

ANALYSIS OF GLAZING AND INSULATION EFFECTS ON UNIVERSITY BUILDING ENERGY EFFICIENCY

Hilal Dođru^[0009-0004-6063-2496], İsmail Caner^{*[0000-0003-1232-649X]}

Mechanical Engineering Department, Faculty of Engineering, Balıkesir University

E-mail: ismail@balikesir.edu.tr ^(✉)

Abstract - This study examines the effects of external wall insulation and window systems on building heating and cooling loads, aiming to reduce energy consumption and improve energy efficiency. The building sector, which accounts for approximately 40% of global energy consumption, has significant potential for reducing environmental impacts through improved energy performance. Since a considerable proportion of heat loss occurs through building envelope components such as walls, windows, and roofs, improving their thermal performance is essential. An uninsulated university building (Faculty of Arts and Sciences) in Türkiye was selected as a case study. Simulations were conducted using energy modeling software by considering the existing building condition, different wall insulation levels, and window heat transfer (U) values. Hybrid scenarios combining different insulation levels and glazing properties were developed to investigate their effects on the annual heating and cooling energy demands of the building. The results demonstrate that improvements to the building envelope have a significant effect on energy performance. In the best-performing scenarios, increasing wall insulation reduced the winter heating load by approximately 12% and the summer cooling load by 10.68%. Similarly, the use of advanced glazing systems with lower U-values reduced the building's energy demand. The findings indicate that insulation and window solutions should be considered from the early design stages to improve energy efficiency and maintain thermal comfort. Appropriate material and design choices can significantly reduce energy consumption and operating costs while contributing to the environmental sustainability of buildings.

Keywords: Energy Efficiency, Building Materials, Insulation, Glazing

1. Introduction

According to the International Energy Agency, 40 % of global energy consumption is attributed to the building sector, whereas in Turkey, this ratio is around 35 % [1] Energy consumption, as the leading contributor to global emissions, must be carefully addressed to mitigate its environmental impact. The increasing energy demand for building operations has nearly matched that of the industrial sector, accounting for 28% of global energy use in 2022. When including the embodied energy required for construction, this figure rises to 36%, making the building sector the largest consumer of energy worldwide and highlighting the urgent need for comprehensive analysis and action. While global building energy policies have contributed to reducing operational energy consumption, significant improvements are still needed. In developing countries, total energy consumption more than doubled between 2000 and 2022, with an average annual growth rate of 1.9%. [2]

Numerous studies have shown that the building envelope particularly exterior Windows offers significant potential for energy savings. A substantial portion of unwanted heat gain occurs through windows due to solar radiation and air infiltration, making them the weakest point in terms of thermal performance. As such, windows play a crucial role in managing energy consumption within interior spaces. In recent years, the use of glass facades in building design has increased significantly. These glass elements are frequently analyzed because of their impact on the building's thermal performance during both summer and winter, as well as their influence on lighting energy demand, and thermal and visual comfort. [3]

Ensuring building sustainability and energy conservation while maintaining a comfortable indoor environment is essential. Window glass, which constitutes a significant portion of a building's façade, plays a key role in regulating indoor thermal and visual comfort. As glazing becomes increasingly prevalent in modern architecture, it also contributes to higher indoor thermal loads.

This, in turn, intensifies global environmental challenges, particularly those related to air pollution caused by energy production—especially in regions with long, hot summers. Traditional absorptive glazing, available in various shades such as bronze and grey, tends to reduce visible light transmission more than it limits solar heat gain. In contrast, tintable smart windows offer dynamic control over daylight and solar energy, presenting a more efficient solution. [4]

The energy performance of a building is largely influenced by its envelope, particularly the windows. Lee et al.[5] highlighted a finding by Bülow-Hübe,[6] stating that windows are responsible for 20–40% of the energy wasted in a building. To minimize heat gain or loss, windows should be kept to a minimum size. However, windows inherently allow natural light to enter the building. Furthermore, research has confirmed the biological benefits of natural lighting and exterior views. Therefore, fenestration design must be carefully planned to fulfill its role of providing natural light and external views, while also maintaining a balanced energy performance for the building.[7] Tzempelikos and Athienitis demonstrates that advanced glazing technologies can significantly reduce both heating and cooling loads in temperate climates.[8] These findings indicate that window systems are a critical factor in achieving energy efficiency in buildings.

