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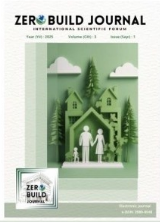

Pencere-Duvar Oranının Binalardaki Enerji Performansına Etkisi: Farklı Cam Sistemleri ve İklim Bölgelerine göre Karşılaştırmalı Analiz

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Öne Çıkanlar:

- %100 cam cephelerde, 55,6 W/m²'ye kadar fazla ısı kaybı hesaplanmıştır.
- Cam oranının %20 artırılması durumunda: Sıcak bölgelerde ısı kaybı en az %19,5 oranında artarken, Soğuk bölgelerde bu oran %122'ye kadar yükselmiştir.
- Cam oranını artırmak yapay aydınlatmaya olan ihtiyacı azaltırken, sıcak iklimlerde aşırı ısınma ve soğuk iklimlerde ısı kaybını artırma riski oluşturur.

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Amaç:
Bu çalışma, pencere-duvar oranının binaların enerji verimliliği üzerindeki etkilerini ele almaktadır. Çalışma, Türkiye'deki derece-gün bölgeleri ve farklı cam türleri göz önüne yapılan analizlerle, pencere/duvar oranının artışının ısı kayıplarına etkisini incelemeyi amaçlamaktadır.

Metot:
Çalışmada, pencere-duvar oranının %0'dan %100'e kadar değişimine göre Türkiye'deki dört farklı derece-gün bölgesi için, piyasada en çok satılan 5 farklı cam türünün (standart çift cam, argon dolgulu çift cam, üçlü cam, kaplamalı çift cam, kaplamalı argon dolgulu çift cam) ısı kayıplarına etkisi analitik olarak hesaplanmıştır. Hesaplamalar, TS825 standardına uygun olarak yapılmış ve her bölge için toplam ısı kaybı ayrı ayrı analiz edilmiştir

Sonuç:
Araştırmada, pencere/duvar oranındaki artışın enerji tüketimini önemli ölçüde artırdığı tespit edilmiştir. Özellikle soğuk bölgelerde bu etkinin daha belirgin olduğu vurgulanmıştır. Farklı cam türlerinin kullanıldığı çalışmada, kaplamalı çift camların enerji verimliliğine katkısının ön plana çıktığı gözlemlenmiştir. Bununla birlikte, argon gazı dolgulu camların enerji tasarrufu etkisinin sınırlı olduğu belirlenmiştir. Pencere/duvar oranındaki her %20'lik artışın, sıcak bölgelerde enerji tüketimini en az %19,5 oranında, soğuk bölgelerde ise %122 oranında artırabileceği belirlenmiştir. Soğuk iklim koşullarında, bina cephesinin tamamen camla kaplanması durumunda ısı kaybının 55,6 W/m² kadar artış gösterdiği gözlemlenmiştir. Bu çalışma, bina tasarımlarında enerji verimliliğini artırmak isteyen mimar ve mühendislere yönelik kapsamlı ve sayısal verilere dayalı önemli bir rehber sunmaktadır.

Anahtar Kelimeler: Pencere/Duvar oranı, Isı kaybı, Bina Enerji Performansı, Cam türleri, Pencere ısı kaybı, Pencere enerji performansı

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Research Article

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The Effect of Window-to-Wall Ratio on the Energy Performance of Buildings: Comparative Analysis According to Different Glazing Systems and Climate Zones

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Highlights:

- 100% window façades has an excess heat loss of up to 55.6 W/m².
- If WWR is increased by 20%: In hot regions, heat loss increased by at least 19.5%, while in cold regions this rate increased up to 122%.
- Increasing WWR can help reduce the need for artificial lighting, excessive WWR in hot climates risks overheating, and in cold climates, it results in substantial heat losses.

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Abstract

This study examines the influence of the window-to-wall ratio on building energy performance across various climatic zones in Turkey. Five glazing types were evaluated: standard double glazing, argon-filled double glazing, triple glazing, coated double glazing, and coated argon-filled double glazing. The analysis focused on heat losses across four distinct degree-day zones, with the window-to-wall ratio ranging from 0% to 100%. Results demonstrate a significant correlation between increased window size and energy consumption, particularly in colder regions. Coated double glazing exhibited the highest energy efficiency, while the impact of argon filling was minimal. In cold climates, a fully glazed façade led to a substantial increase in heat loss (55.6 W/m²). This research provides valuable insights for architects and engineers to optimize building designs by considering the window-to-wall ratio and glazing selection in relation to specific climatic conditions.

