. The building was chosen as the case study due to its distinct design features that pose both challenges and opportunities for daylight utilization. The faculty comprises multiple interconnected blocks with varying heights, window-to-wall ratios, and facade orientations, making it a complex structure for daylight analysis. Additionally, its location in central Anatolia, characterized by high solar radiation levels and extreme seasonal variations, necessitates a tailored daylighting strategy. These findings warranted a detailed investigation into potential design improvements using empirical and simulation-based methods. The case study is illustrated both in a plan diagram and in 3D modelling (see Fig. 2). In this regard, the selected case study comprised classrooms E103, E104, and E105 in Block E, the corridor above these classrooms, and the offices and corridors in Block F.

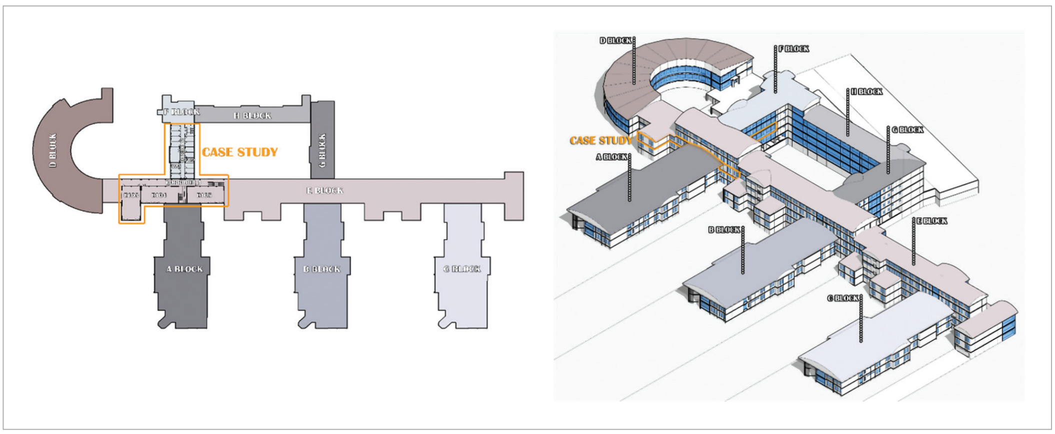


Fig. 2

Plan diagram and 3D model of the case area at YOBU

Comparative analysis of the illumination values measured in 2023 and 2024

Initially, the daylighting and integrated lighting values of the classrooms E103, E104, and E105, as well as the corridor area in front of these classrooms in Block E where the architecture department was, and the offices F103 and F120, along with the corridors in front of these offices in Block F were measured with a lux meter. The measurements were repeated on the same date and at the same time, with a one-year interval between each instance. With regard to this matter, the vernal equinox occurring on March 21, 2023, and March 21, 2024, at approximately 11:30 am–12:30 pm, was identified as the optimal temporal reference point for the measurements, due to the fact that this represents a period when the length of daylight and darkness is perceived to be equal. The obtained lux values were converted into plan graphs with contour lines. The color transition from blue to red represents the increasing lux values (see Fig. 3). The 18-watt, 1050-lumen fluorescent-type lamps in the lighting fixtures in classrooms E103, E104, and E105 when the lux value in classrooms measured first time in 2023 were replaced with 36-watt, 4140-lumen LED-type luminaires in 2024. Consequently, the illumination values of these spaces were measured once more in 2024, and the effects of such a change on the classrooms were subsequently analyzed. In the course of observations conducted in 2023, it was noted that the fluorescent luminaires installed in classrooms and corridors were not functioning as intended in certain locations. By 2024, all of the LED luminaires in the classrooms had been fully operationalized. In 2024, no modifications were made to the fixtures in the corridors and offices. In this regard, the aforementioned areas were not subjected to a re-evaluation of their lux levels in 2024. The classrooms, offices, and corridors all feature light-colored finishes with reflective glass windows and white suspended metal ceilings; the main differences are the flooring materials, which are vinyl in classrooms, wood parquet in offices, and ceramic tiles in corridors (see Fig. 9).

The dimensions of classrooms E103, E104, and E105 were 20.0m x 9.8m, 10.0m x 19.5m, and 10.0m x 19.5m, respectively. The ceiling heights of the classrooms were 2.9m for the E103 and E104, 2.9m and in some locations, 2.6m for the E105. The Block-E classrooms on the second floor were oriented with their windows facing northwest. The window-to-wall ratios in the classrooms were approximately 5.3%, 7.2%, and 5.4%, respectively. In consideration of the optimal classroom dimensions and window-to-wall ratios put forth in the existing literature (Liu et al. 2024), it was observed that the width and height of these classrooms did not align with the suggested parameters. Conversely, the window-to-wall ratio was found to be within the optimal range. In consideration of the orientation of the classrooms to the south, it was observed that they did not align with the angles recommended in the literature (Liu et al. 2024). Classroom E103 was oriented in a northwest direction with respect to the short wall, and the classrooms E104 and E105 were oriented in the same direction with respect to the long wall (see Fig. 3).

