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Prof. Dr. Ziya Sogut

Editorial

The building sector is at the forefront of the global fight against climate change, playing a pivotal role in decarbonization and the transition to renewable energy. Zero Energy Buildings (ZEBs) are a cornerstone of this transformation, offering innovative solutions like heat recovery systems, phase-change materials, and renewable energy integration to create sustainable, carbon-neutral spaces.

ZeroBuild Journal is dedicated to advancing these efforts by sharing cutting-edge research and strategies that inspire change—from individual buildings to entire cities. By fostering collaboration between scientists, policymakers, and industry leaders, we aim to drive the innovation needed for a sustainable, high-quality future.

Join us as we continue to shape the future of the building and energy sectors.

January, 2025

Editörden

Yapı sektörü, küresel iklim değişikliğiyle mücadelede ön saflarda yer alarak karbon salınımının azaltılmasında ve yenilenebilir enerjiye geçişte kritik bir rol oynamaktadır. Sıfır Enerji Binalar (SEB), bu dönüşümün temel taşıdır ve ısı geri kazanım sistemleri, faz değişim malzemeleri ve yenilenebilir enerji entegrasyonu gibi yenilikçi çözümler sunarak sürdürülebilir, karbon nötr yaşam alanları yaratır.

ZeroBuild Journal, bireysel binalardan tüm şehirlere kadar uzanan bu çalışmaları desteklemek için en son araştırmaları ve stratejileri paylaşmaya adanmıştır. Bilim insanlarını, politika yapıcıları ve sektör liderlerini bir araya getirerek, sürdürülebilir ve yüksek yaşam kalitesine sahip bir geleceğe ilham vermeyi amaçlıyoruz.

Yapı ve enerji sektörlerinin geleceğini birlikte şekillendirmeye devam edelim.

Ocak, 2025

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Araştırma Makalesi

Soyhan ve Yeşilağaç 03:01 (2025) 01-13

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

Soyhan and Yesilagac 03:01 (2025) 01-13

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).

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

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

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

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

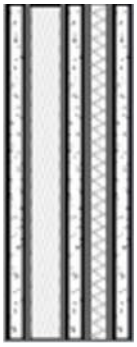
Wall structure	***Wall construction elements (from outside to inside)***	***Thickness (m)***
	4.8.2 Plaster mortars made of inorganic based lightweight aggregates	0.006 m
	10.3.3.1.1.4 Polystyrene - Particulate Foam - Thermal conductivity groups in accordance with TS 7316 EN 13163 040	For Zone 1: 0.03m 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

