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Analytical Study on Reducing the Heating Effects of Daylight and Improving Natural Lighting Performance at Erzincan Train Station in the Context of Climate Change

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Abstract

Climate change is an environmental issue that is rapidly escalating due to the effects of global warming. The increase in carbon emissions, along with various human activities such as industrial processes, land use changes, and the reckless consumption of natural resources, are among the primary causes of global warming. Various architectural interventions are being implemented in historical buildings to mitigate the impact of global warming and its consequence, climate change. The study aims to protect the historical building from the harmful effects of climate change by reducing the heating effects of direct sunlight during the summer and enhancing the efficiency of natural lighting throughout the day. In this context, the Erzincan Train Station is located in Erzincan in Eastern Anatolia. Erzincan is one of the most affected by the climate change crisis has been selected for the study. The plans of the Erzincan Train Station were digitized using AutoCAD software and subsequently modeled in three dimensions using Revit software. Daylight analysis was conducted on the created model using the Insight plugin in Revit software. The analysis determined that recommendations should be made for the building's south facade. Based on the climate data of Erzincan province and the conducted analyses, the light shelf system was designed and implemented due to its applicability, shading, and lighting advantages among daylighting systems. The effects of the proposed system were examined using spatial daylight autonomy (sDA) and annual sunlight exposure (ASE) daylight metrics according to LEED v4 EQc7 standards. The study found that the light shelf system resulted in a 5% reduction in ASE values building-wide and a 6% reduction in the average values of specific areas while increasing sDA values. In this context, it has been observed that areas experiencing a decrease in direct sunlight exposure (ASE values) also show an increase in sufficient daylight exposure (sDA values), which could contribute to improving the building's energy performance.

1. Introduction

Historical buildings are structures that provide information about all the accumulated knowledge of a society, including its culture, architecture, art, traditions, and way of life, in short, all aspects of its past. They bear significant traces of the urban identity of the place where they are located [1]. Stations and railway structures, which are part of these buildings and fall within the scope of industrial heritage, have become places for city dwellers to meet, wait, rest, and depart. Therefore, they have become spaces that are more actively used and have a high metabolic rate. These spaces, which have abundant natural light, should have their heating and cooling loads optimized, with excessive heat loss reduced in winter months and overheating prevented in summer months.

In natural lighting design, it is essential to ensure that adequate daylight levels and uniform distribution of light meet the user's visual performance, as well as their psychological and physiological needs, while also avoiding the harmful effects of direct sunlight [2]. Therefore, various measures have been taken to benefit from the beneficial effects of sunlight in different climate types while also protecting against harmful effects. In warm climate types, daylight illumination is desired, but living spaces within buildings are positioned to avoid direct sunlight to prevent overheating caused by sunlight. In cold climate types, buildings are oriented towards the south, and transparency

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surfaces are increased on the southern facade to maximize the heat energy gained from sunlight. Shading elements are used on transparent surfaces created on the southern facade to protect against the adverse effects of direct sunlight and to benefit from daylight illumination while ensuring the required natural lighting [3].

In this context, the city of Erzincan, where the studied structure is located, is the province in Turkey's Eastern Anatolia Region with the most temperature variation [4]. While the fluctuations caused by this change in temperature were more stable between 1900-2000 in Erzincan, they have increased continuously in the 2000s. This situation has led to effects such as an increase in cooling load, frequent use of ventilation systems, and the need for proper lighting in historical buildings, causing damage to the buildings.

While the harmful effects of direct sunlight are considered in newly constructed buildings, this effect has not been taken into account in historical buildings. Historical structures that are actively used are particularly at greater risk. In this study, Erzincan Train Station, which has significant importance in the history of Erzincan, was selected, and a case study was conducted in the following sections. This study is important in drawing attention to these harmful effects on historical buildings and emphasizing the necessity of considering them.

1.1. Interventions suggestions and daylight studies in historical buildings

To deal with human-induced climate change, two approaches stand out: mitigation and adaptation. The 'mitigation' approach aims to take the necessary measures to prevent or slow down human-induced climate change, while the adaptation approach aims to prepare for the conditions that climate change will cause [5].

Another important point to consider in the proposed system is the nature of the building. Since the Erzincan Train Station is a monumental structure, certain considerations must be taken into account when making interventions:

- To ensure the longevity of historical buildings and to pass them on to future generations, they need to be adapted to contemporary usage conditions, if necessary, by changing their current functions or adding secondary functions [6]. Article 4 of the Carta del Restauro, published in 1931, states that interventions on living monuments, those that are still standing, should be made without significantly departing from their original function and without causing significant damage to the building [7].
- Italian conservation-restoration theorist Cesare Brandi, in his 1963 publication "Theory of Restoration," stated that contemporary interventions should be limited to the minimum necessary to preserve the integrity of the existing structure. These interventions should ideally be reversible without leaving any trace, so as not to impede future necessary interventions [8].

In this study, the proposed interventions on the facades of the Erzincan Train Station take into account the principles outlined above and the climate conditions of its location.

When examining studies on daylight in historical buildings, it is seen that they focus on improving lighting performance and visual comfort in spaces. In a study conducted by Lana Abubakr and Faris, the morphologies of historical mosques were analyzed, and daylight analyses were performed using the Revit program to evaluate the lighting level and amount of daylight entering historical mosques [9]. In another study by Jose and colleagues, the lighting performance of the historical Saint Louis church was analyzed through simulations and then physically tested to assess the suitability of the data [10].

In another study by Farimah et al., research was conducted on how to increase daylight in a historical building without intervening on the facade. The study involved an example case using roof lighting systems, which were evaluated based on daylight metrics [11]. Mohamed et al. focused on the historic