Keywords: Window/Wall ratio (WWR), Heat loss, Building Energy Performance, Glazing types, Heat loss from windows, Window energy performance, Zero Energy Buildings

1. *Introduction*

Today, energy efficiency and sustainability have become increasingly important in building design due to rapidly increasing energy costs and environmental concerns. In line with sustainable development, studies on energy efficiency and management are becoming increasingly important [1]. With the rising demand for energy efficiency and sustainability, countries like the European Union, China, and the United States have started to examine buildings with high energy efficiency and low emissions [2]. According to the reports of the United Nations Environment Program, 30% of raw material use, 25% of solid waste production, 25% of water consumption, 12% of land use and 33% of greenhouse gas emissions worldwide are caused by buildings [3]. In the United States, India, China and the United Kingdom, commercial office buildings account for about 35% of total energy consumption [4]. The main reasons for high energy consumption in buildings include inadequate insulation, inefficient window and wall designs, old and low efficiency systems and user behavior. Lack of insulation significantly increases energy losses by causing heat loss in buildings [5]. Although heat losses vary depending on the architectural design of the building, its location, the insulation methods used and the properties of the building materials, it is generally observed that heat losses from external walls and windows increase proportionally as the building height increases [6]. In addition, old or low energy efficient heating, cooling, lighting and ventilation systems cause energy wastage. Therefore, strengthening or improving building insulation stands out as a measure to reduce energy consumption [7]. Building insulation, on the other hand, can provide energy savings of up to 50% and reduce energy dependence to some extent [8]. A study funded by the European Union reveals that 36% of greenhouse gas emissions across the Union originate from buildings [9]. The Council of Europe has made a long-term commitment to reduce the greenhouse gas emissions of the EU and other developed countries by 80-95% by 2050 [10]. In Turkey, the building sector accounts for about 40% of the total energy consumption and the rapidly growing construction and increasing demands for quality of life further increase the energy consumption in buildings [11]. Turkey imports 70% of its energy needs and according to analyses conducted after 2000, buildings in Turkey consume more energy than buildings in European countries with similar climatic conditions [12]. Turkey is taking important steps towards harmonizing with the European Union standards on energy efficiency but continues to work to fully reach these standards in terms of performance. In addition, by analyzing the data for the period 2015-2017, it was determined that Turkey's energy efficiency performance is below the average compared to 18 European countries. The importance of raising public awareness for the effective implementation of existing policies has also been emphasized [13].

Approximately 65% of the energy consumed in buildings is spent on needs such as heating, cooling and ventilation [14]. Today, the building sector is responsible for about one third of total energy consumption and 15% of carbon emissions in the sectors. When indirect emissions due to electricity use and heating are added, the rate of carbon emissions reaches 30% [15].

Energy losses in buildings may vary depending on the qualities of building elements, design preferences and climatic characteristics of the region. A study conducted in 2008 reveals that 30-40% of energy losses in buildings are caused by walls. The study emphasizes that energy losses are quite high, especially in cases where the insulation of external walls is missing or completely inadequate [16]. Along with good wall insulation, the right choice of a window with an appropriate Total Heat Transfer Coefficient (U), (W/m^2.C) provides a significant reduction in energy demand by minimizing the heating and cooling needs of the environment [17]. Wall insulation can reduce energy consumption in houses by 15% [18].

Heat losses in buildings can be analyzed in five different areas: exterior walls, windows, roof, basement floor and air leaks [19]. Energy loss from roofs in buildings generally varies between 15-25%. Due to the tendency of warm air to rise, inadequate roof insulation poses a serious problem in terms of energy efficiency. This situation clearly demonstrates the importance of effective insulation applications on roofs in terms of saving energy and preventing heat loss [16]. Heat losses from floor and foundation sections (slabs) vary between 10-15% [20]. Heat losses through air leaks are 17% [21].