Proper implementation of thermal insulation in buildings provides both economic benefits and energy savings. It minimizes heating and cooling demands while enhancing indoor comfort, ultimately leading to reduced overall energy consumption.[9] The external envelope of a building—including walls, floors, roofs, and windows—plays a crucial role in energy efficiency, with nearly 70% of total heat loss occurring through these elements.[10] Gönül and Cicek have shown through energy analyses that the selection of exterior wall systems has a decisive effect on annual heating, cooling, and total energy consumption in different climate regions of Türkiye.[11] Amani investigated the impact of polystyrene insulation on energy consumption in residential buildings through simulations conducted with DesignBuilder software. The study found that selecting appropriate insulation for exterior walls and roofs significantly reduces heat losses, resulting in a 47.2% decrease in total energy consumption.[12] Aljashaami et al. examined the effects of building envelopes on energy consumption and thermal comfort in Iraq. They found that using advanced insulation materials and optimized window designs can reduce energy consumption and enhance thermal performance.[13] Zhang et al.

investigated energy-saving technologies for building envelopes and analyzed the energy efficiency of wall, window, and roof designs using a multi-dimensional evaluation model. Their study demonstrated that optimized designs can achieve up to 15.2% energy savings and that structural collaboration can enhance sustainability.[14] Exterior walls are fundamental building elements that separate indoor and outdoor environments, and a building's energy consumption is largely influenced by the characteristics of these walls.

This study aims to improve the energy efficiency of residential school building in Turkey. There are 4 objectives for this study;

- 1- Selecting a representative school building and characterizing it
- 2- Performing parametric simulations focused on different glazing
- 3- Using different insulation types for evaluation.
- 4- By creating mixed scenarios, the possibilities will be evaluated.

Based on the results obtained, the effect of changes in windows and walls on the energy efficiency of the school building will be assessed.

2. Material and Method

Analyses conducted since 1960 indicate a notable increase in temperatures in Türkiye, particularly during the summer season. Similar increases have also been observed in spring and autumn, while no significant change has been detected in winter temperatures. This suggests an extension of the warm period and an overall upward trend in annual average temperature.[15]

The case study building selected for this research is a school located in Balıkesir, Türkiye. Meteorological measurements for the city, spanning the period from 1938 to 2019, were analyzed to characterize the local climate. The annual average temperature is 24.8 °C, with the highest temperatures recorded in July and August. The mean maximum temperature reaches 32.5 °C in July, while the lowest average temperature of 0.8 °C occurs in January. Additionally, average sunshine duration is greatest in July, providing important information for building energy simulations.[16]



Figure 1. Temperature distribution map of Türkiye in 2008. (TS825 March 2025)

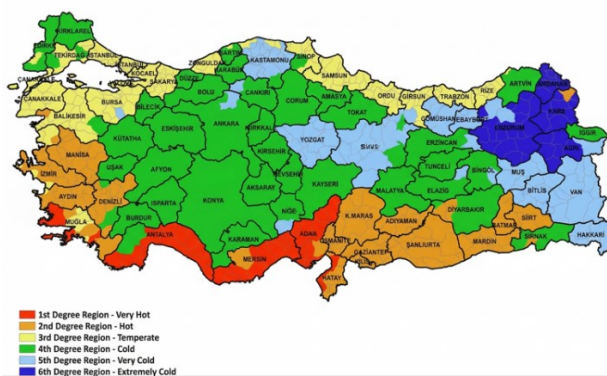


Figure 2: Temperature distribution map of Türkiye in 2024. (TS825 March 2025)

Climate change observed in Türkiye has exhibited similar patterns across different provinces. As shown in Figures 1 and 2, an examination of the temperature distribution maps of Türkiye for 2008 and 2024 indicates that colder regions have decreased, while warmer regions have expanded over time.