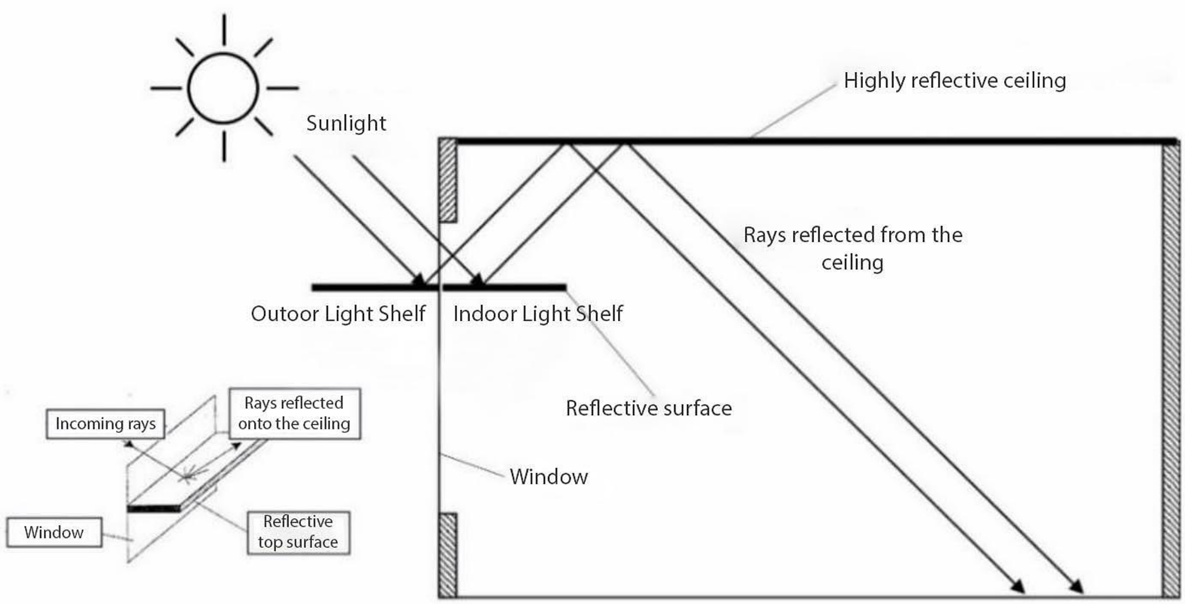
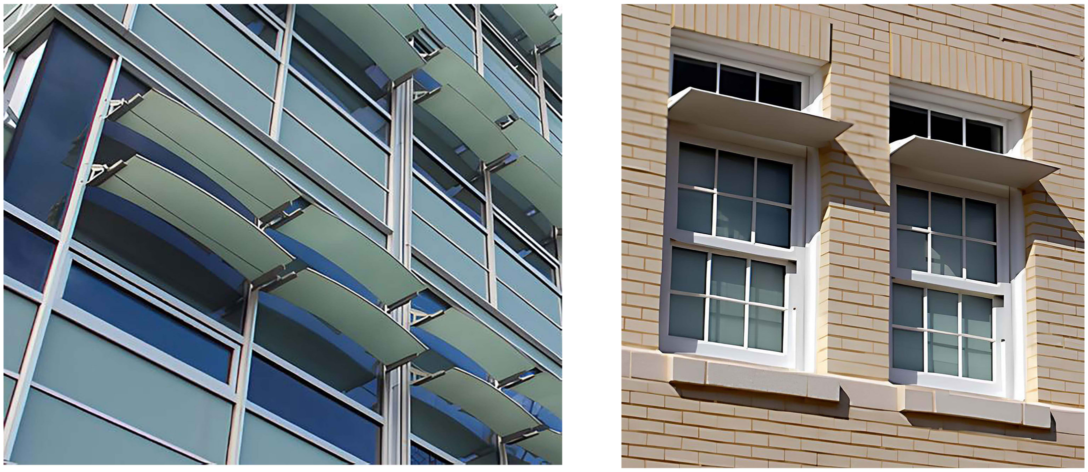


Fig. 1. Light Shelf Working Principle [3].



(a) (b)

Fig. 2. (a) Light shelf application in SURREY tax office building facade [3] (b) light shelf system application example [18].

Tosson Palace in Egypt, aiming to meet the palace's daylight requirements and improve the building's energy performance by increasing the use of daylight and reducing artificial lighting. The daylight conditions of the space, illuminated from above through a roof window, were parametrically optimized using Rhino + Grasshopper programs. The results were evaluated according to daylight metric criteria using LEED V4.1 [12]. The reviewed studies indicate that while some focus on assessing daylight performance in historical buildings, others aim to enhance this performance.

When examining studies on daylight redirecting systems, it is observed that these systems are predominantly used in office, residential, and educational buildings. In this study, daylight redirecting systems in both historical and new buildings were analyzed, and it was proposed to implement such a system in the Historical Erzincan Train Station.

1.2. Daylight guidance systems and light shelves

To reduce energy consumption and increase the use of daylight in traditional architecture, daylight redirecting systems have been developed. The objectives of daylight redirecting systems include delivering daylight to areas that it cannot naturally reach to achieve sufficient and uniform illumination levels indoors, providing shading to prevent direct sunlight from entering in sunny climates and helping to create thermal comfort conditions, and minimizing lighting disadvantages caused by climatic effects [3,13]. Examples of daylight redirecting systems include light shelves, anabolic systems, prismatic systems, laser-cut panels, and holographic optical elements. In this study, the light shelf system was selected. The main reasons for choosing this system are the high windows on the ground floor, the desire to make minimal interventions to the historical building (allowing for removal and reinstallation), and the need to block harmful direct sunlight that comes at a steep angle during the summer.

Light shelves are systems installed above eye level that divide the window into two parts without affecting the exterior view. They are used to direct daylight deeper into the room and to provide shading by preventing direct sunlight from entering at undesirable angles [14]. This system works by reflecting daylight onto the interior ceiling through a reflective surface placed on the top side of the shelf, functioning as a shading element to reduce cooling and lighting loads (Fig. 1) [15]. Light shelves are particularly effective for southern exposures [14].

To prevent excessive daylight from entering, the depth of the light shelf can be increased. However, deeper light shelves can reduce the view provided by the window. This problem can be mitigated by covering the light shelf with a movable reflective film [16]. Light shelves can be integrated into the facade or added as an aftermarket element [17] (Fig. 2).

2. Material and method

In this context, necessary efforts should be made for historical buildings to adapt to the changing climate conditions of today, and measures should be taken against climate change to preserve these structures. The Erzincan Train Station is one of these historically significant buildings that is still actively used and in need of preservation. Completed in 1938, the station building survived two major earthquakes in 1939 and 1992 with minimal damage, establishing itself as a significant part of the city's identity. However, the increasingly pressing issue of climate change has not been anticipated to pose risks of overheating to this structure. In this study, recommendations have been made on how to minimize the potential damage from extreme heat effects resulting from climate change in historical buildings. This involves improving the energy performance of the building through various interventions and measures.