The study encompassed an analysis of two offices, namely F103 on the north façade and F120 on the south façade. The dimensions of the offices are 5.0 meters by 3.0 meters, with a ceiling height of 2.9 meters. The window-to-wall ratios for Offices F120 and F103 are 10% and 3.1%, respectively.

The measurements conducted with a lux meter on March 21, 2023 indicated that the natural illumination values in Classrooms E103, E104, and E105 were considerably below the minimum threshold required by TS EN 12464-1, which specifies 300 lux for classrooms (Bayram et al. 2020) (see Fig. 3). Thus, daylighting in these classrooms was found to be inadequate. On the same day, the integrated lighting levels in the classrooms were analyzed. According to the results, the mean illumination values showed that Classroom E104 was below the established standard, whereas Classrooms E103 and E105 demonstrated compliance (see Table 2). Therefore, integrated lighting was inadequate in certain areas of all classrooms, and particularly throughout Classroom E104.

In consideration of the daylighting performance in 2023 and 2024, the plan graphs indicating a rise in lux values from blue to red with contour lines (see Fig. 3), demonstrated that only a limited number of areas proximate to windows in classrooms possessed adequate illumination, and that the distribution of light was not homogeneous. The majority of the classroom area was situated at a considerable distance from the window, resulting in a lack of adequate daylight. The planning and design of the classrooms were identified as the primary factors contributing to this issue. Despite the presence of curtain walls and windows on the shorter wall of Classroom E103, as well as windows on the longer wall of Classrooms E104 and E105, these spaces were unable to receive an adequate amount of daylight. This was due to the fact that half of the walls in question were blind walls, situated adjacent to Block-A, and that all of the classrooms were oriented towards the north, rather than the south. There are notable discrepancies between the daylighting values recorded on the same day and within the same time interval in 2023 and 2024. The atmospheric conditions were conducive to achieving lower lux values in 2023. On March 21, 2023, the sky was overcast, whereas on March 21, 2024, the sky was clear. This further illustrates the significance of simulation studies that present instantaneous lux values as opposed to in-situ measurements that can change drastically in a short period of time.

As illustrated by the table depicting the daylighting and integrated lighting performances in the classrooms in 2023 and 2024, the greatest improvement was observed in Classroom E104, while the least improvement was noted in Classroom E103 (see Table 2). The lux values of the measurement points in these graphs demonstrate that, across the classrooms, LED luminaires produce a more homogeneous distribution of light, whereas fluorescent lighting sources cannot achieve this level of homogeneity due to fluctuations in a few measurement points. This phenomenon was particularly evident in Classrooms E103 and E105.

As indicated by the measurements obtained with a lux meter on March 21, 2023, the daylighting values in Offices F103 and F120 showed significant variation (see Fig. 3 and Table 2). According to the CIBSE standard, a minimum illuminance of 300 lux is required for office spaces (Bayram et al. 2020). However, the observed levels in Office F103 were below this threshold, while those in Office F120 exceeded it. Similarly, the integrated lighting analysis demonstrated that Office F103 on the north façade achieved compliance with the standard, whereas Office F120 on the south façade exhibited values far above the required level (see Fig. 3 and Table 2). In this context, the illumination performance in Office F103 was inadequate, while Office F120 presented a tendency to cause glare.

This study analyzed the daylighting and integrated lighting performance in Corridor-1, which provides access to classrooms in Block E, and in Corridor-2, which provides access to the offices in Block F. According to the measurements (see Fig. 3 and Table 2), the daylighting and integrated lighting levels in both corridors showed significant differences. The TS EN 12464-1 requires corridors to achieve a minimum illumination level of 100 lux to meet the standard (Bayram et al. 2020). In this context, Corridor-1 demonstrated a tendency to cause glare, while Corridor-2 showed a significant deficiency in daylighting and excessive integrated lighting compared to the standard. Furthermore, it was noted that the distribution of light in Corridor-1 was not homogeneous, and that the level of daylighting in the area where the circulation routes converge was inadequate.