As a result of the changing temperature patterns, significant revisions have been observed in the wall, roof/ceiling, floor, and window U-values specified in TS 825, prepared by the Turkish Standards Institution for Türkiye, based on the 2024 climate data, compared to the 2008 values.[17] For example, the wall U-value for a city located in the 2nd climatic region was reduced from 0.6 in 2008 to 0.4 in 2024. Similarly, in another example, the window U-value for a city in the 3rd climatic region was revised from 2.4 to 1.8.

The research methodology is organized into three main stages, starting with data collection and progressing toward the calculation of operative temperatures. The detailed steps of the study are outlined below.

1. The Faculty of Art and Science building at Balıkesir University, located in the province of Balıkesir, was selected as the reference building.

2. The Faculty of Art and Science building was modeled and calibrated using the EnergyPlus software.

3. In the simulation, the variations in heating and cooling loads of the building were examined using different wall insulation levels and window specifications.

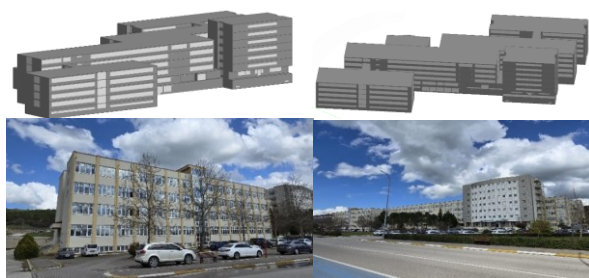


Figure 3: The Faculty of Art and Science

The Faculty of Arts and Sciences building is an uninsulated structure with double-glazed windows made of clear glass. It spans over 30,000 m², and the classrooms are naturally ventilated. The building is equipped with a cooling system, but it is only utilized in offices and lecture halls, while the classrooms do not have a cooling system.

For the annual heating and cooling energy requirements of the school building, simulations were conducted in DesignBuilder using alternative wall insulation values and window U-values. The results of these simulations were analyzed, and the selected alternative values for wall insulation and window U-values are presented in Table 1. The U-values employed in this study were determined based on the values specified in TS 825, and alternative scenarios were generated by selecting both higher and lower values. The current values for the building are 0.058 W/m²·K for the walls and 1.8 W/m²·K for the windows.

Table 1. Selected wall Insulation Values and Ug Values (W/(m²·K))

External wall U-value	Ug (glass) Values
0,058	1,8
0,07	2,7
0,08	1,5
0,09	1,2
0,1	0,9
0,15	0,7
0,2	0,5

Additionally, five alternative scenarios were developed by selecting different wall and glazing U-value from the determined alternatives. These selected values were re-simulated in DesignBuilder to obtain the corresponding energy consumption, and the created scenarios are presented in Table 2.

Table 2. Mixed Scenario (W/(m²·K))

Mixed Scenarios	
external wall U-value	Ug (glass) Values
0,07	0,5
0,2	2,7
0,09	1,2
0,15	0,7
0,08	1,5

3. Simulation Results

The existing thermal insulation value of the building envelope is 0.058. Alternative insulation values evaluated in the study are presented in Table 1. The results of the heating load simulations corresponding to these alternatives are illustrated in Figure 4. An analysis of Figure 2 reveals that increasing the insulation level leads to a reduction in the energy demand for heating, indicating a clear inverse relationship between insulation performance and

heating energy consumption. In the graph shown in Figure 4, the values for June, July, August, September, and October appear as zero due to the absence of heating demand during these months.

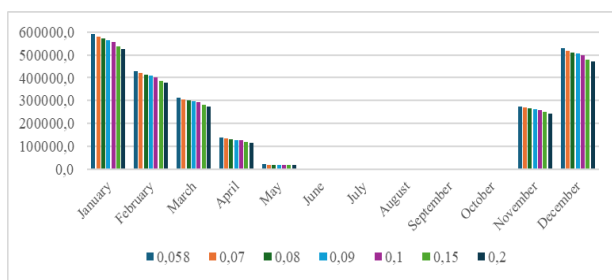


Figure 4: Effect of External Wall Insulation Modification on Energy Consumption ($W/(m^2 \cdot K)$)

As shown in Figure 4, the heating energy load for February under the existing insulation value of 0.058 was calculated as $430,038 W/(m^2 \cdot K)$. In contrast, in the scenario where the insulation value was selected as 0.2, the heating load for February decreased to $378,806 W/(m^2 \cdot K)$. When the existing condition is compared with the selected U-value of 0.2, an approximate 12% reduction is observed.