Windows on the exterior façades of buildings are also one of the main causes of heat loss. The use of poor quality glass and insufficient insulation makes it difficult to maintain the indoor temperature. Especially in cold regions, windows have a significant impact on energy efficiency. Studies show that approximately 20-30% of energy consumption for heating and cooling is due to window losses [21]. To reduce these losses, it is important to modernize window systems and apply advanced insulation technologies. In 87% of the houses in Turkey, single-glazed windows with low thermal efficiency are preferred, while double-glazed windows are used in 9% and low-e glazed windows are used in only 4% [22]. Sealing and regular maintenance of window edges to prevent heat losses from windows increases energy efficiency, reduces building costs, provides high energy savings and offers environmental benefits [23]

One of the most important parameters affecting building energy performance is the window-wall ratio (WWR). Energy savings can be achieved in buildings by determining the correct WWR. Energy consumption cost increases with the increase in window area. For example, the increase in window area in cold regions increases the annual energy consumption cost more than 2.5 times compared to hot regions. [24]. On the other hand, large windows can reduce the need for artificial lighting by 80% by increasing natural light intake [25], but heat loss and overheating problems may occur in hot and cold climates. Therefore, the correct WWR is important for the energy performance of buildings and sustainable environment

In this paper, the effects of WWR on energy efficiency and indoor comfort in buildings are analyzed. The paper makes an important contribution to the field of building façade design and energy efficiency. Firstly, it fills a gap in the literature by analyzing the effect of window-to-wall ratio on heat losses in detail for different climate zones and glazing types. While most of the studies deal with either only certain glazing types or a single climate zone, this study provides a comprehensive analysis by comparing different WWR for five different glazing types and four different climate zones. For example, in the study [26] for an educational building in Izmir, only façade orientations are focused and the window/wall ratio is evaluated in the range of 10%-60%. In this study, the results are calculated for four different climate zones and detailed analyses are presented by varying the window/wall ratio between 0%-100%. In particular, the analysis of heat loss when the

WWR varies from 0% to 100% emphasizes the importance of this design element, which is generally ignored in the literature. It also represents a unique approach, comparing the effects of modern insulation technologies such as coated double glazing and argon gas filled systems on a zonal and ratio basis. This paper makes a scientific contribution to sustainable building design and energy conservation strategies by providing applicable insights for professionals and researchers working in architecture, engineering and energy efficiency.

2. Material and Method

Heat losses from façades in buildings are calculated by using the general heat loss calculation equation specified in TS825 [27] standard (Equation 1).

$$\dot{Q} = U \times A \times (T_{i,\infty} - T_{d,\infty}) \quad (1)$$

When calculating the heat flux, the general heat flux calculation equation was used (Equation 2).

$$\dot{q} = U \times (T_{i,\infty} - T_{d,\infty}) \quad (2)$$

In the study, a 15m*3m long exterior wall of a building was considered. Wall structures suitable for the degree day zones in TS 825 were determined and U_D (Total side heat transfer coefficients) values were calculated according to different window wall ratios. The wall structure for each zone and the thicknesses of the structural elements forming the wall are shown in Table 1. The total side heat transfer coefficients (U_D) of the external wall recommended in TS825 standard and the calculated heat transfer coefficients are given in Table 2

U_D values of the walls were calculated using Izoder software. Material types and thicknesses of the building elements were entered into the software and the program calculated the U values for the climate zones in Turkey by using these data with heat conduction calculation methods.

In heat loss calculations according to TS 825, the coldest month (TS825 Annex B.2) was taken into consideration when selecting the monthly average outdoor temperature values to be used for each region. While determining the internal temperature values, the monthly average internal temperature values (TS825 Annex B.1) to be used in the calculations for dwellings were taken into consideration. Heat losses through walls and windows are analytically calculated for each climate zone. The total heat losses from different façades obtained were determined according to the regional characteristics. Glazing types have different thermal transfer coefficients. Glazing with low U-value increases energy efficiency by reducing heat loss [28]. Another important parameter affecting building energy performance is the ratio of Window / Wall areas (WWR). As the window surface area increases, the wall surface area shrinks. The thermal resistance of windows is lower than that of walls. Therefore, large window areas increase heat loss. The most energy efficient WWR for almost zero energy buildings in severe cold regions is between 10-15% for east-west facing façades and between 10-22.5% for south facing façades. In the north, the WWR should be reduced by considering lighting and ventilation [29].