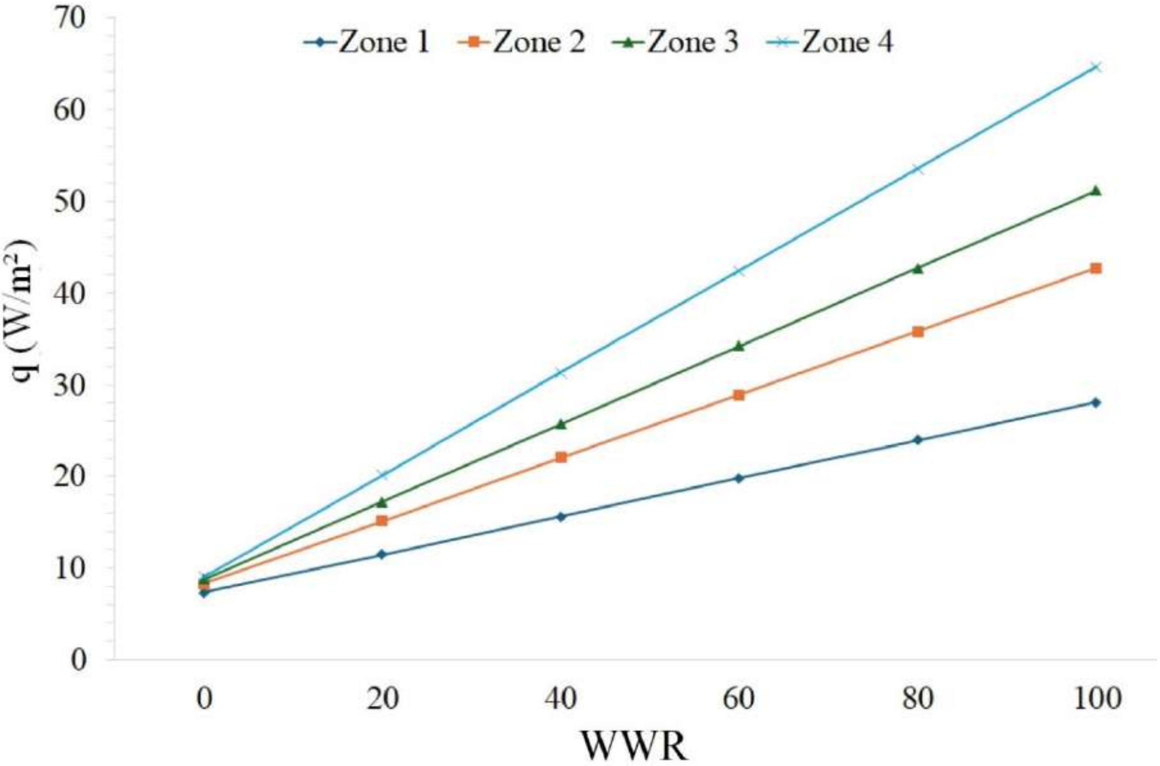


Figure 1. Total heat loss of the façade with double glazing (4+12+4) + wall (C1) according to window/wall ratio

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

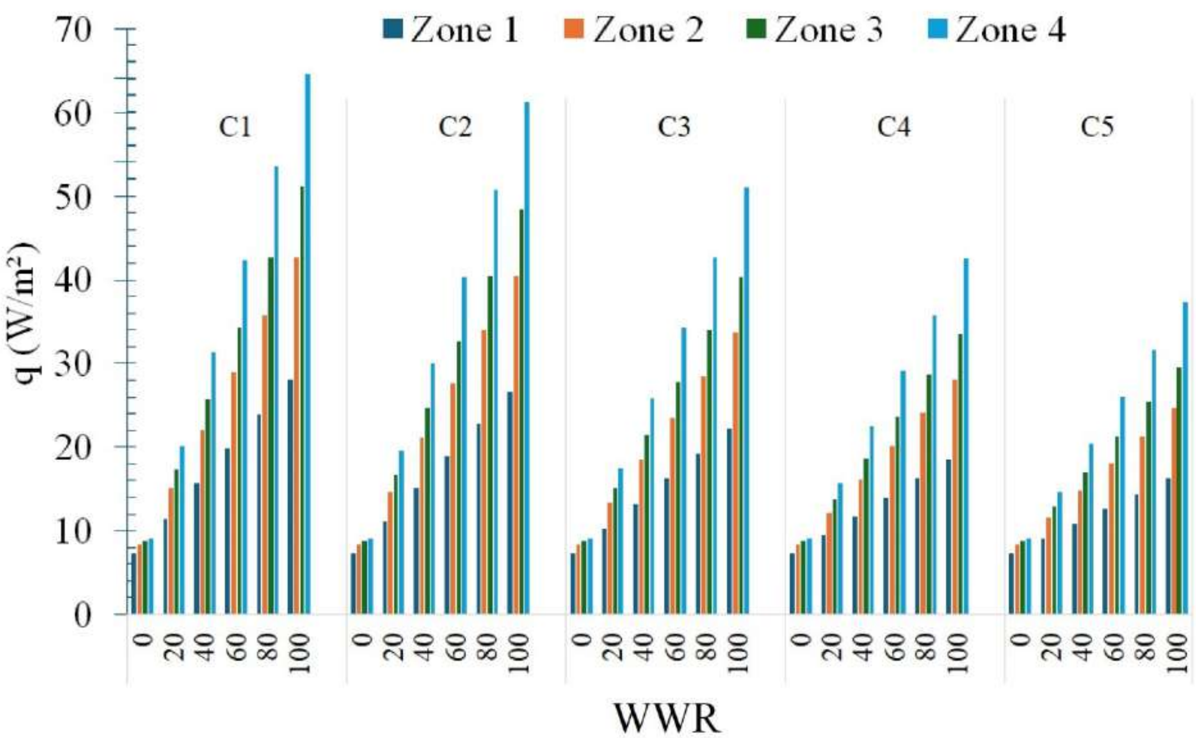


Figure 2. Heat losses according to different façade types and WWR

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

ZERO BUILD JOURNAL

Kısa Bildirim

Kasapoğlu ve ark. 03:01 (2025) 14-21

Isı Yalıtımının Kritik Rolünün Ortaya Çıkarılması: Yalıtım Kalınlığının Azalan Marjinal Fayda Etkisi