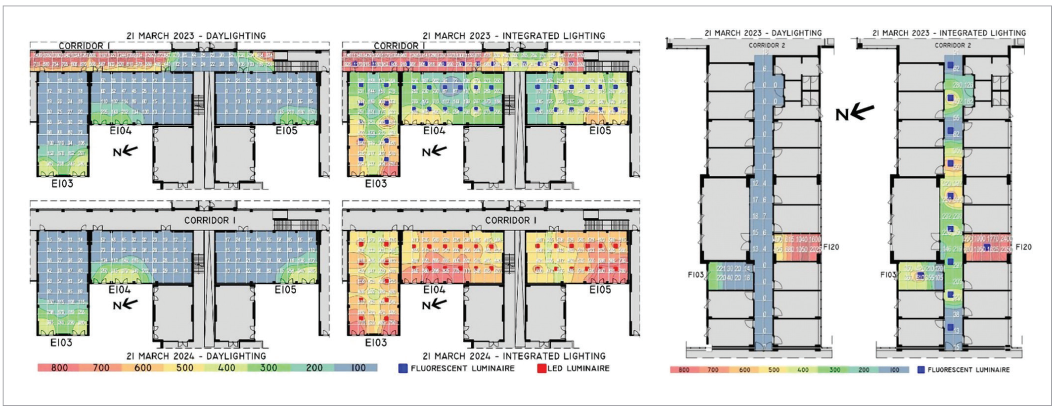


Fig. 3

Plan graphs of the lighting values measured using a lux meter in classrooms, offices and corridors on March 21, 2023 and 2024

The planning and façade design were identified as the primary factors responsible for the occurrence of this issue in such spaces. The window wall ratio in Office F103 on the north façade, which requires an increased level of daylight, was 16%. In contrast, the window wall ratio in Office F120 on the south façade, which necessitates a reduced level of daylight, was 53%. This resulted in insufficient illumination and glare in office environments where uniform conditions are expected to be maintained. A comparable issue is evident in the design of corridors. The design of Corridor-1 on the south facade employed the use of unnecessary glass curtain-wall, and the design of Corridor-2, situated between the office spaces, incorporated the use of blind wall.

In regard to integrated lighting performance, the corridor and office plan graphs (see Fig. 3) revealed enhanced illumination levels in the deficient areas within the office spaces and Corridor-1. However, the inhomogeneous distribution of light and glare was persisting. The illumination provided by the electric lighting in Corridor-2 was inadequate in certain areas, and the distribution of the light was not homogeneous. In Office F103, the electric lighting contributed to the overall lighting values, yet the distribution was not homogeneous. Furthermore, the glare problem persists in Office F120.

Fig. 4

Interior photographs of E103, E104 and E105 classes taken without electric lighting on March 21, 2023

Table 2

The mean illumination values for the classrooms, offices and corridors in 2023 and 2024.

Zone List	2023 Daylighting	2023 Integrated Lighting	2024 Daylighting	2024 Integrated Lighting
E103	86	352	102	477
E104	51	237	83	569
E105	48	310	80	561
Corridor 1	570	820	-	-
F103	73	303	-	-
F120	979	1418	-	-
Corridor 2	6	214	-	-

It is presumed that Yozgat Bozok University was designed with consideration for the semi-arid climate characteristics of the Central Anatolia region. This is evidenced by larger glass surfaces used on the south facade for thermal gain, in contrast to the minimal use of glass surfaces on the north facade. The faculty's location in a cold climate zone necessitated the implementation of design practices aimed at reducing the surface area of the classrooms. This undoubtedly had a significant effect on the visual comfort and utilization of daylight within the classrooms. These gave rise to considerable challenges with respect to the incorporation of daylighting.

In-situ light measurement and verification of daylight simulation program

The use of simulation tools is crucial for evaluating building performance from the design phase onwards and for ensuring sustainable high-performance buildings. These tools allow designers to assess both daylighting and electric lighting, predict potential deficiencies, and test design alternatives such as windows or brise-soleil before construction. In this study, the Velux Daylight Visualizer (VDV) was selected because it offers a fast, practical, and user-friendly interface. Unlike more complex programs, VDV can be easily installed and used without requiring extensive training, which makes it accessible to a wide range of building designers. This ease of use accelerates the transition toward energy-efficient and sustainable building design. However, VDV has limitations, as it is less advanced than other software in terms of detailed climate-based analysis. Despite this, it provides reliable results for comparative daylight studies and is therefore considered appropriate and functional for the aims of this research.

In this study, the base case of the classrooms and offices within the designated case study were initially modeled through the utilization of the SketchUp software, and daylight graphics were generated employing the Velux Daylight Visualizer. To substantiate the precision of the program, a simulation of the edifice was executed under analogous conditions to those of the in-situ measurement methodology. In this regard, the coordinate information of the building, its inclination to the north, the reflectivity, and the transmittance coefficients of the building surfaces were entered into the tool and the simulation was conducted on March 21 at 12:00 pm on a moderately overcast day. The reflectivity and transmittance coefficients of the materials utilized in the construction of the building facades were derived from the extant literature on the subject, specifically from the studies referenced in (Liu et. al,2024, Dinçer et al. 2013, Sezer 2015). The data pertaining to the materials utilized in the construction of the building entered into the simulation tool are presented in Table 3. The mean lux values for the classrooms, offices, and corridors were identified by referencing the plan graphics obtained from the simulation conducted under the same conditions as the in-situ measurement. To verify the accuracy of the tool, the mean lux values obtained from the in-situ measurement, and the tool were subjected to a comparative analysis.