Table1 .Wall structure, elements and thicknesses

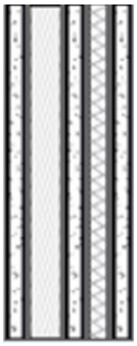
Wall structure	***Wall construction elements (from outside to inside)***	***Thickness (m)***
	4.8.2 Plaster mortars made of inorganic based lightweight aggregates	0.006 m
	10.3.3.1.1.4 Polystyrene - Particulate Foam - Thermal conductivity groups in accordance with TS 7316 EN 13163 040	For Zone 1: 0.03m For Zone 2:0.05m For Zone 3:0.06m For Zone 4:0.08m
	4.2 Cement mortar	0.02 m
	7.1.5.4 Walls made of horizontally perforated bricks (TS EN 771-1)	0.2 m
	4.1 Lime mortar, lime-cement mortar	0.02 m

Table2 . Recommended and calculated U values for climate zones according to TS825

Regions	***U_D (W/m^{2}K) (Recommended according to TS 825)***	***U_D (W/m^{2}K) (Calculated)***
Region 1	0.7	0.692
Region 2	0.6	0.514
Region 3	0.5	0.455
Region 4	0.4	0,371

Table3 . Façade codes, window system structures and U-values

Code	***Glazing Type***	***Up (W/m²K)***
C1	Double glazing 4+12+4 (100% Air)	2,65
C2	Double glazing 4+12+4 (90% Argon)	2,51
C3	Triple glazing 4+9+4+4+9+4	2,09
C4	Coated double glazing 4+12+4 (100% Air)	1,74
C5	Coated double glazing 4+12+4 (90% Argon)	1.53

In the study, the analyzed glasses in this study are the top-selling products from glass companies. Heat losses from 5 different glazing types were analyzed when the window/wall ratio was 0%, 20%, 40%, 60%, 80%, 100%. 0% means that the façade is completely wall and 100% means that the façade is completely glass. Heat loss was calculated separately for each window to wall ratio. Five different building façades were designed with five different glazing types. The codes of the glazing types used and the total side heat transfer coefficients (U_p) are presented in Table 3

3. Results and Discussion

3.1 Effect of WWR on Heat Loss According to Climate Zones

The figure demonstrates the relationship between heat loss (q, W/m²) and the WWR for four Degree-Day (DD) zones in Turkey, which represent varying climatic conditions. Zone 1 corresponds to the warmest climate, while Zone 4 represents the coldest. A clear trend can be observed: as the WWR increases, heat loss rises consistently across all zones. This outcome aligns with the general understanding that larger window areas contribute to greater heat loss due to the lower thermal resistance of glazing compared to opaque walls. However, the extent of this increase varies significantly between zones.

In Zone 4, the coldest climate, heat loss is the highest at every WWR value. This can be attributed to the colder external temperatures and the relatively higher thermal conductivity of glazing. The steep slope of the curve for Zone 4 highlights how heat loss escalates rapidly with increasing WWR. In contrast, Zone 1, which represents the warmest climate, exhibits the lowest heat loss across all WWR values. The curve for Zone 1 has a relatively gentle slope, indicating that the increase in WWR has a less pronounced impact on heat loss in warmer climates. Zones 2 and 3 show intermediate heat loss values, with Zone 3 being closer to Zone 4 due to its colder climate characteristics.

At lower WWR values, such as 20%, the differences in heat loss between the zones are