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Öne Çıkarılanlar:

1. Yalıtım malzemesinin ilk 1 cm kalınlığında uygulanması, ısı kaybını % 26.87 azaltmaktadır.
2. Yalıtımı artırmak ısı kayıplarını azaltsa da; kalınlık arttıkça marjinal fayda azaldığından, optimum yalıtım kalınlığını tespit edebilmek için ekonomik analiz de yapılmalıdır.
3. İç ve dış sıvanın ısı kaybına etkisi son derece sınırlıdır.
4. Tuğla en kalın boyutunun kullanılması ile en ince boyutunun, duvar kalınlığını belirleyecek şekilde kullanılması arasında, ısı kaybında maksimum %11.2 fark bulunmaktadır.

Geliş Tarihi: 28.12.2024 Kabul Tarihi: 25.01.2025 Doi: 10.5281/zenodo.14757651

Amaç:
Bu çalışma, farklı katmanlardan oluşan bina duvar kalınlıklarının ısı transferi üzerindeki etkilerini incelemeyi amaçlamaktadır. En sık kullanılan iç sıva, tuğla, yalıtım malzemesi ve dış sıva olmak üzere dört katmandan oluşan modelde, termal kayıplar analiz edilerek karşılaştırıldı. Analizde bütün katmanların ısı kaybına etkisinin karşılaştırılması ve yalıtım malzemesinin marjinal faydasının belirlenmesi amaçlandı.

Metot:
Çalışmada en sık kullanılan, iç sıva, tuğla, yalıtım malzemesi (EPS) ve dış sıva olmak üzere, TS825 standardına uygun dört katmandan oluşan bir model analizler edilmiştir. İç ve dış sıva kalınlıklarının 0.01-0.05 m, tuğla kalınlığının 0.09 m, 0.19 m ve 0.135 m, EPS türü yalıtım kalınlığının ise 0 – 0.2 m arasında değiştiği göz önüne alınarak ısı kayıpları hesaplanarak karşılaştırılmıştır.

Sonuç:
Bulgular, EPS yalıtım malzemesinin haricindeki duvar katmanlarının kalınlaştırılmasının ısı kaybını önlemek için önemli bir katkı sağlamadığını ortaya koydu. 20 cm lik EPS malzemesinin uygulanmasıyla yalıtımsız bir duvarın ısı kaybını %86 oranında azalttığı hesaplandı. Bununla birlikte, sıva kalınlığındaki artışın ısı kaybını etkilemediği, tuğlanın en uzun ölçüsünü duvar kalınlığı olacak şekilde kullanmanın ise en kısa ölçüsünü kullanmaya göre %11.2 oranında bir iyileşme sağladığı tespit edilmiştir. Çalışmanın sonuçları, yalıtım malzemesi kalınlık artışının ısı kaybını azalttığı ancak marjinal faydasının da azaldığını, bu yüzden en uygun yalıtım kalınlığına karar verirken ekonomik analiz de yapılması gerektiği sonucuna ulaşılmıştır.