Table 3

Data pertaining to the materials utilized in the construction of the building's surfaces

Building Surface	Reflectance	Roughness	Transmittance
Wall (Light-Colored Paint)	0.75	0.05	-
Flooring (Light-Colored Glossy Ceramic)	0.65	0.05	-
Flooring (Wooden Parquet)	0.25	0.05	-
Flooring (Vinyl)	0.40	0.05	-
Ceiling (Suspended Metal Ceiling, White)	0.65	0.05	-
Reflective Tinted Glass	-	-	0.33
Clean Float Glass	-	-	0.78

In order to ascertain the precision of the tool, a review was conducted of studies that described the bias error and deviation rate associated with the lighting simulation. Some studies employed the coefficient of determination (R^2) and linear regression equation (Bayram and Kazanasmaz 2016) or deviation Δ equation (De Rubeis et al. 2017) in Excel, and the majority of studies utilized MSE and RMSE equations (Kong and Jakubiec 2019, Freewan and Al Dalala 2020, Qin et al. 2023, Liu et al. 2024, Li et al. 2004, Ferraro et al. 2011, Jones and Reinhart 2017, Kong et al. 2018, Quek and Jakubiec 2021). According to these studies, MSE and RMSE values should be below 0.20 to ensure the accuracy of the program. Comparable results were reported in previous studies, with RMSE values ranging from 0.10–0.16 (Kong and Jakubiec 2019), 0.05–0.12 (Freewan and Al Dalala 2020), and 0.01–0.11 (Liu et al. 2024). In this study, MSE and RMSE were calculated using the mean lux values obtained from the classrooms through in-situ measurement and simulation tool for 2024. The formulas used were as follows:

$$MBE_{rel} = \frac{1}{n}\sum_{i=1}^{n} \frac{E_{simu,i} - E_{mea,i}}{\bar{E}_{mea}} \quad (1)$$

$$RMSE_{rel} = \frac{1}{\bar{E}_{mea}} \sqrt{\frac{\sum_{i=1}^{n}(E_{simu,i} - E_{mea,i})^2}{n}} \quad (2)$$

MBE_{rel} : The relative mean bias error

$RMSE_{rel}$: The relative root mean square error

$E_{simu,i}$: The ith simulated value.

$E_{mea,i}$: The ith measured value.

$\overline{E}_{mea}$: The average of the measured values

Table 4

In-situ measurement and simulation values, MBE and RMSE calculations for the classrooms

Zone List	2024 Daylighting	Velux Daylighting	MBErel / RMSErel	MBErel / RMSErel
E103	102	122	0.17	0.18
E104	83	101	0.19	
E105	80	97	0.19	

Table 4 presents the Mean Bias Error (MBE_{rel}) and Root Mean Square Error ($RMSE_{rel}$) values, which are used to evaluate the accuracy of the Velux Daylight Visualizer simulation tool. These metrics provide a quantitative comparison between in-situ measured lux values and simulated values. The MBE_{rel} indicates the average deviation between the measured and simulated values, while the $RMSE_{rel}$ accounts for both the magnitude and frequency of these deviations. Consistent with the thresholds reported in the literature, the values obtained in this study (0.17–0.19) fall within the acceptable range, thereby demonstrating the reliability of the Velux Daylight Visualizer for predicting daylighting performance.

Design Suggestions by the Simulation Tool

Three distinct design suggestions were developed to address the identified daylighting issues. Instead of selecting a single "best" design, multiple design suggestions were analyzed to provide a flexible range of solutions based on feasibility, cost, and adaptability to different areas within the building. The key considerations for each design suggestion were:

- Design suggestion 1: Maximizing daylight penetration by increasing window sizes and integrating strip windows in corridors. However, this approach posed potential glare risks.
- Design suggestion2: Incorporating shading elements to control glare while maintaining adequate daylight levels. This solution was effective but reduced daylight in certain areas.
- Design suggestion3: Optimizing window dimensions and configurations to balance daylighting and glare control. This scenario provided the most consistent performance across all spaces.

The reason for not selecting a single optimal solution is that different spaces within the building require different lighting strategies. For example, offices may benefit from smaller, controlled apertures to prevent glare, while classrooms require more uniform daylight distribution. The findings highlight the need for a context-sensitive approach rather than a one-size-fits-all solution.