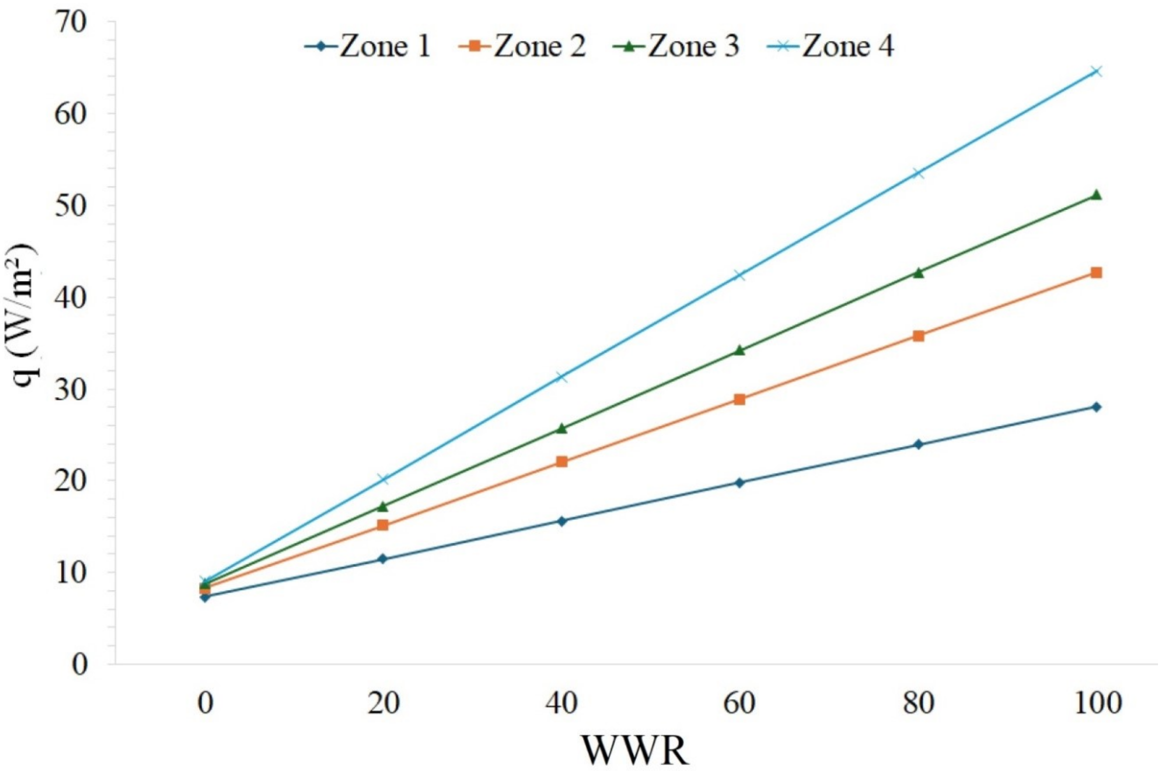


Figure 1. Total heat loss of the façade with double glazing (4+12+4) + wall (C1) according to window/wall ratio

less pronounced. However, as the WWR increases, the divergence between zones becomes more significant. This trend underscores the critical role that glazing plays in determining heat loss, especially in colder climates. For colder zones such as Zones 3 and 4, minimizing the WWR is essential to reduce heat loss and improve the building's energy efficiency. In warmer zones like Zones 1 and 2, WWR can be slightly higher without significantly affecting thermal performance, offering greater flexibility in architectural design while maintaining energy efficiency.

3.2 Effect of Different Glazing Types and Window/Wall Ratio on Heat Loss According to Climate Zones

The façade analyzed was replicated and evaluated for five different glazing types, as detailed in Table 3. Heat losses for each façade were calculated based on the variation of the WWR from 0% to 100% and are presented separately for each DD zone specified in TS 825 (Figure 2).

The figure illustrates the heat loss (q, W/m²) across different Window-to-Wall Ratios (WWR, %) for varying glazing types (C1–C5) in the four Degree-Day Zones of Turkey. The vertical axis represents the heat loss, while the horizontal axis indicates the WWR. Theperformance of each glazing type is compared for all zones, showcasing the influence of window type, filling gas, and thermal properties on heat loss.

Among the glazing types, C1 (double glazing with air filling and U=2.65 W/m²K) exhibits the highest heat loss across all WWR values and zones. This result emphasizes that the thermal performance of this glazing type is inferior compared to the others. In contrast, C5 (coated double glazing with 90% argon filling and U=1.53 W/m²K) consistently shows the lowest heat loss. The improved performance of C5 can be attributed to the use of argon gas, which has lower thermal conductivity than air, and the coating, which reduces heat transfer further.

The impact of these design improvements is particularly evident when comparing heat loss in Zone 4 at 100% WWR. For C1, the heat loss is significantly higher than for C5, highlighting the potential energy savings achievable through better glazing technologies. This observation is critical for colder climates, where reducing heat loss directly translates to improved energy efficiency and lower heating costs.

The intermediate performance of C2, C3, and C4 demonstrates the incremental improvements associated with using argon gas (C2), triple glazing (C3), and low-emissivity coatings (C4). For example, C2, which uses 90% argon instead of air, shows lower heat loss compared to C1. Similarly, C3 benefits from triple glazing, resulting in better insulation, while C4 leverages low-emissivity coatings to achieve superior thermal performance.

Another key observation is that the relative difference in heat loss between glazing types becomes more significant at higher WWRs and in colder zones. For example, in Zone 4, the performance gap between C1 and C5 widens as the WWR increases, indicating that the choice of glazing becomes more critical as window areas grow larger.