The study utilized quantitative methods, particularly daylight analysis. Initially, literature reviews were conducted on railways and train stations to determine the importance of train stations for industrial heritage and urban identity. Subsequently, architectural data of the Erzincan Train Station was obtained from the Republic of Turkey State Railways (TCDD) 4th Regional Directorate archives and transferred to computer software using Autocad, then modeled in 3D using Revit. Autocad and Revit were chosen for their ease of architectural transfer, availability of free student versions, and their frequent use in literature studies.

The modeled train station was created in Revit according to the LEED v4 EQc7 standards included in the Insight plugin of the

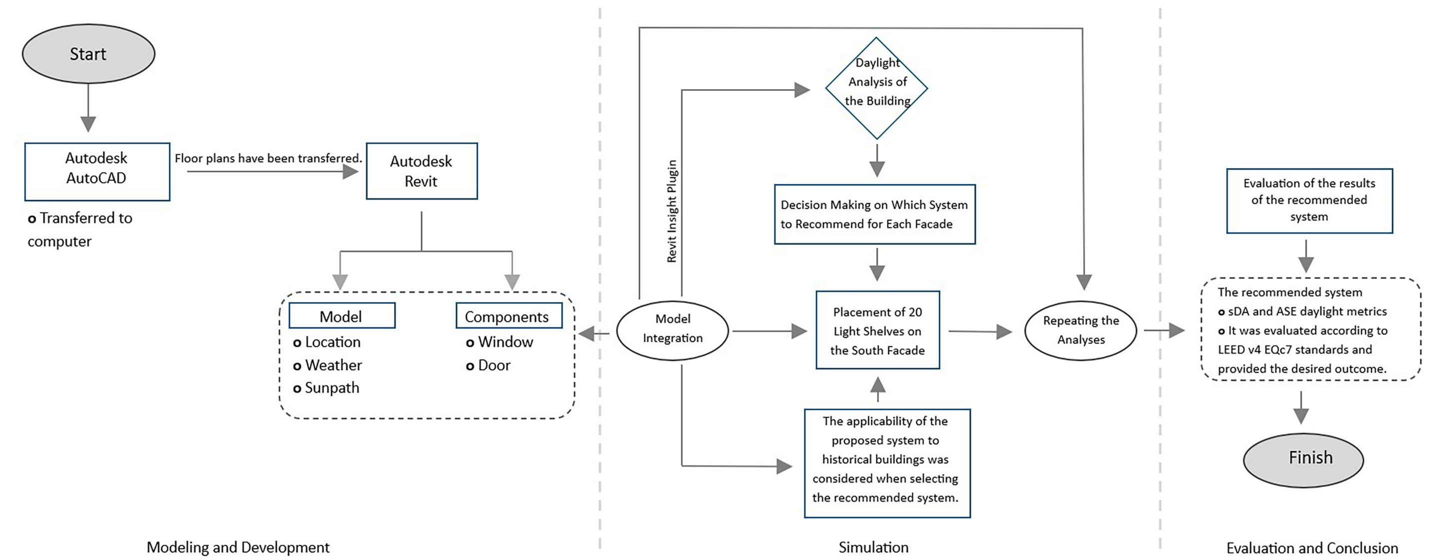


Fig. 3. Workflow chart.

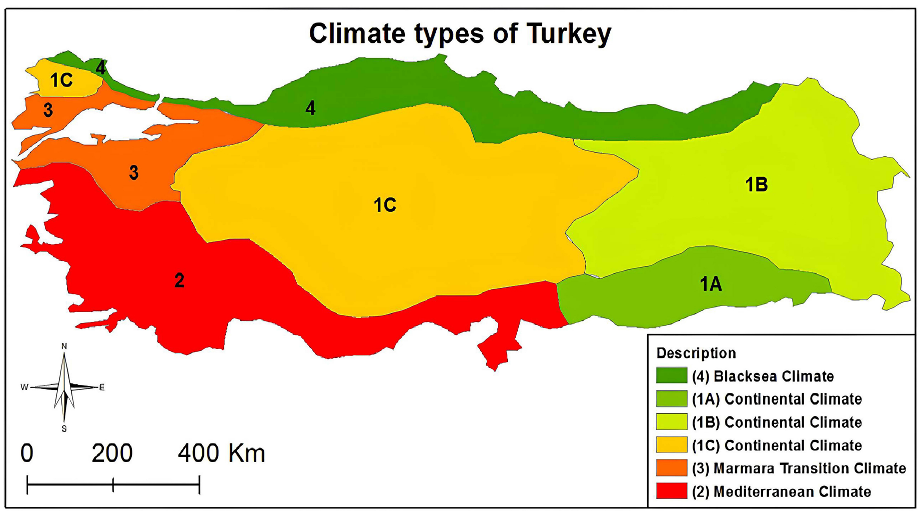


Fig. 4. Climate zones of the Turkey [23].

program. Leadership in Energy and Environmental Design (LEED) v4 EQc7 is a certification system that evaluates indoor environmental quality by measuring daylight [19]. The preference for this standard is due to its utilization of spatial daylight autonomy (sDA) and annual sunlight exposure (ASE) daylight metrics and the provision of values in lux units for daylight analysis [20]. According to the analysis data, it was decided to implement a daylight shelf system on the southern facade of the building. To examine the effects of the proposed system on the Erzincan Train Station, the proposed system was added to the three-dimensional model in the Revit program, and the analyses were conducted again (Fig. 3). The results of the reanalyzed data, including sDA, ASE, and LEED v4 EQc7 values, were compared with the previous analysis results to measure the effectiveness of the proposed system.

2.1. Climate change in Turkey and Erzincan

In the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, it is stated that there will be a general temperature increase of 1-2°C in the Mediterranean Basin in Turkey, and particularly in inland areas, the number of heatwaves and extremely hot days will increase (Turkey's Climate Change Adaptation Strategy and Action Plan) [21]. Turkey has seven regions (Marmara, Aegean, Mediterranean, Blacksea, Central Anatolia, Eastern Anatolia and Southeastern Anatolia Region) and four main climate regions (Blacksea, Contiental, Marmara and Mediterranean Climate) (Fig. 4) [22].

The province of Erzincan, located within the Eastern Anatolia region, where the study was conducted, has a continental climate. It is characterized by cold and snowy winters and hot and dry summers. Significant changes have occurred in the region due to climate change and global warming. The largest decrease in the annual average global solar radiation is observed in Erzurum, while the highest increase is observed in Erzincan (Fig. 5(a)). The highest increase in the annual average sunshine duration is observed in Erzincan, while the greatest decrease is seen in Bitlis (Fig. 5(b)) [4].