Anahtar Kelimeler: Duvar kalınlığı, Isı Yalıtımı, Bina enerji performansı, Duvardan ısı kaybı, Yalıtım etkisi, Sıfır Enerji Binalar

ZERO BUILD JOURNAL

Short Communication

Kasapoglu et al. 03:01 (2025) 14-21

Unveiling the Critical Role of Thermal Insulation: The Diminishing Marginal Benefit Effect of Insulation Thickness

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Highlights:

1. The first cm of EPS insulation reduces the thermal loss from a wall by 26.87%.
2. Increasing insulation thickness reduces heat loss; however, the marginal benefit decreases as the thickness increases. This diminishing return highlights the need for economic analysis to determine the optimal insulation thickness.
3. Increasing Inner and Outer plaster has a negligible effect on the heat losses of an insulated of a wall
4. There is a maximum difference of 11% between using the thickest dimension of the brick and using its thinnest dimension to determine the wall thickness

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Abstract

This study investigates the effects of thickness variations in different layers of building walls on heat transfer. A four-layered wall model, consisting of interior plaster, perforated brick, expanded polystyrene (EPS) insulation material, and cement-based exterior plaster, was analyzed in compliance with the TS825 standard. By systematically increasing the thickness of each layer, the impact on the total heat loss of the wall was evaluated analytically. The results indicate that plaster layers had negligible effects on heat loss, while increasing the thickness of the perforated brick reduced heat loss by up to 11.2%. However, the most significant reductions in heat loss were achieved by increasing the thickness of the EPS insulation layer. Notably, this reduction follows a diminishing marginal benefit pattern, where the initial increases in insulation thickness yield substantial energy savings, but further increases provide progressively smaller benefits.

These findings highlight that insulation thickness cannot be the sole consideration in optimizing building energy efficiency. Economic analysis is also essential to determine the optimal insulation thickness, ensuring both energy efficiency and cost-effectiveness. This study provides valuable insights for sustainable building design, particularly for projects with limited budgets.

Keywords: Wall thickness, thermal insulation, building energy performance, heat loss through walls, insulation effect, Zero Energy Buildings

1. Introduction

The increasing awareness of the climate crisis caused by greenhouse gas emissions from fossil fuels, combined with the slow adoption of renewable energy sources, and has heightened the focus on energy efficiency [1] and zero energy buildings. Among the three major energy consumption sectors—industry, transport, and buildings—the building sector attracts significant attention due to its potential for energy savings, especially in construction and use phases [2, 3]. In Turkey, residential buildings account for 35% of energy consumption, with 80% of this used for heating and cooling [4, 5]. Therefore, improving insulation has a significant impact on energy efficiency and reducing the carbon footprint [6].

Thermal insulation, one of the most widely studied methods, minimizes heat losses through the exterior facades, roofs, floors, and other building components [7]. In Turkey, insulation thicknesses range from 2.8 cm to 9.6 cm, necessitating detailed calculations to determine optimum thickness [8]. Research indicates that applying the appropriate insulation thickness can reduce CO_2 emissions by 50% in cold climates [9]. Heat losses in buildings vary by architectural design but generally occur predominantly from external walls (40% in multi-storey buildings and 25% in single-storey houses), windows, roofs, and air leaks [10].

Heat losses primarily arise through the building envelope, including walls, windows, and thermal bridges, and may occur via direct transfer or through gaps in materials [11]. Studies show that insulated walls significantly reduce heat losses. For example, analysis of mezzanine floors with balcony extensions found that uninsulated walls had 85% higher heat loss compared to insulated walls with 5 cm insulation thickness [12]. Increasing wall thickness further enhances energy efficiency and interior comfort by mitigating outdoor influences [13].

Many studies explore the relationship between insulation material thickness and thermal conductivity. For instance, in Malaysia's hot and humid climate, non-linear polynomial models were developed to describe this relationship for materials like fiberglass and extruded polystyrene [14]. Research in Turkey shows that the optimum insulation thickness varies between 0.036 m and 0.1 m depending on climate and material type, with energy savings of up to 76.8% using expanded polystyrene (EPS) [15, 16]. Comparative analyses of insulated and uninsulated conditions demonstrate significant reductions in energy requirements and heat loss with insulation [17]. In Ankara, rock wool with aerated concrete walls and glass wool with brick walls yielded the lowest and highest optimum insulation thicknesses, respectively [18]. However, studies also reveal diminishing returns when continuously increasing EPS board thickness [19].