The findings have important implications for building design and policy. The results underline the importance of selecting glazing types with low U-values, especially for buildings in colder zones (Zone 3 and Zone 4). While Zone 1 and Zone 2 experience lower overall heat losses due to their milder climates, the choice of glazing can still impact energy efficiency, particularly for buildings with high WWRs. In colder zones, stricter

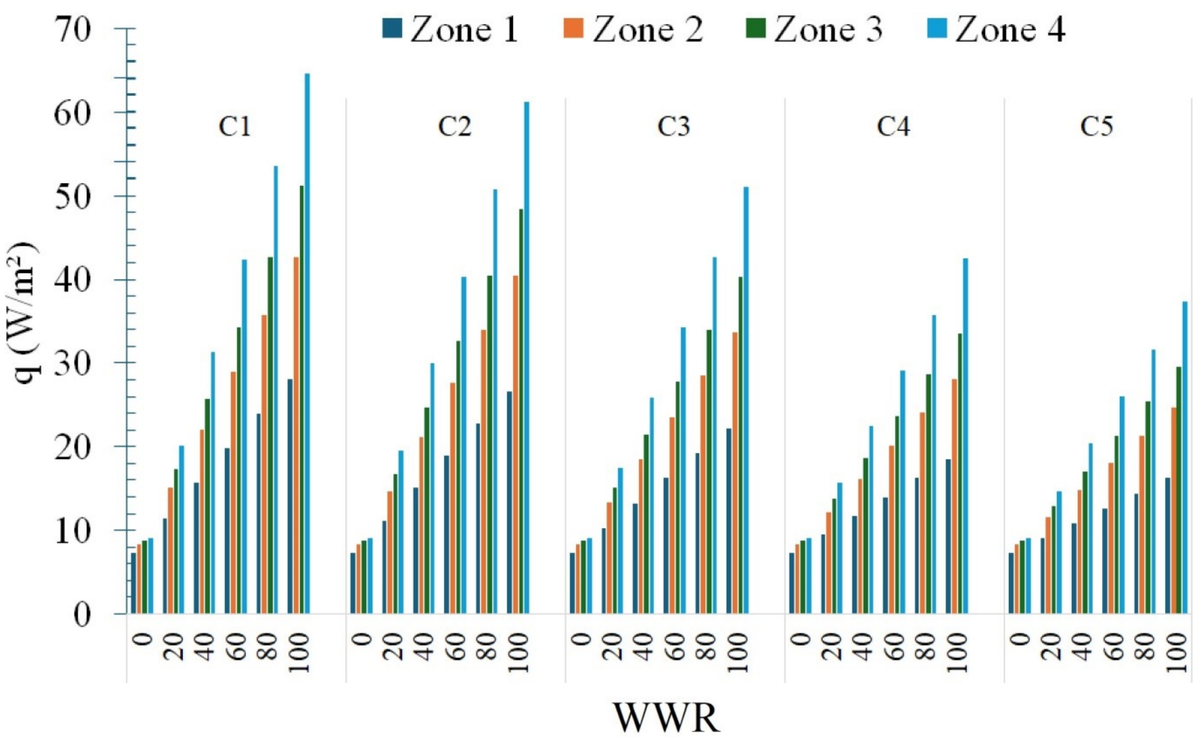


Figure 2. Heat losses according to different façade types and WWR

building codes and standards regarding WWR are necessary to limit heat loss. Additionally, the use of advanced glazing technologies, such as low-emissivity coatings or argon-filled windows, can help mitigate heat loss and make higher WWRs more viable, even in colder climates. In warmer zones, the less steep increase in heat loss with WWR suggests that designers can prioritize aesthetic and daylighting considerations without substantial energy losses.

Future studies and designs should consider not only heat loss but also factors like solar heat gains, window orientation, and the use of shading devices to optimize building performance. Balancing these aspects will ensure that buildings are both energy-efficient and comfortable, regardless of climatic conditions.

4. Conclusion

In this study, heat losses were calculated based on the window-to-wall ratio (WWR) of exterior walls for Turkey's climate zones during January in winter. The results confirm that as the WWR increases, heat losses also rise significantly, with variations depending on the glazing type and climate zone. Among the glazing types analyzed, the best insulation performance was achieved with coated double glazing (4+12+4 with 90% argon), which has the lowest thermal transmittance coefficient (U=1.53 W/m²K). For instance, in the coldest climate zone (Zone 4), replacing traditional double glazing with this coated and argon-filled double glazing reduced heat loss by 11.98% at 100% WWR. Even in Zone 1, the warmest climate, heat loss increased by 19.5% when the WWR rose from 20% to 40%, demonstrating the importance of careful design across all regions.

In colder climates, such as Zone 4, heat losses increased dramatically as the WWR rose. For example, a façade entirely made of windows (100% WWR) exhibited heat losses up to 55.6 W/m² higher than a façade without any windows (0% WWR). Similarly, the increase in heat loss for Zone 4 exceeded 2.5 times when the WWR increased from 20% to 100%.