The fundamental circumstances and suggestions were modeled using the SketchUp software, and the daylight graphics were created in the Velux Daylight Visualizer simulation tool on March 21 at 12:00 pm on a moderately overcast day. **Fig. 5** depicts the façade elements of the base case and the three design suggestions, and the simulation plan graphics with the model images to illustrate the architectural elements in detail. In the plan graphs, the increase in lux values from blue to red is represented by a curve. The presence of red and orange curves indicates the existence of glare, while black and blue curves indicate inadequate lighting. Furthermore, it can be concluded that the presence of these color differences within a given space indicates a lack of homogeneous distribution of light within that space. In this regard, the plan graphs illustrate that with the base case, the daylighting in Classrooms E103, E104, and E105, Corridor-2, and Office F103 is insufficient, and there are glare issues in Corridor-1 and Office F120. Additionally, it was noted that the distribution of light across the case study was not homogeneous. Subsequently, the mean lux values were calculated for the spaces from the plan graphics produced from the simulation conducted with the base case, and each of the three distinct suggestions.

In Classrooms E103, E104, and E105 where insufficient daylighting values were identified within the scope of the first design scenario, it was suggested that glass wall be employed to provide maximum daylighting, as an alternative to 1.0mx2.2m single casement windows on the façade (see Fig. 5). In order to address the inadequate illumination in the corridors facing the classrooms, a 0.8-meter-high strip window was installed on the walls of the aforementioned classrooms. To mitigate the glare problem, it was suggested that a movable shading element be installed on the façade of Corridor 1 and that 1.2m x 1.2m windows on the base case be placed on the north façade of Office F120. In order to address the inadequate illumination in Corridor-2 facing the classrooms, a 0.8-meter-high strip window was installed. To ensure that Office F103 could benefit from as much daylight as possible, it was suggested that a glass curtain-wall be used for the building's façade. Although the plan and linear graphs indicated an increase in the mean lux values across the three classrooms, it was observed that the distribution of light was inadequate in certain areas of each of the three classrooms. Furthermore, in Classroom E013, a glare issue was identified (Fig. 6). In Office F120 where glare was the primary issue, it was observed that the implementation of the suggestion resulted in inadequate lighting. It was thus concluded that the 1.2m x 1.2m windows utilized in the base case were unsuitable for deployment in educational buildings. In Office F103 where a comparable scenario was encountered, and illumination was inadequate, the suggested utilization of glass curtain-wall resulted in glare issues. It was therefore concluded that the unmanaged use of glass walls in educational buildings may not result in the desired positive outcomes. The inadequate lighting in Corridor-2, and the glare issues in Corridor-1 remain unresolved. It is evident that the suggestion did not result in the desired outcome of achieving homogeneous light distribution in all spaces within the case study.

In contrast to the initial suggestion, the second design suggestion included the incorporation of a shading element in Office E103 where glare was identified as a significant issue. The shading element, typically in an open configuration in Corridor 1, was adjusted to a half-open configuration (Fig. 5). An identical shading element was installed to the glass curtain-wall in the base case setting in Office F120. Although the plan and linear graphs revealed a decrease in the mean lux values in the E103, it was observed that the distribution of light was inadequate in certain areas of each of the three classrooms (Fig. 6). The implementation of the suggested improvements resulted in a notable enhancement in the lux values observed in Office F120 and Corridor-1, both of which were previously affected by glare. The issues that manifested in F103 and Corridor-2 as a consequence of the initial suggestion were also evident in this suggestion. According to the plan graphs, the second suggestion did not result in a homogeneous distribution of light across the other spaces, with the exception of Office F120.

The third design suggestion differed from the other two in that it called for the use of 3.0m x 2.2m casement windows in classrooms, 3.0m x 2.2m in Corridor-1, and 1.8m x 2.2m in Office F120 and F103 (Fig. 5). The plan and linear graphs revealed that the implementation of this suggestion did not result in glare within the classrooms, but the illumination was inadequate, similar to the situation that arose following the previous suggestion. (see Fig. 6). The implementation of this suggestion improved the lux values in Corridor-1, and F103 and F120 where glare was a concern in the base case, but the other issues observed in Corridor-2 after the first two suggestions remained unresolved. As illustrated in the plan graphics, even after implementing the suggested modifications, it was not possible to achieve homogeneous light distribution in spaces other than Office F103 and F120. The issues encountered in the offices showed a marked improvement, particularly following the third suggestion. Furthermore, the simulations provided clear evidence that the problems had been successfully resolved (see Fig. 6).