In this study, the authors aimed to determine the rate of heat loss prevention utilizing insulation and the marginal benefit of insulation. The investigation analyzed the effect of individual layer thicknesses—interior plaster, brick, insulation material, and exterior plaster—on heat transfer in a multi-layered building wall, considering conduction and convection mechanisms. The study theoretically presents the marginal benefit analysis of increasing insulation thickness and demonstrates how maximum energy savings can be achieved with limited budgets. The "Diminishing Marginal Benefit" expressed in the study aligns with the physical principles of insulation; however, it emphasizes the necessity of conducting thermodynamic analysis in conjunction with economic analysis.

2. Material and Method

Within the scope of the study, the heat losses of the four-layer wall model shown in Figure 1 are analyzed to represent an ordinary building wall in accordance with TS825 standard. In the analyses, the effect of the extra thickened wall layer on the heat loss was calculated by thickening each wall layer and keeping the thicknesses of the other wall layers constant. In the case of increasing the thickness of the internal and external plaster from 0.01 m to 0.05 m, obtaining 3 different brick wall thicknesses by placing the perforated brick in all 3 dimentions and thickening the EPS insulation material from 0.03 m to 0.09 m, the heat losses from the wall were calculated and compared separately.

Table 1 presents the thickness ranges, heat transmission coefficients, and densities of the materials used [20]. These materials are utilized in building walls because each contributes significantly to protecting the structure from various external factors. Consequently, this wall model and its components, identified as the most commonly used wall model within the scope of this study, were taken into consideration.

The method used in this study is explained in detail in heat transfer textbooks, which also include numerous examples on the subject. Within the scope of this study, the aim was to compare the effects of thickening each layer on the building's heat loss and to determine the impact ratios.

3. Results and Discussion

In this study, the effect of various materials comprising a wall on heat loss was examined through analytical calculations for different wall layer thicknesses. The results indicate that layer other than the insulation material (EPS) have no significant effect on preventing heat loss, while EPS becomes more beneficial as its thickness increases. However, the benefit increment diminishes with increasing thickness.

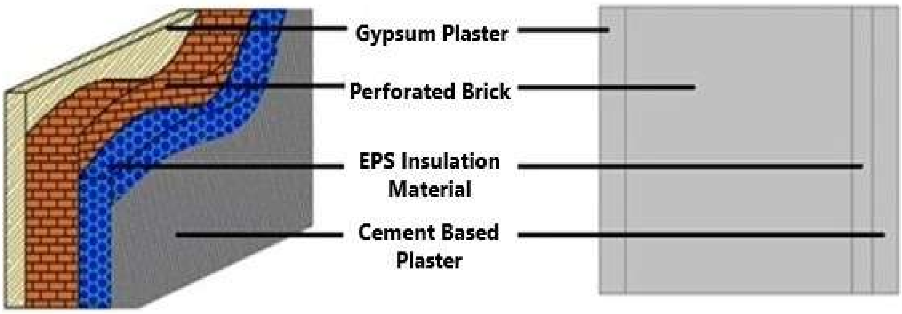

Figure 1. Four-layer wall model

Table 1. Table of Wall Materials and Thickness Changes

Material	Thickness Range (m)	Heat Transmission Coefficient (k) (W/m.K)
Gypsum Plaster	0.01 - 0.05	0,70 W/m.K
Perforated Brick	0.09 / 0.19 / 0.135 (3 settlements)	0.45 W/m.K
EPS (Polystyrene)	0.03 - 0.09	0.05 W/m.K
Cement Based Plaster	0.01 - 0.05	1.6 W/m.K