While the use of argon gas as a filler in double glazing provided some improvement, its impact was relatively modest, reducing heat losses by 5.28% compared to air-filled double glazing at 100% WWR in the same façade. These findings highlight the critical need for selecting glazing with low U-values and limiting the WWR in colder climates to optimize energy performance. Keeping the WWR between 10-15% is recommended in these regions to balance heat loss and lighting requirements.

Finally, while increasing the WWR can help reduce the need for artificial lighting, excessive WWR in hot climates risks overheating, and in cold climates, it results in substantial heat losses. Future studies could investigate the interplay between WWR, lighting needs, and energy gains in greater detail to further refine building energy efficiency strategies.

5. References

[1] İ. Sercan, Ü. Ünver, T. Güneş. "Energy management system for Istanbul urban electric transport systems: Traction consumption performance monitoring system proposal and evaluation", *Journal of the Faculty of Engineering and Architecture of Gazi University* 37:2, 889-905, 2022, doi:10.17341/gazimmfd.786144

[2] X. Chen. Vand, S. Baldi, "Challenges and Strategies for Achieving High Energy

Efficiency in Building Districts" *Buildings*, 14,1839, 2024, doi:10.3390/ buildings14061839

[3] G. Ö. Yaman, "The effect of building façades window/wall ratio and window properties on energy performance", *Journal of the Faculty of Engineering and Architecture of Gazi University* 38:2, 851-863, 2023, doi:10.17341/gazimmfd.1053674

[4] J. C. Salcidoa, A. A. Raheemb and R. R. Issac, "From simulation to monitoring: Evaluating the potential of mixed-mode ventilation (MMV) systems for integrating natural ventilation in office buildings through a comprehensive literature review", *Energy and Buildings* 127, 1008-1018, 2016, doi:10.1016/j.enbuild.2016.06.

[5] M. Soğukoğlu, M. Vatan, "Architectural Solution Suggestions for Increasing Energy Efficiency in Existing Reinforced Concrete Residential Buildings", *Istanbul Aydın University Journal*, 6(21), 13-22, 2014

[6] S. Usta, "Comparison of Uninsulated and Insulated Conditions of a Building in the Second Zone in terms of Energy Efficiency According to TS 825 "Thermal Insulation Rules in Buildings" Standard", *Electronic Journal of Building Technologies*, Vol: 5, No: 1, 1-24 , 2016

[7] N. Mirabella, M. Röck, M. R. M. Saade, C. Spırınckx, M. Bosmans, K. Allacker, İ. Passer, "Strategies to Improve the Energy Performance of Buildings: A Review of Their Life Cycle Impact ", *Buildings,* 8, 2018, 105; doi:10.3390

[8] H. C. Ülgüner, A. Değirmenci, A. Üstüntürk, A. Keleşoğlu and Ü. Ünver, "Evaluation of Insulation Thickness in Buildings for Yalova", *International Journal of Multidisciplinary Studies and Innovative Technologies*, 5(1), 114 - 122, 2021,

[9] Mata E., Korpal A., Cheng S., Jimenez Navarro J.P., Filippidou F., Reyna J., Wang R., "A map of roadmaps for zero and 126323. low energy and carbon buildings worldwide", *Environmental Research Letters,* 15(11), 2020, 113003. doi:10.1088/1748 9326/ABB69F

[10] H. Koukkari, L. Brangança, "Review on the European Strategies for Energy-Efficient Buildings", *International Journal of Sustainable Building Technology and Urban Development,* 2:1, 87-99, March 2012, doi:10.5390/SUSB.2011.2.1.

[11] G. Ö. Yaman, "The Effect of Window/Wall Ratio and Orientation Parameters of Buildings on Solar Energy Gain", *International Journal of Eastern Anatolia Science Engineering and Design,* 3(2), 425-441., 2021, doi:10.47898/ijeased.999450

[12] C. Yıldız, "Recent Developments in Energy Efficiency in Buildings: Turkey Example", *Istanbul Technical University Energy Institute, Journal of Science* Istanbul, Turkey, GU J Sci, Part C, 12(1): 176-213, 2024, doi:10.29109/gujsc.1293759

[13] Yağcı, B. E., & Sözen, A. "Turkey's Energy Efficiency Analysis" *Politeknik Journal*, 1-1. doi:10.2339/POLITEKNIK. 859790, 2021

[14] M. Yılmazoğlu, A. Timoçin, A. Şenlik, K. Al, Ü. Ünver, "Investigation of Fuel Cell Cogeneration Systems for Energy Efficient Buildings", *Al-Jazari Journal of Science and Engineering*, Vol: 8, No: 2, 766-781, 2021, doi:10.31202/ecjse.875033

[15] " Paris: International Energy Agency", *World Energy Outlook* 2021, IEA, Paris, 2021.