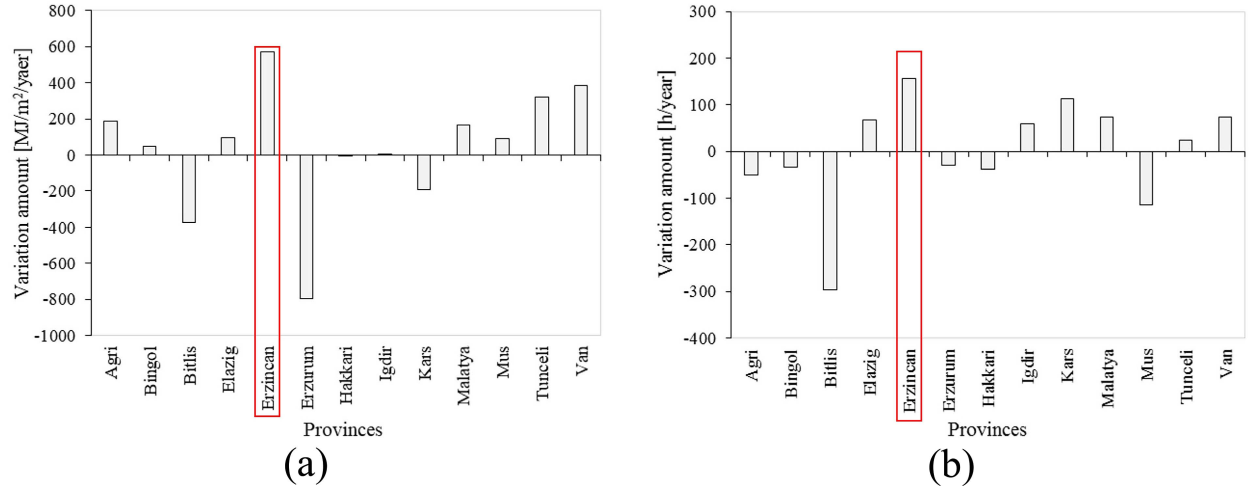


Fig. 5. (a) Annual variation of global solar radiation (b) Annual variation of global sunshine duration [4].

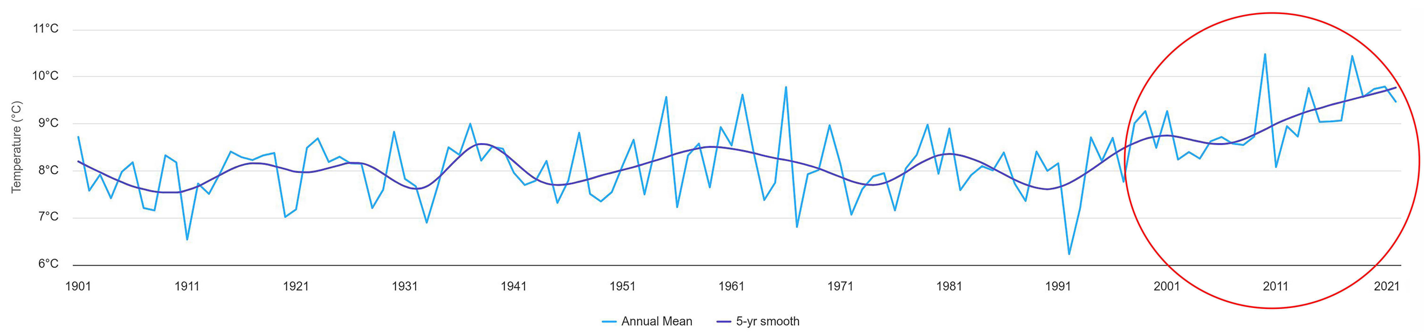


Fig. 6. Graph of the average surface temperature of Erzincan from 1901 to 2022 [24].

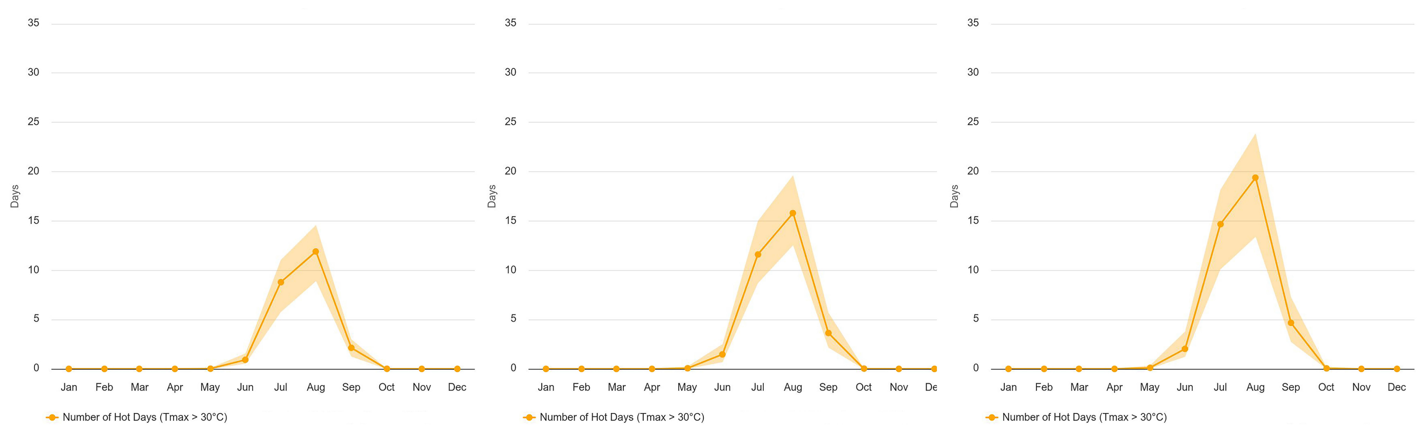


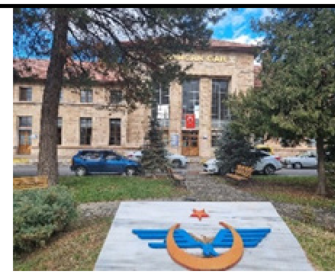
Fig. 7. Number of days with temperatures above 30°c in erzincan province according to ssp4.5 a) ssp4.5 2020-2039 b) ssp4.5 2040-2059 c) ssp4.5 2060-2079 [26].