In all three design suggestions, the primary reason for failing to meet the minimum value of 300 lux, as stipulated in the literature for classrooms, was due to the building's plan scheme. Given the dimensions of the classrooms, the positioning of adjacent structures, and the orientation of the building in relation to the sun, it was evident that merely modifying the façade could not fully address the identified issues. The aforementioned assertion also applies to Corridor 2; consequently, a solution to this problem cannot be achieved without the direct illumination of this area with windows.

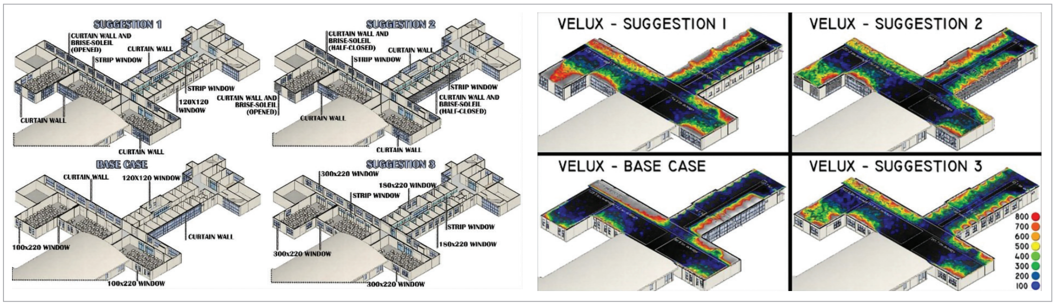
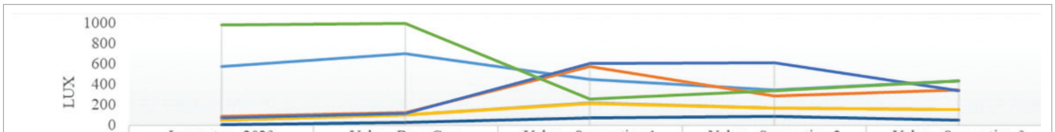


Fig. 5

SketchUp models of the base case and design suggestions, and iso-contour plan graphics obtained from Velux Daylight Visualizer simulation tool on March 21 at 12:00 pm



	Luxmeter - 2023	Velux -Base Case	Velux - Suggestion 1	Velux - Suggestion 2	Velux - Suggestion 3
Corridor 1	570	695	446	340	432
E103	86	122	573	285	346
E104	51	101	221	170	151
E105	48	97	214	165	152
F103	73	116	601	607	339
F120	979	994	253	333	432
Corridor 2	6	23	71	86	48

Fig. 6

The mean lux values obtained from the simulator of the base case and suggested designs at 12:00 pm on March 21

The base case and ideal suggestion annual daylighting performance

Following the simulation studies, a comparative analysis was conducted on December 21, March 21, and June 21 between the third simulation suggestion, considered to provide the best daylighting values and the most ideal initial construction costs, and the base case. In this regard, the light distributions at 09:00 am, 12:00 pm, and 3:00 pm in the spaces related to the base case and the third suggestion were measured on the scheduled dates using the simulation tool (see Fig. 7). Thereafter, the mean lux values in the spaces in the case study were measured using the plan graphs, and these numerical values were converted into linear graphs (Fig. 8 and 9).

Simulations conducted on December 21 (09:00–15:00) revealed glare problems in Corridor-1 and Office F120 under the base case, whereas these issues were resolved with the third (ideal) design suggestion. However, despite improved illuminance, Classrooms E103, E104, E105, Office F103, and Corridor-2 still showed inadequate daylighting. On March 21, the base case indicated glare in Corridor-1 and Office F120 during morning hours, while the third design suggestion reduced glare but classrooms and Corridor-2 again failed to meet adequate illumination. In contrast, Offices F103 and F120 achieved optimal daylight values across all intervals. Similarly, the June 21 simulations showed persistent glare in Corridor-1 and Office F120 under both the base case and the suggested design. The base case provided inadequate daylighting in all classrooms, Office F103, and Corridor-2. The third design suggestion improved performance, particularly in Offices F103 and F120, but illumination in classrooms and Corridor-2 remained below standard levels.