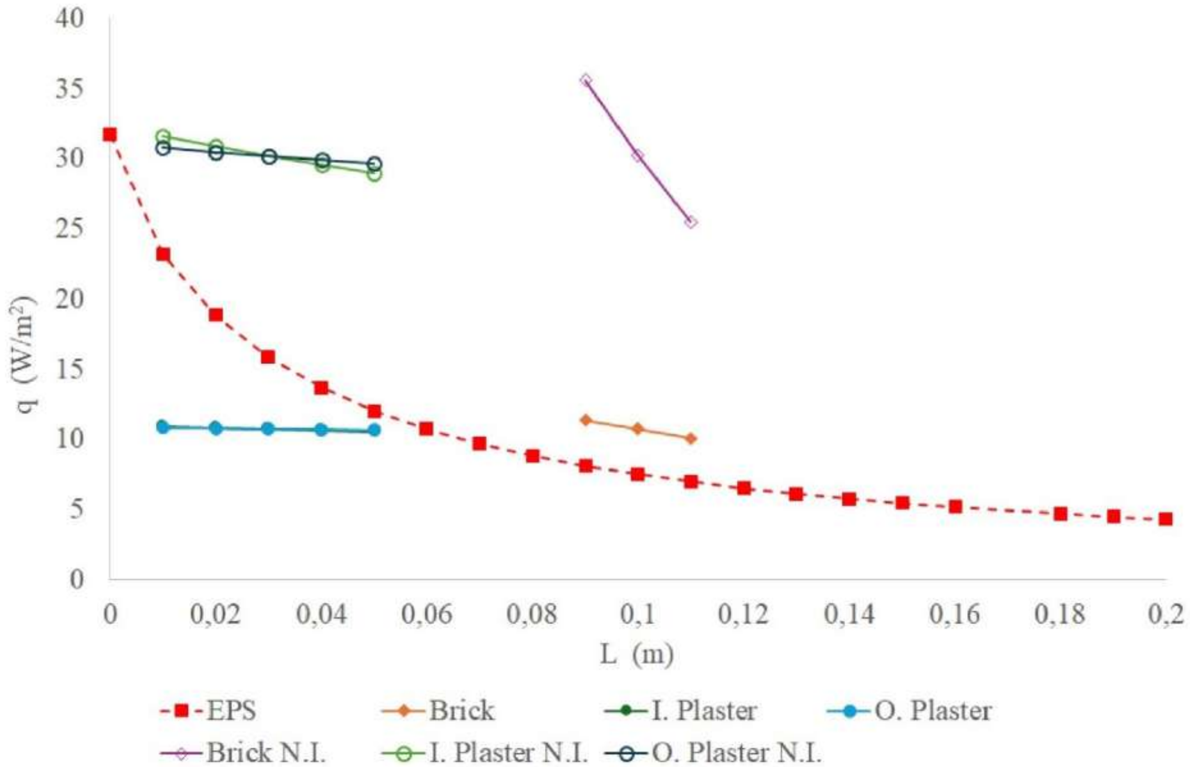

Figure 2. Effect of Different Wall Layer Thicknesses on Heat Transfer.

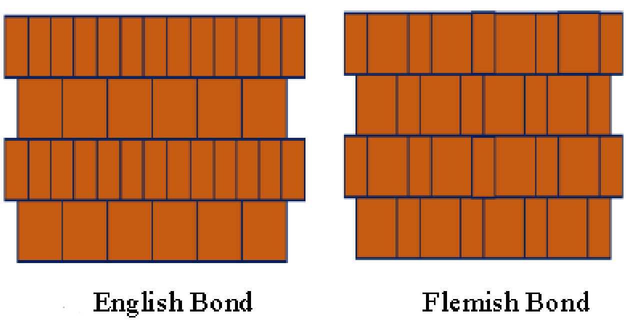

Figure 3. English and Flemish Bond [21].

In Figure 2, the red line represents EPS insulation material, "I. Plaster" denotes interior plaster, "O. Plaster" represents outer plaster, and the letters "N.I." indicate "Not-insulated." The interior and exterior plasters, whether insulated or not, provide only a very limited reduction in heat loss. The curves on the right represent changes in brick thickness. The relationship between brick thickness variation and heat loss is shown on the right side of the figure for both insulated and non-insulated wall configurations. It is observed that increasing the brick thickness alone has an effect on energy savings in a non-insulated wall. But its effect on an insulated wall is negligible.

However, it has been reported that not only the thickness of the brick used but also factors such as brick type, mortar, layout and wall structure affect the thermal insulation performance of the wall [22]. Different brick layouts can affect thermal insulation in different ways by changing the amount and distribution of air voids within the wall. For example, brick layouts such as English and Flemish bond (Figure 3) can improve thermal insulation at different rates by changing the internal structure of the wall [23]. However, ultimately, although the air layer within the perforated brick has a slightly positive effect on insulation, it can never replace proper insulation.