For November, the thermal demand obtained for the existing baseline condition was calculated as $275,630 W/(m^2 \cdot K)$. When the insulation value was increased to 0.08, this value decreased to $265,544 W/(m^2 \cdot K)$. Although the reduction achieved in the 0.08 scenario is relatively modest compared to the 0.2 case, a 3.66% decrease remains significant and warrants consideration for energy efficiency optimization.

Figure 5 presents the percentage differences between the alternative insulation values and the current insulation value (0.058). Upon examining Figure 4, it is evident that the difference becomes significantly more pronounced, particularly for the 0.2 insulation value. This clearly demonstrates the impact of increased insulation levels on energy consumption.

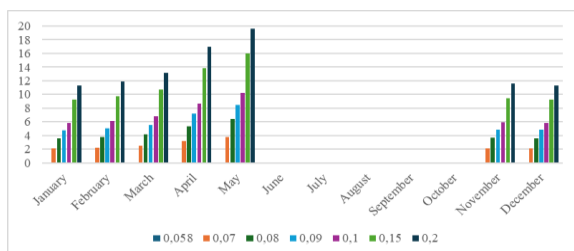


Figure 5: Difference Between the Current Value and Selected Insulation Values (Heating) (%)

The variation in the cooling load was also simulated simultaneously for the selected wall insulation values of the school building. The results obtained are presented in Figure 6.

When the figure is examined in general, it shows a trend similar to the results obtained for heating. As the insulation level increases, the energy consumption for cooling also decreases.

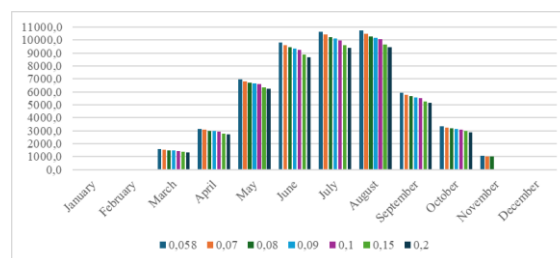


Figure 6: Temperature Variation with Changing Window U-Values ($W/(m^2 \cdot K)$)

A trend similar to that observed in the heating scenario is also evident in the cooling load results. With the current wall insulation value of 0.058, the cooling load for May is calculated as $6965 W/(m^2 \cdot K)$ whereas under the 0.2 insulation scenario, this value decreases to $6222 W/(m^2 \cdot K)$. This corresponds to a difference of approximately 10.68%.

As another example, the cooling load in August is calculated as $10723 W/(m^2 \cdot K)$ for the current insulation value, while it drops to 10156 with an insulation value of 0.09. This indicates a reduction of 5.29%. Overall, the best performance is observed under the 0.2 wall insulation scenario.

Figure 7 presents a percentage-based comparison of the cooling loads corresponding to different wall insulation values relative to the current insulation value of 0.058. The figure indicates that a scenario similar to the one observed in the heating load analysis is also evident in the cooling load results.

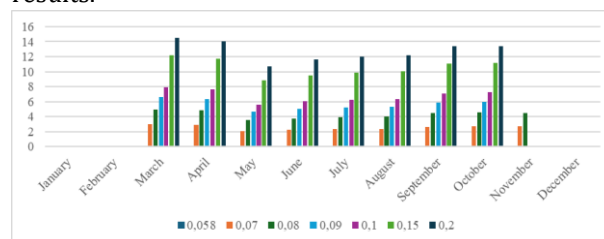


Figure 7: Difference Between the Current Value and Selected Insulation Values (Cooling) (%)

Another step of our study involved simulating the glazing U-values specified in Table 1. The results of the simulations conducted with the selected U-values, showing the monthly variation in heating load, are presented in Figure 8. In the graph, the heating load values for June, July, August, September, and October are zero due to the absence of heating demand during these months.