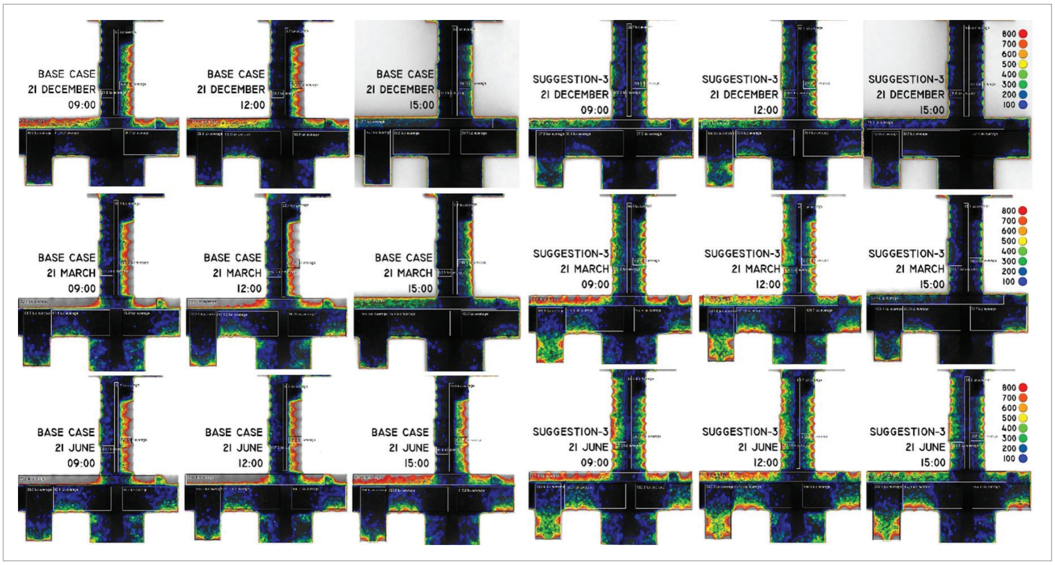
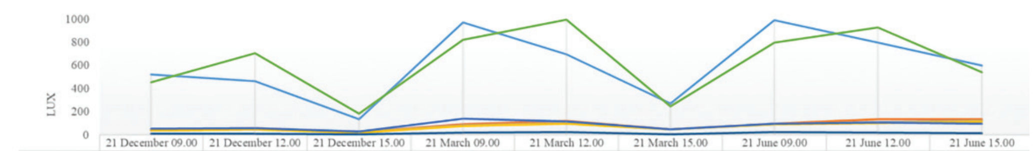


Fig. 7

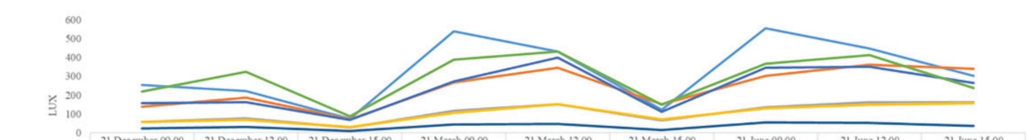
Plan graphs of the base case and the ideal suggestion on December 21, March 21 and June 21



	21 December 09.00	21 December 12.00	21 December 15.00	21 March 09.00	21 March 12.00	21 March 15.00	21 June 09.00	21 June 12.00	21 June 15.00
Corridor 1	524	464	137	973	695	271	993	800	601
E103	46	59	26	90	122	49	99	137	134
E104	41	50	22	81	101	47	92	112	121
E105	37	50	21	79	97	48	91	101	116
F103	52	59	27	142	116	50	99	107	95
F120	456	707	185	821	994	249	800	927	541
Corridor 2	9	10	4	19	23	7	24	19	14

Fig. 8

Annual mean lux values of the base case spaces obtained from the simulation tool



	21 December 09.00	21 December 12.00	21 December 15.00	21 March 09.00	21 March 12.00	21 March 15.00	21 June 09.00	21 June 12.00	21 June 15.00
Corridor 1	255	221	74	538	432	122	556	449	302
E103	138	187	72	268	346	153	304	363	339
E104	58	77	30	118	151	66	135	163	162
E105	57	70	32	106	152	71	132	149	157
F103	159	164	70	272	399	113	347	350	265
F120	219	324	87	390	432	149	367	412	237
Corridor 2	23	32	11	44	48	16	56	54	36

Fig. 9

Annual mean lux values of the ideal suggestion spaces obtained from the simulation tool

A comprehensive examination of the graphical data revealed that the optimal design for the base case ensured that the offices on the north and south facades received approximately equal or near-equal levels of daylighting. The illumination levels in the aforementioned classrooms and Corridor-1 were increased, and the glare issue in Corridor-2 was resolved. A comparative analysis of the graphs in terms of homogeneous distribution of daylight indicates that the later configuration was an improvement over the base case. In contrast with the anticipated outcome, there was no improvement in the lighting performance in the classrooms and corridors. This can be attributed to flaws in the planning and design of these spaces. In the case study, design issues are evident, including the placement of the corridor on the south façade but not the classrooms, the classrooms receiving daylight from the short wall or not having sufficient window apertures due to the adjacent building block, and the lack of window apertures in some corridors. To prevent such complications, daylight simulation tools should be used prior to the construction phase, and the data obtained should guide the design.