Figure 2 also highlights the dramatic reduction in heat loss observed with the change in EPS insulation thickness, as indicated by the red dashed line. In the non-insulated case, the heat loss from the wall is 31.74 W/m², while adding the first 1 cm of EPS insulation reduces heat loss to 26.87 W/m², corresponding to a 26.87% decrease. This demonstrates the critical impact of the initial thickness of insulation material on energy efficiency. However, as the thickness increases, the diminishing marginal benefit effect becomes apparent. For instance, increasing the insulation thickness from 19 cm to 20 cm reduces heat loss from 4.48 W/m² to 4.29 W/m², corresponding to only a 4.29% decrease. Comparing the non-insulated wall with a wall insulated with 20 cm of EPS reveals an 86% reduction in total heat loss. However, the marginal benefit of insulation continues to decrease steadily.

An important finding is that the first centimeter of EPS insulation thickness is critical for energy efficiency. While the initial 1 cm of EPS reduces total heat loss by 26.87%, the effect of each subsequent 1 cm decrease in heat loss diminishes. This demonstrates that increasing insulation material thickness exhibits diminishing marginal benefit, underscoring the importance of the concept of optimal insulation thickness. Energy efficiency and cost-effectiveness analyses can serve as critical guides, particularly for applications aiming to achieve energy savings on limited budgets. The dramatic benefit observed in the first centimeters of insulation can serve as a strategic starting point for achieving maximum energy savings with minimal budgets during insulation design. However, maintaining the insulation material thickness at an optimal level is crucial for both economic and environmental sustainability. In this context, insulation thickness design should consider not only energy savings but also cost-effectiveness.

4. Conclusion

The first 1 cm of EPS insulation reduces heat loss by approximately 26.87%, underlining its critical role in achieving energy efficiency. However, as the insulation thickness increases, the marginal benefit diminishes, as seen with the reduction in heat loss from 19 cm to 20 cm, which was limited to 4.29%. This diminishing return effect highlights the importance of determining an optimal insulation thickness that balances energy efficiency with cost-effectiveness.

Moreover, the air layer within perforated bricks, while contributing marginally to insulation, cannot substitute for proper insulation materials. These findings emphasize that for sustainable and cost-effective building designs, prioritizing insulation material and optimizing its thickness is essential. Such an approach is particularly valuable for projects with limited budgets, where maximum energy savings can be achieved through strategic initial investments in insulation.

In conclusion, incorporating insulation material with an optimal thickness not only enhances energy efficiency but also supports economic and environmental sustainability in construction practices.

5. References

[1] H. Doğan and N. Yılankırkan, "Turkey's energy efficiency potential and projection," *Gazi University Journal of Science Part C: Design and Technology*, vol. 3, no. 1, pp. 375-384, 2015

[2] M. S. Al-Homoud, "Computer aided building energy analysis techniques," *Building and Environment*, vol. 36, pp. 421-433, 2001

[3] M. Yılmazoğlu, A. Timoçin, A. Şenlik, K. Al, and Ü. Ünver, "Investigation of Fuel-Cell Cogeneration Systems for Energy Efficient Buildings", ECJSE, vol. 8, no. 2, pp. 766–781, 2021, doi: 10.31202/ecjse.875033

[4] D. Paralı, *Investigation of thermal insulation systems applied on building walls*, M.S. thesis, Sakarya University, Institute of Science, 2009

[5] A. Bahadiroğlu, A. Y. Koç, E. Parlak, N. Larsson, W. Kujawski, & U. Unver, Sustainable building evaluation: a case study," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects,* 44(2), 3149–3163. 2022. https://doi.org/10.1080/15567036.2022.2061646

[6] Ü. Ünver, E. Adıgüzel, E. Adıgüzel, S. Çivi, and K. Roshanaei, "Thermal Insulation Applications in Buildings According to Climate Zones in Turkey," *Journal of Advanced Engineering Studies and Technologies*, vol. 1, no. 2, pp. 171-187, 2020

[7] H. Tan and B. Doğan, "Experimental and numerical investigation of thermal conductivity of EPS insulation material used in buildings according to different densities," *Teskon / Symposium on Energy Performance in Buildings, Izmir, Turkey, 19 - 22 April 2017*