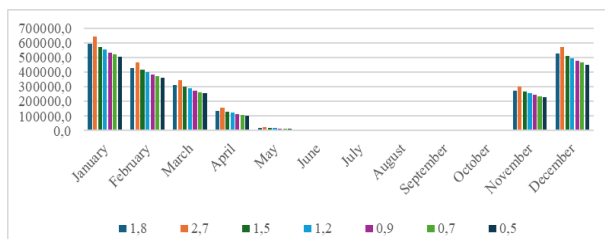


Figure 8: Influence of Glazing Thermal Transmittance (U-Value) on Thermal Response ($W/m^2 \cdot K$)

The current glazing U-value of our building is 1.8. For example, in March, the heating load is calculated as $314209 W/(m^2 \cdot K)$ with the current U-value. However, under a less efficient scenario with a U-value of 2.7, this load increases to $347756 W/(m^2 \cdot K)$ representing a 10.68% increase.

In another example, for the month of December, the heating load is $530369 W/(m^2 \cdot K)$ with the current U-value, whereas it decreases to $450812 W/(m^2 \cdot K)$ with an improved U-value of 0.5. These results clearly indicate that as the U-value decreases, the required heating load is significantly reduced.

In the comparison graph for the windows, the results appear negative because the U-value of 2.7 is higher than the current value of 1.8. To provide a more meaningful analysis, the 2.7 U-value was compared with the other alternative values, resulting in a clearer and more informative graph.

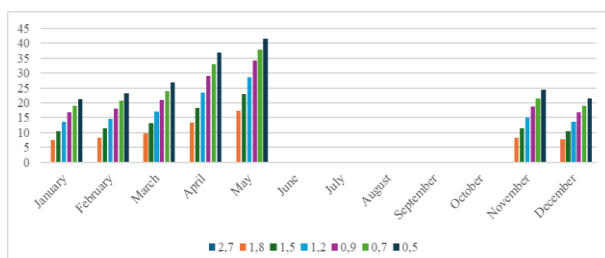


Figure 9: Comparative Analysis of Baseline and Alternative Glazing U-Values on Heating Demand (%)

The cooling loads corresponding to the selected glazing U-values were also calculated in the same manner and are presented in Figure 8. Similar to the cooling load graph for wall insulation values, the values for December, January, and February are zero in this graph as well. As illustrated in the figure, a decrease in the glazing U-value leads to a reduction in cooling load.

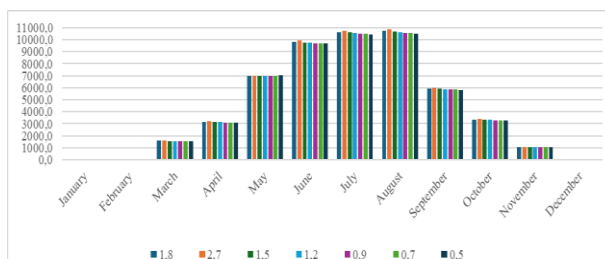


Figure 10: Influence of Glazing Thermal Transmittance on Annual Cooling Loads ($W/(m^2 \cdot K)$)

For instance, in July, the cooling load for the current glazing U-value of 1.8 was calculated as $10,654 W/(m^2 \cdot K)$. In the worst-case scenario, with a U-value of 2.7, the load increases to $10,776 W/(m^2 \cdot K)$. Conversely, in the best-case scenario with a U-value of 0.5, the cooling load decreases to $10,465 W/(m^2 \cdot K)$.

An analysis of the other U-values further indicates that as the glazing U-value decreases below the current level, the cooling load consistently follows a declining trend, highlighting the significant impact of improved glazing performance on building energy demand.

Since the cooling load results exhibited a trend similar to that observed in the heating scenario, this comparison graph was generated by referencing the worst-case scenario with a U-value of 2.7, resulting in a more meaningful and informative representation.