When examining the temperature data for the province of Erzincan between 1901 and 2022, it is observed that the temperatures varied in the range of 6-9°C until the 2000s, whereas after the 2000s, the temperature data changed to the range of 8-11°C (Fig. 6). Furthermore, the temperature values after the 2000s have consistently increased until 2022. Climate change, one of the main reasons for this increase depicted in the graph, is intensifying its impact day by day.

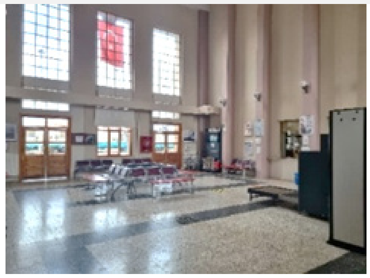
The main cause of climate change, global warming, is projected to continue primarily due to cumulative increasing CO2 emissions in almost all assessed scenarios in the near future (2021–2040). The increase in CO_2 emissions, a greenhouse gas, leads to an increase in the number of hot days. This situation, combined with the heating effect of direct sunlight, is predicted to harm historical buildings. Therefore, the examined greenhouse gas emission scenarios indicate a range of best estimates for warming from 1.4°C for very low greenhouse gas emission scenarios (SSP1-1.9) to 2.7°C for intermediate greenhouse gas emission scenarios (SSP2-4.5), and up to 4.4°C for very high greenhouse gas emission scenarios (SSP5-8.5) for the period 2081–2100 [25]. In this study,

Table 1. Erzincan train station in 2023 (11.12.2023) (author archive).





North and south facade of the train station (from left to right)


Foyer area and waiting hall (from left to right)

the province of Erzincan, where the Erzincan Train Station is located, was examined based on the SSP2-4.5 scenario, which is most likely to deviate from both the minimum and maximum projections among the scenarios considered (Fig. 7).

2.2. Erzincan train station

Construction of the Sivas-Erzurum railway line, which was part of the development plan in the early years of the Republic, began on September 4, 1933 [27]. The railway line, which heavily relied on manual labor, was completed in a short period of about 6 years. The Erzincan Train Station, which was part of this line, was opened for service on October 8, 1938. Shortly after its opening, on the night of December 27, 1939, during an earthquake with a magnitude of 7.9, the Erzincan train station stood as the only building that remained intact. After the earthquake, it was effectively used for communication, transportation, and delivering aid supplies (Table 1) [28]. Although there is information among the public that the Erzincan Train Station was built by German engineers, this has not been confirmed by written sources. The architectural style of the station reflects the characteristics of the Second National Architecture Period, during which it was constructed [29].

The Erzincan Train Station has four facades (south, north, east, west), all of which feature an unadorned, symmetrical, and geometric facade composition. The station, which has a rectangular plan, consists of a basement floor, ground floor, and first floor (Fig. 8). The southern facade of the building features a large projection that provides access to the main hall entrance, equipped with a single door. On the northern facade (platform side), this projection is much smaller, with two doors for entry and exit. Above these doors, there is a three-row window arrangement. Currently, the station is actively used for its intended function.

2.3. Daylight analysis in Erzincan train station

Daylight is defined as the combination of all direct and indirect sunlight throughout the day [31]. Direct radiation, as the name suggests, is the radiation that comes directly from the sun. The intensity of direct solar radiation reaching the Earth's surface continuously varies depending on the angle of incidence. Direct radiation reaching the Earth's surface reaches its highest value (energy) at noon, while at sunrise and sunset, the incoming radiation is at a low angle, causing it to be scattered and lose its intensity. Direct radiation provides illumination in buildings due to its high energy, but it also has a heating effect [3]. Therefore, access to the right amount of daylight is important for providing comfort and improving energy performance in buildings. When improving the energy performance of a building, daylight measurement criteria in dynamic metrics (such as sDA, ASE, etc.) should be calculated taking into account the characteristics of the building, and efforts should be made to achieve the most accurate values. TS EN 17037 Building Daylight Standard and CEN/TC 169, prepared by the "Light and Lighting Technical Committee", contains standards for the use of daylight in buildings. According to this standard, the minimum performance of daylight in spaces is defined, and recommendations are provided for ensuring minimum daylighting for spaces where daylight is a lighting element, as well as for exposure to sunlight and glare [32].

In this study, the sDA and ASE values (lighting thresholds defined by the standard; sDA: 300 lux for 50% of the period, ASE: 1000 lux for more than 250 occupied hours per year) [33] were considered and evaluated to determine the amount of direct daylight entering the Erzincan Train Station and the daylight performance of the spaces within the building. sDA is used to define how much of an area receives sufficient daylight, while ASE is used to describe how much of an area receives too much direct sunlight, which can cause visual discomfort (glare) or increase cooling loads [31]. As part of the study, a daylight analysis was conducted at the Erzincan Train Station to identify areas receiving direct sunlight. Based on these findings, various solutions were proposed to reduce heating and lower cooling loads.

In the study, the path of the sun was determined by entering the location information and the date for analysis into the model