Discussion

In this study, the illumination values in seven different spaces, including classrooms, offices, and corridors in the Department of Architecture at YOBU, were measured with a lux meter at one-year intervals (2023 and 2024). The case study was simulated using the Velux Daylight Visualizer, a tool widely utilized for daylight analysis in buildings. Then, alternative design suggestions were developed through façade modifications, while maintaining the base case plan diagram. Following the completion of daylight simulations for the base case and design suggestions, an analysis was conducted to quantify the annual natural lighting performance of the optimal case and base case at three distinct time intervals (December 21, March 21, and June 21).

The results reveal several critical design implications:

- In the process of designing buildings, the use of daylighting simulation programs is of considerable importance, as they facilitate the achievement of energy savings and sustainability.
- While the classrooms exhibit an optimal window-to-wall ratio, they lack the ideal dimensions and south orientation angle (Classrooms E103, E104, and E105).
- Classrooms should not receive daylight from the north facade and short wall (Classroom E103)
- The south façade should be constructed with classrooms, not corridors (Corridor-1).
- Spaces at the intersection of buildings are not suitable for use as classrooms (Classrooms E104 and E105).
- Office corridors should receive direct daylight (Corridor-2)
- The presence of glass curtain-wall causes glare in corridors and offices (Corridor-1, and Office F120)
- The 1.2m x 1.2m windows are not an optimal choice for educational buildings due to inadequate illumination issues (Office F103)
- In the case of office rooms with dimensions of 5.0m x 3.0m x 2.9m, the optimal window size is 1.8m x 2.2m (Suggestion-3; Offices F103 and F120)
- The optimal dimensions for the windows along the south façade are 3.0m x 2.2m (Suggestion-3; Corridor 1).
- The best efficient utilization of natural light in the classrooms on the north facade does not, in and of itself, represent an optimal solution in terms of natural lighting (Suggestion-3; Classrooms E103, E104, and E105).

In regard to the provision of visual comfort in the educational building under consideration, it is evident that the plan scheme, the orientation of the building, and the façade components are inadequate in light of the regional and climatic conditions that prevail in the area. The incorporation of daylighting is of particular significance in the context of specific building types, such as educational institutions.

Conclusions

It is important to consider visual comfort in educational buildings as a key factor that can positively impact users, enhancing both learning outcomes and motivation. This study contributes to the literature by integrating empirical measurements and simulations, offering a holistic approach to daylight performance analysis. Unlike previous research that often addresses isolated parameters, this study demonstrates the added value of a multi-method approach. The findings of this study emphasize the importance of considering architectural constraints, such as orientation and adjacent structures, when designing daylighting solutions. The close correlation between measured and simulated data validates the reliability of simulation tools for daylight performance analysis. Results further highlight the necessity of integrating shading elements and strategic window placement to balance daylighting and visual comfort. Employing daylighting simulations at the early design stage is particularly significant, as it can help avoid costly post-construction modifications. Since only a limited number of studies in Turkey have addressed this subject, there is a clear need for further locally adapted research. The design suggestions developed in this study can be transferred to similar educational buildings, particularly in regions with comparable semi-arid climates. For other climatic zones, the methodology remains valid, though window dimensions and shading strategies must be adapted. By addressing these factors, future educational buildings can be designed with improved energy efficiency and enhanced visual comfort. The findings underscore the importance of an interdisciplinary approach, combining architecture, lighting engineering, and environmental design to achieve sustainable daylighting solutions. In a world where sustainable architecture is gaining importance, daylighting must be considered from the outset of the design process. Rather than implementing post-design modifications, it is essential to design buildings according to their intended function and geographical context. Thus, the creation of energy-efficient, climate-responsive, and sustainable educational buildings represents not only a design preference but an inevitable necessity for the future.

Acknowledgment

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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About the authors

SADAKAT SAFIYYE MUMCUOĞLU TÜRKER

Yozgat Bozok University, Faculty of Engineering and Architecture, Architecture Department, Yozgat, Turkey

Main research area

Architecture, Design & Planning, 3D, and Simulation Programs in Architecture.

Address

Yozgat Bozok University, Faculty of Engineering and Architecture, Architecture Department, Yozgat, Turkey
Tel. +90 506 431 38 79
E-mail: ss.mumcuoglu@yobu.edu.tr

SELAHADDIN SEZER

Yozgat Bozok University, Yozgat Vocational School, Program of Interior Design, Yozgat, Turkey

Main research area

Architecture, Design & Planning, 3D, and Simulation Programs in Architecture

Address

Yozgat Bozok University, Yozgat Vocational School, Program of Interior Design, Yozgat, Turkey
E-mail: selahaddin.sezer@yobu.edu.tr