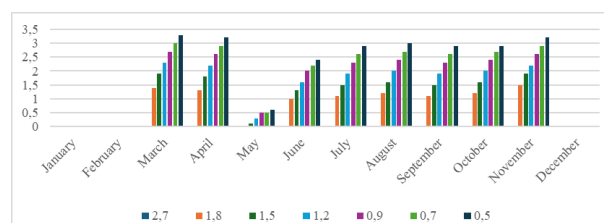


Figure 11: Comparative Analysis of Baseline and Alternative Glazing U-Values on Cooling Demand (%)

In the final phase of the study, five different wall insulation and glazing U-values were selected to create various mixed scenarios. The selected values for these mixed scenarios are presented in Table 2. The highest heating load values in both the best-case and worst-case scenarios were observed in January. The heating demand for June, July, August, September, and October was considered negligible and therefore assigned a value of zero.

According to the obtained simulation results, the worst performance was observed in the scenario with 0.2 wall insulation and a 2.7 glazing U-value, while the best performance was achieved in the scenario with 0.15 wall insulation and a 0.7 glazing U-value. For instance, in January, the heating load reached $575,943 W/(m^2 \cdot K)$ in the worst-case scenario, whereas it was $464,633 W/(m^2 \cdot K)$ in the best-case scenario.

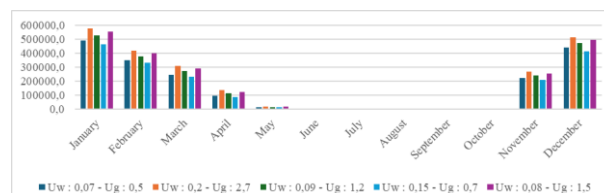


Figure 12: Mixed Scenario (Heating) ($W/(m^2 \cdot K)$)

For the cooling values of the mixed scenarios, the worst performance was observed in the scenario with 0.07 wall insulation and a 0.5 glazing U-value,

while the best performance was achieved in the scenario with 0.15 wall insulation and a 0.7 glazing U-value.

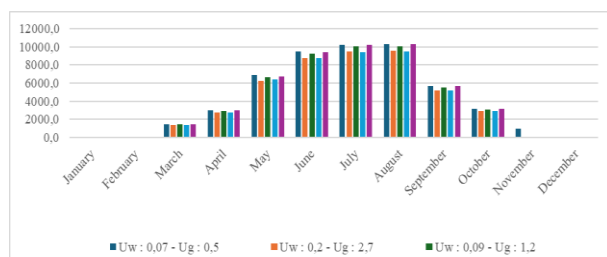


Figure 12: Mixed Scenario (Cooling) ($W/(m^2 \cdot K)$)

An examination of the results indicates that the highest cooling demand occurred in August. In this month, the worst-case scenario yielded a value of 10,268 $W/(m^2 \cdot K)$, while the best-case scenario resulted in 9,479 $W/(m^2 \cdot K)$. Excluding the winter months, the lowest cooling demand was observed in March, with values of 1,492 $W/(m^2 \cdot K)$ for the worst-case scenario and 1,348 $W/(m^2 \cdot K)$ for the best-case scenario.

4. Discussion and Conclusion

In this study, various simulations were carried out using the DesignBuilder software in order to examine how the heating and cooling loads of the The Faculty of Art and Science at Balıkesir University change under different alternative scenarios. Accordingly, a set of data was obtained.

Analysis of the obtained data reveals that increasing wall insulation leads to a reduction in the required heating and cooling loads. A similar trend is observed with the decrease in the glazing U-value, which also contributes to lower energy demand. Our simulation results demonstrate that significant energy savings can be achieved in the selected building.

When designing buildings, energy efficiency should be a primary consideration, with architects and engineers playing a crucial role in the process. While improperly designed structures can be reinforced later, it is more effective to address energy efficiency during the initial design phase. There are various ways to enhance a building's energy efficiency, such as implementing thermal insulation, using materials with low thermal conductivity, installing energy-efficient doors and frames, and integrating renewable energy systems. However, focusing on these improvements later in the process may lead to unnecessary resource use and financial costs, which should be carefully considered.

Overall, implementing thoughtful and strategic design measures is necessary to achieve a balance between comfort and energy conservation.