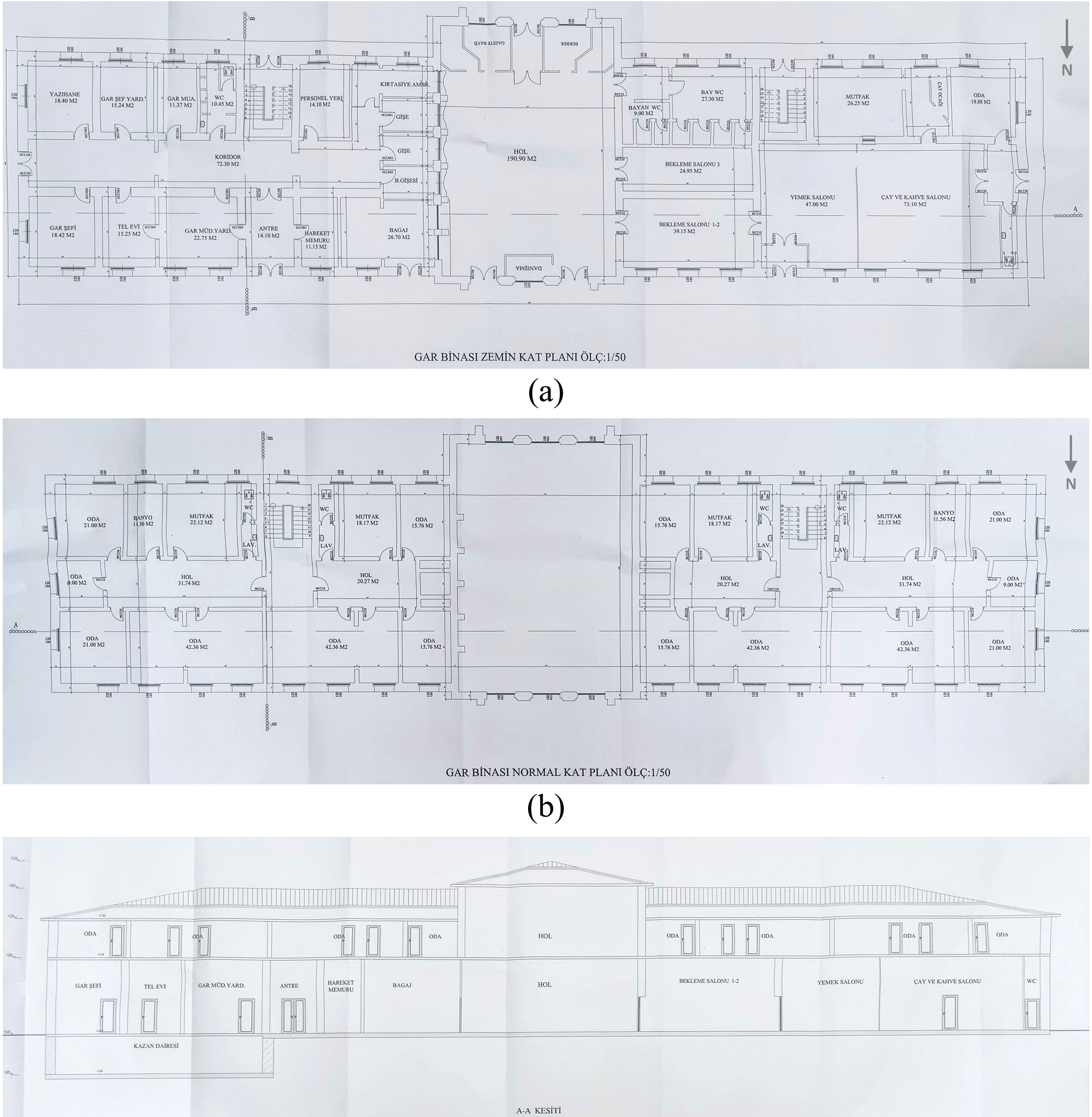
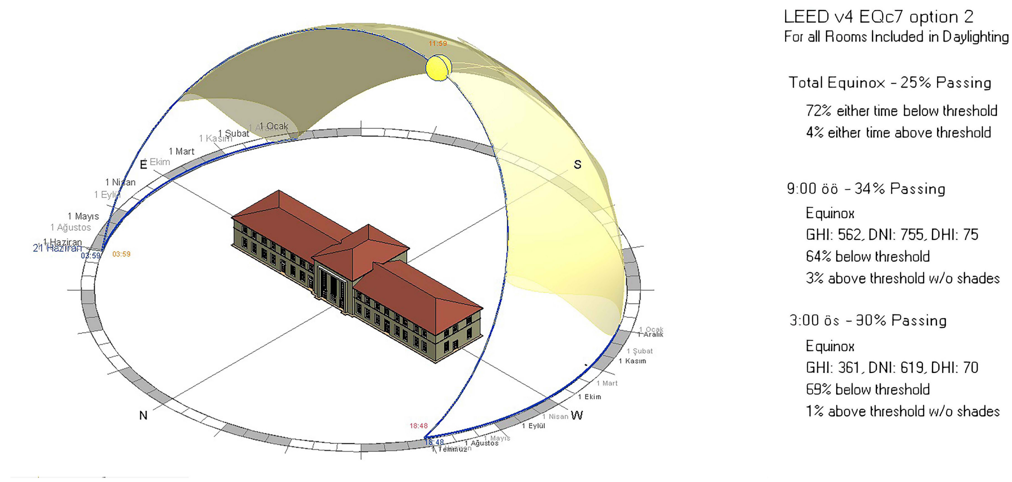


Fig. 8. (a) Ground Floor Plan of Erzincan Train Station (b) First Floor Plan of Erzincan Train Station (c) Section A-A of Erzincan Train Station (TCDD 4th Regional Archive) [30].

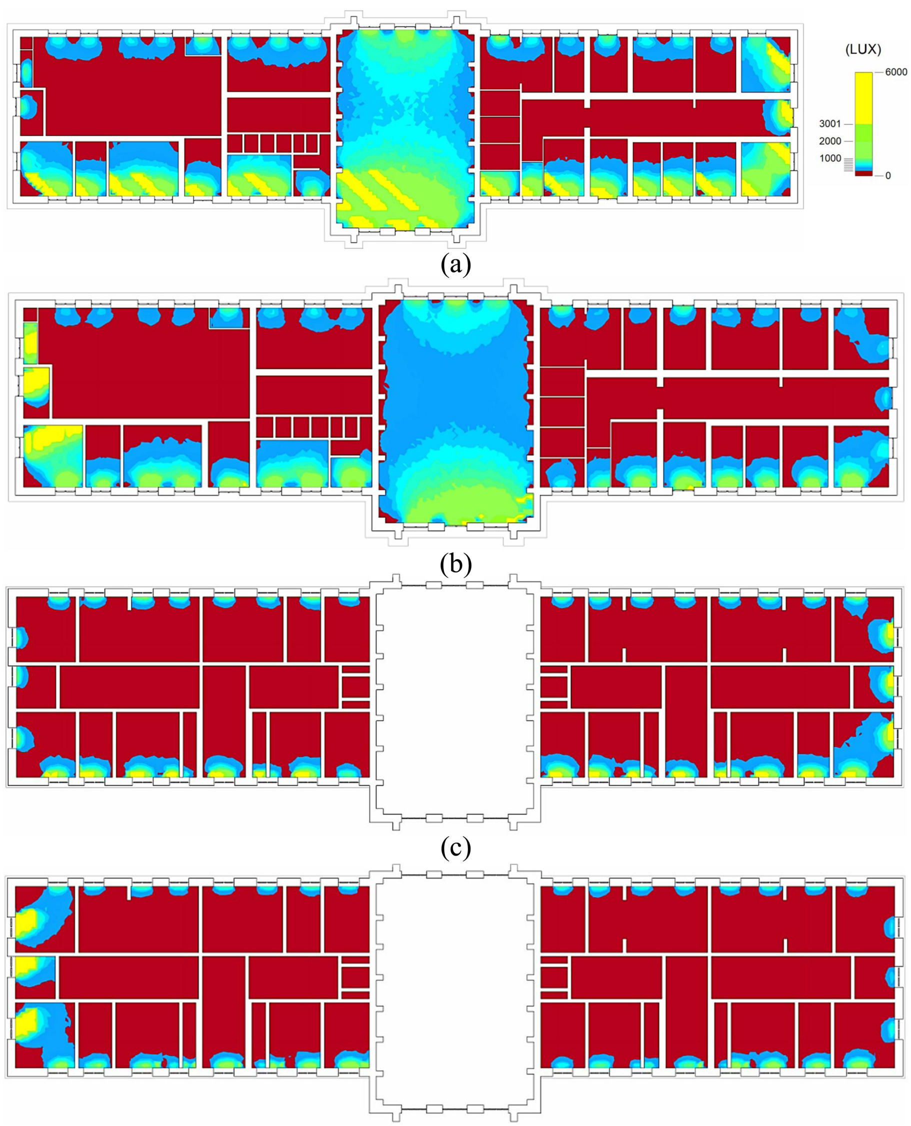
prepared in the Revit program (Fig. 9(a)). The Insight plugin of the Revit program was used to conduct the daylight analysis. The Insight plugin performs the analysis based on the location, date, and time information of the model and visualizes the amount of daylight entering the spaces according to the desired standards. Using LEED v4 EQc7 opt2. (300-3000 lux threshold values), daylight analyses were conducted on the model (Fig. 9(b)). The results of the daylight analysis for September 21st between 09:00 and 15:00 are shown in Fig. 10.