[16] Pérez-Lombard, L., Ortiz, J., & Pout, C. A "review on buildings energy consumption information", *Energy and buildings,* 40(3), 394-398. 2008,

[17] A. Akbaş, "For Reducing Energy Consumed in Buildings, Efficient Thermal Insulation is a Must", *Journal of Energy Efficiency,* 12(3), 45-58, 2023

[18] A. Shahee, M. Abdoos, A. Aslani, R. Zahedi*,* "Reducing the energy consumption of buildings by implementing insulation scenarios and using renewable energies", *Shahee et al. Energy Informatics,* 7:18, 2024, doi:10.1186/s42162-024-00311-9

[19] Ü. Ünver, E. Adıgüzel, E. Adıgüzel, S. Çivi, K. Roshanaei*, "*Thermal Insulation Applications in Buildings According to Climate Zones in Turkey", *Journal of Advanced Engineering Studies and Technologies*, 1(2), 171-187, 2020

[20] T. Koyun, E. Koç, "The Effect of Window/Wall Area Ratios According to Variable Glass and Exterior Wall Types of a Building on Building Heat Losses*", Engineer and Machinery,* vol. 58, no. 688, pp. 1-14, 2017

[21] U. Teoman Aksoy, "Investigation of the Effect of Sandwich and Aerated Concrete Wall Applications on Average Heat Permeability Coefficient and Heat Loss" *Erciyes University Journal of Institute of Science and Technology* 24 (1-2) 277- 290 2008

[22] Y. Yaşar, A. Pehlevan, S. Maçka, "Determination of Suitable Window Types in Terms of Thermal Performance According to Trabzon Climate Conditions", VIII. National Installation Engineering Congress, Technological Research Paper

[23] T. Türel, Ş. Eren, S. N. Erkara, A. Kuruçay, M. C. Uzun, and Ü. Ünver, "An Experimental Approach to Investigate the Effects of Infiltration Losses on Building Energy Performance", ZeroBuild J., vol. 2, no. 01, pp. 99-114, Jan. 2024

[24] S. Efe, "The Effect of Using Tall Windows in Buildings on the Thermal Load of the Building and Its Cost Analysis: A Comparative Case Study for Antalya and Erzurum", Engineering Faculty, Ataturk University, Erzurum, *Buildings*, 13, 731, 2023,

[25] H. Demir, G. Çıracı, R. Kaya, Ü. Ünver, "Energy Efficiency in Lighting: Yalova University Faculty of Engineering Situation Assessment", *Journal of Uludag University Faculty of Engineering,* Volume 25, Issue 3, 2020, doi:10.17482/uumfd.795971

[26] Y. Yıldız, T. Göksal Özbalta, Z. Durmuş Arsan, "The Effect of Window/Wall Area Ratio on Building Energy Performance According to Different Glass Types and Orientations: Education Building, Izmir", *Yıldız Technical University Faculty of Architecture*6(1), January 2011

[27] TSE, "TS 825 Thermal Insulation Rules in Buildings," Turkish Standards Institute, 2013

[28] T. Pekdogan, H. Yildizhan, M. Ahmadi, and M. Sharifpur, "Assessment of window renovation potential in an apartment with an energy performance approach," *International Journal of Low-Carbon Technologies,* 19, 1529-1539, 2024, doi: 10.1093/ijlct/ctae066

[29] G. Feng, D. Chi, X. Xu, B. Dou, Y. Sun, and Y. Fu, "Study on the Influence of Window-wall Ratio on the Energy Consumption of Nearly Zero Energy Buildings," *Procedia Engineering*, vol. 205, pp. 730-737, 2017, doi:10.1016/j.proeng

[30] G. Ulpiani, M. Benedettelli, C. Perna, and B. Naticchia, "Overheating events caused by fully glazed façades: A study of a sick building in Italy and the benefits obtained through model predictive control of the AC system," *Solar Energy*, vol. 157, pp. 572-594, 2017, doi:10.1016/J.SOLENER