References

- [1] Caner, I.; Comparative study of overheating assessment approaches in university buildings: Impact of different climate zones and shading devices in Turkey. *Journal of Building Engineering*. 99, 109825 (2025).
<https://doi.org/10.1016/j.jobbe.2024.111536>
- [2] González-Torres, M.; Pérez-Lombard, L.; Clementi, E. L.; Coronel, J. F.; Examining the reasons for changes in buildings' energy consumption in the United States, China and the European Union. *Energy and Buildings*. 332, 115372 (2025).
<https://doi.org/10.1016/j.enbuild.2025.115461>
- [3] Usta, P.; Zengin, B.; An evaluation of the glazing type impact on building energy performance through a building simulation. *Journal of Energy Systems*. 6(1), 1–17 (2022).
<https://doi.org/10.30521/jes.945193>
- [4] Fengxiang, T.; Energy-saving Glazing System (Proceedings). China Architecture and Building Press, Beijing. 7-30 (2003).
- [5] Lee, J. W.; Jung, H. J.; Park, J. Y.; Lee, J. B.; Yoon, Y.; Optimization of building window system in Asian regions by analyzing solar heat gain and daylighting elements. *Renewable Energy*. 50, 522–531 (2013).
<http://dx.doi.org/10.1016/j.renene.2012.07.029>
- [6] Bülow-Hübe, H.; Energy-Efficient Window Systems Effects on Energy Use and Daylight in Buildings. Lund University, www.byggark.lth.se (2001).
- [7] Chang, C. Y.; Chen, P. K.; Human Response to Window Views and Indoor Plants in the Workplace. *HortScience*. 40(5), 1354–1359 (2005).
- [8] Tzempelikos, A.; Athienitis, A. K.; The impact of shading design and control on building cooling and lighting demand. *Solar Energy*. 81(3), 369–382 (2007).
doi:10.1016/j.solener.2006.06.015
- [9] Ü. Ünver, E. Adıgüzel, E. Adıgüzel, S. Çivi, ve K. Roshanaei, "Türkiye'deki İklim Bölgelerine Göre Binalarda Isı Yalıtım Uygulamaları", *imctd*, c. 1, sy 2, ss. 171–187, Ara. 2020, [çevrimiçi].
<https://izlik.org/IA99ER79EM>
- [10] Chen, G.; Hou, Y.; Ge, H.; Zhang, S.; Liu, X.; Guo, X.; Xie, D.; Effect of thermal bridges on the energy performance of Chinese residential buildings. *Energy and Built Environment*. 6(3), 545–554 (2025).
<https://doi.org/10.1016/j.enbenv.2024.01.008>

- [11] Çiçek, H.; Gönül, İ. A.; Determining the amount of energy consumed in buildings according to exterior wall type under the climatic conditions of Türkiye using BIM tools. *Online Journal of Art and Design*. 14(1), 1–15 (2026).
<https://doi.org/10.30935/ojad/2513081>
- [12] Amani, N.; Energy efficiency of residential buildings using thermal insulation of external walls and roof based on simulation analysis. *Energy Storage and Saving*. 4(1), 48–55 (2025).
<https://doi.org/10.1016/j.enss.2024.11.006>
- [13] Aljashaami, B. A.; Alwan, N. T.; Al-Attar, A. A.; Tarish, A. L.; Humada, A. M.; Velkin, V. I.; Majeed, M. H.; Implementing sustainable zero energy building standards in Iraq: Energy efficiency measures. *Results in Engineering*. 28, 107567 (2025).
<https://doi.org/10.1016/j.rineng.2025.107567>
- [14] Zhang, J.; Rasdi, M. T. M.; Zainordin, N.; Qin, Y.; A comprehensive review of advanced energy-efficient technologies for building envelopes: Focus on walls, windows, and roofs. *Energy Reports*. 15, 108981 (2026).
<https://doi.org/10.1016/j.egyr.2025.108981>
- [15] Şen, Ömer Lütfi. "A holistic view of climate change and its impacts in Turkey." *Report. Istanbul Policy Centre, Sabanci University, Istanbul* (2013).
- [16] T.C. Ministry of Agriculture and Forestry, General Directorate of Meteorology; Official Statistics. BALIKESİR Climate Data, <https://www.mgm.gov.tr> (2021).
- [17] Turkish Standards Institution; TS 825: Thermal Insulation Requirements for Buildings. Turkish Standards Institution: Ankara, Türkiye (2024).