As a result of the analyses, it was determined that the east, west, and south facades are directly affected by daylight. Due to the large number of windows on the south facade and the extended duration of daylight, architectural recommendations are proposed to be implemented on the south facade of the building (Table 2).



(a) (b)

Fig. 9. (a) Path of the sun between June 21 and September 21 (b) LEED v4 EQc7 opt2. daylight analysis result.



(a)

(b)

(c)

(d)

Fig. 10. (a) Ground floor plan at 09:00 (b) Ground floor plan at 15:00 (c) First-floor plan at 09:00 d) First-floor plan at 15:00.

Table 2. Proposed daylighting system for the structure.

The system utilized	Facade	Floor	Quantity	Dimensions
Light Shelf	South	Ground floor	14	150x80x5
		Entrance floor	4	180x80x5
			2	170x80x5

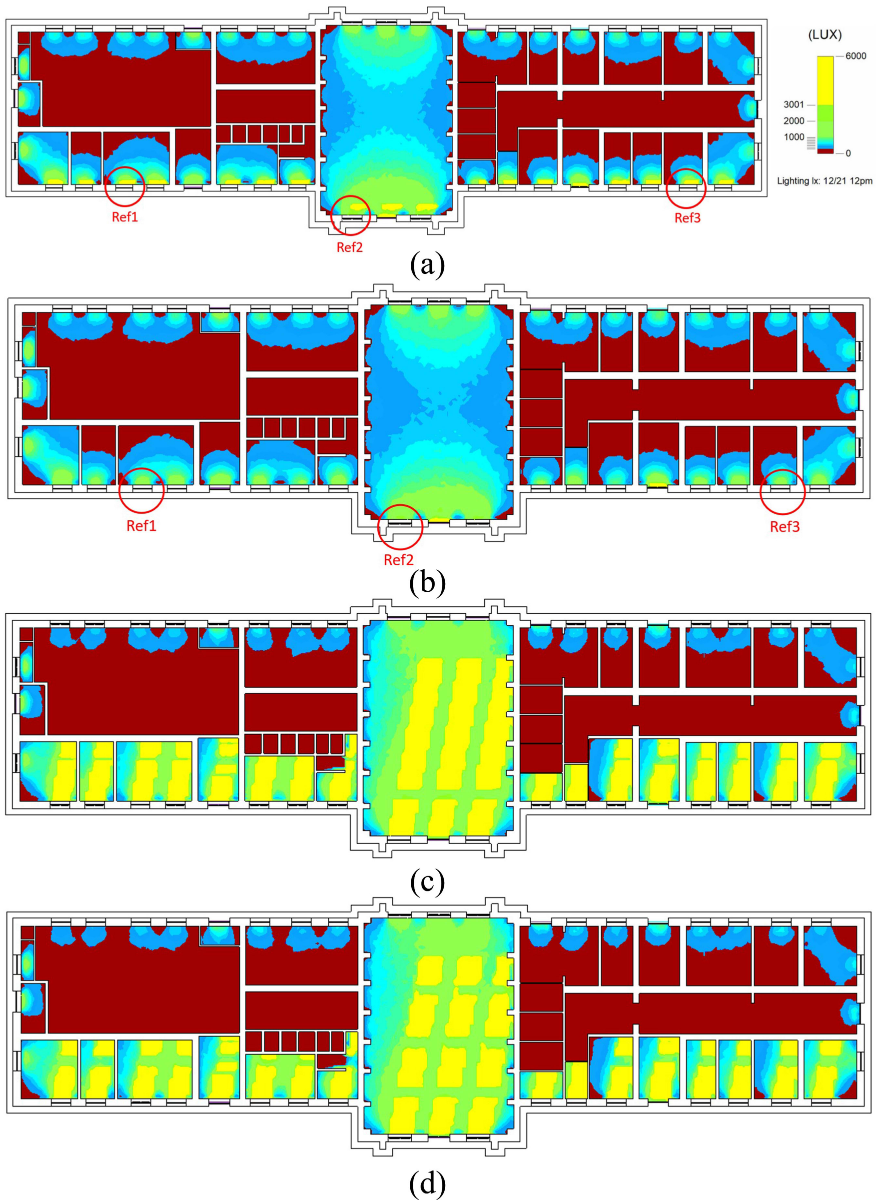


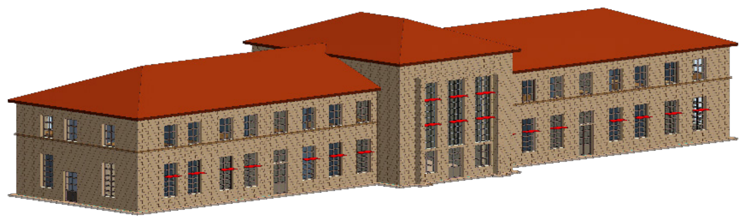
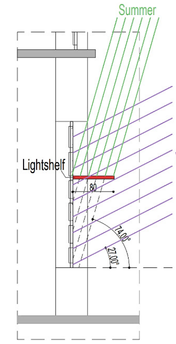
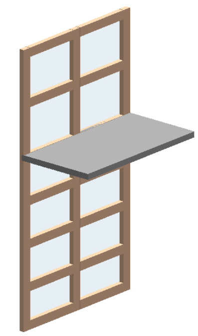
Fig. 11. (a) Analysis without Exterior Light Shelf on June 21 (b) Analysis with Exterior Light Shelf on June 21 (c) Analysis without Exterior Light Shelf on December 21 (d) Analysis with Exterior Light Shelf on December 21.

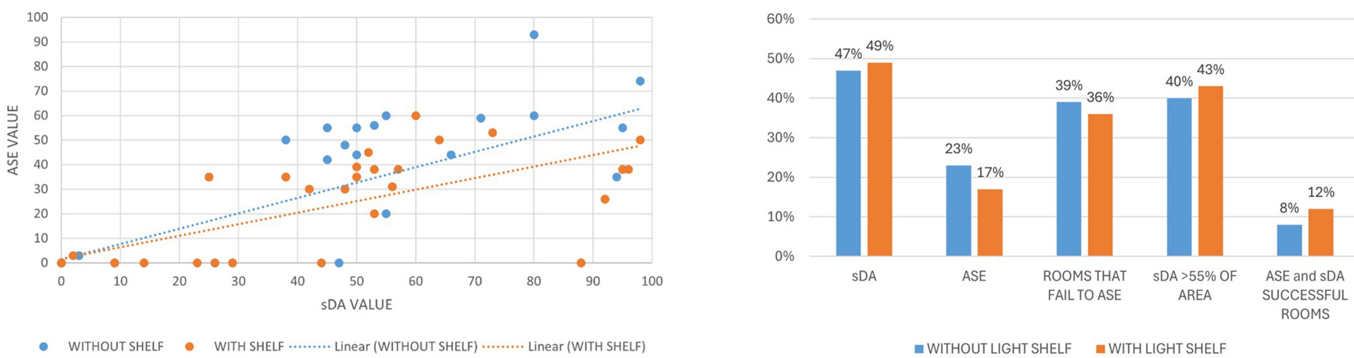
3. Findings and discussion

Based on the data obtained from previous analyses and considering the cold winters in Erzincan, it has been determined that utilizing daylight during winter months is necessary while avoiding the heating effects of direct sunlight during summer months is crucial. The angle at which sunlight enters is directly related to the energy it carries. In this context, the time periods when direct sunlight carries the highest energy and enters at the steepest angle were researched for June 21 and December 21. According to the research, the maximum solar angle in Erzincan throughout the day is 74 degrees on June 21 (summer) and 27 degrees on December 21 (winter) [34]. Based on these findings, the incoming sunlight was analyzed in the model section, and the length of the exterior light shelf was designed to be 80 cm (Table 3).

Analyses were repeated for June 21 and December 21 at 12:00 PM with and without the external light shelf (using 300-3000 lux and LEED v4 threshold values). The results showed that the use

Table 3. Implementation of the light shelf system in the structure.

 Erzincan Train Station Model with Light Shelf Implemented	 Light Shelf System Section	 Implementation of the Light Shelf



(a) (b)

Fig. 12. (a) Scatter plot of sDA and ASE values in places (b) Graph of sDA and ASE values for the entire building.

of light shelves reduced the light levels in the specified regions from the 6000-300 lux range to the 3000-1000 lux range on June 21 (Figs. 11(c) and (d)). However, the effectiveness of the light shelves varied depending on the building's design. For reference points Ref1 and Ref3, the light levels decreased from the 6000-3000 lux range without the light shelf to the 2000-1000 lux range with the light shelf. In contrast, for Ref2, due to the building's design, the light level decreased from the 3000-2000 lux range to the 2000-1000 lux range (Figs. 11(a) and (b)).

The metrics used in LEED V4, namely sDA and ASE values, were graphically represented based on the analysis results to examine the impact of light shelves on the entire building (Fig. 12(b) and individual spaces (Fig. 12(a)). When the graphs were examined, it was observed that the light shelf system resulted in a 5% reduction in ASE values for the entire building and a 6% reduction in ASE values on average for individual spaces, while there was an increase in sDA values.

4. Conclusion

As one of the few remaining structures after two major earthquakes in Erzincan and having monument status, the Erzincan Train Station plays a significant role in the formation of the city's identity. This study addresses the building within the context of the climate change disaster, whose effects we feel increasingly more each day. Upon examining the climate change disaster, Erzincan was found to be the most affected city in the Eastern Anatolia Region. Therefore, the proposed systems for the building were developed by researching the heating loads and effects of solar radiation on the building, leading to the recommendation of a light shelf system to mitigate the direct impact of daylight. Based on the analyses, the south facade was identified as the most suitable for this intervention. Consequently, a total of 20 light shelves were proposed for the windows on the ground floor and entrance section of the south facade. Considering the building's monument status, the proposed system was designed to be non-damaging and removable, which were important factors in its selection.

Analyses were conducted to test the effectiveness of the proposed system in the building. The results showed that the system achieved the desired effect by blocking direct sunlight during the summer, thereby preventing excessive heating, while not significantly reducing daylight usage in the winter. The evaluation of ASE and sDA graphs showed that the areas ASE values decreased and sDA values increased. These observations indicate potential improvements in the building's energy performance. In these significant structures, considering the climate change disaster, the design of the proposed light shelves can be customized and modified based on the design of the historic buildings to ensure their preservation for future generations. This way, the effectiveness of the light shelves can vary depending on the building's design and the angle of sunlight. The number and type of light shelves can be adjusted according to the design scheme of the building. In future studies, detailed examination of various parameters such as the facade of the building where the shading element will be applied, the climate it is located in, and its architectural features can be conducted. Based on this examination, the most suitable daylight redirecting systems can be selected and implemented. This study has significant potential and importance as it can serve as an example for similar structures in similar regions.

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Contributions

Ayşe Mehlika Top: Conceptualization, Data collection and preparation, Research, Methodology, Visualization, Use and evaluation of simulation tools, Review and Editing; Asena Soyluk: Data collection, Writing the 'Abstract' and 'Conclusion' sections, Review and Editing, Supervision, Proofreading the paper; İdil Ayçam: Writing the 'Abstract' section, Review, Supervision, Proofreading the paper.

Declaration of competing interest

The authors declare no conflict of interest.

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