[8] Ö. Kaynaklı, & R. Yamankaradeniz, "Heating Process and Optimum Insulation Thickness Calculation," *VIII. National Installation Engineering Congress, Proceedings*, pp. 187-195, 25-28 October 2007, Izmir

[9] K. Çomaklı, & B. Yüksel, "Environmental impact of thermal insulation thickness in buildings,"*Applied Thermal Engineering*, vol. 24, no. 2, pp. 933-940, 2004

[10] E. Buyruk, A. Fertelli, and K. Karabulut, "Experimental and numerical investigation of the effects of different insulation applications on heat loss," *Plumbing Engineering*, vol. 136, pp. 53-64, 2013

[11] N. Koçu and A. G. M. Dereli, "Energy saving by thermal insulation on exterior walls and problems encountered in detail," *5th National Roof & Facade Symposium*, *Dokuz Eylül University, Izmir,* 15-16 April 2010

[12] K. Karabulut, E. Buyruk, & A. Fertelli, "Numerical Investigation of Heat Transfer in Heat Bridges Depending on Different Indoor Temperature Between Floors," *Plumbing Engineering*, vol. 137, pp. 54-61, Sep./Oct. 2013

[13] M. Özel, "Investigation of the effects of different exterior wall building materials on heating load in cold climate zone," *Fırat University Journal of Engineering Sciences*, vol. 30, no. 1, pp. 105-113, 2019

[14] T. M. I. Mahlia, B. N. Taufiq, B. N. Ismail & H. H. Masjuki, "Correlation between thermal conductivity and the thickness of selected insulation materials for building wall," *Energy and Buildings*, vol. 39, pp. 182-187, 2007

[15] A. Gürel, & A. Daşdemir, "Determination of Optimum Insulation Thicknesses for Heating and Cooling Loads in Four Different Climate Zones of Turkey," *Journal of Erciyes University Graduate School of Natural and Applied Sciences*, vol. 27, pp. 346-352, 2011

[16] M. S. Mohsen & B. A. Akash, "Some prospects of energy savings in buildings," *Energy Conversion and Management*, vol. 42, pp. 1307-1315, 2001

[17] O. Özütku, & C. Karakuş, "Energy Saving through Thermal Insulation in Buildings and a Sample Application: Energy Performance Values and Costs of MKU Engineering Faculty Building," *Journal of Plumbing Engineering*, no. 137, Sep./Oct. 2013

[18] S. Y. Kandemir, V. Bektaş, & E. Açıkkalp, "Determination of optimum insulation thicknesses for different wall models in external insulation applications and economic analyses," *Dicle University Faculty of Engineering Journal of Engineering*, vol. 10, no. 1, pp. 275-288, 2019

[19] J. Li and W. Cao, "The heat transfer coefficient of recycled concrete bricks combined with EPS insulation board wall," *Mathematical Problems in Engineering*, vol. 2015, no. 1, 2015

[20] Turkish Standards Institute, *TS 825: Thermal Insulation Standards in Buildings*, Ankara, Turkey: TSE, 2020

[21] F. M. Wani, R. Kodali, V. A. Reddy, D. Sowmya, A. Bondada, S. Reddy, & M. A. Khan, "Finite element analysis of unreinforced masonry walls with different bond patterns," *Sustainable Engineering and Innovation*, vol. 5, no. 1, pp. 58-72, 2023

[22] D. Tokgöz, "Air Layer Exterior Walls - Brick Example," Master Thesis, Institute of Science and Technology, Istanbul Technical University, Istanbul, Turkey, 2010

[23] K. Tarabieh, S. Abdelmohsen, Y. Elghazi, R. El-Dabaa, A. Hassan, & M. Amer, "Parametric investigation of three types of brick bonds for thermal performance in a hot arid climate zone," *Proceedings of the 32nd International PLEA Conference DESIGN TO THRIVE*, Edinburgh, July 2017

ZERO BUILD JOURNAL

Derleme

Turhan ve Turhan 03:01 (2025) 22-40

Enerji Etkin Binalarda Finansal ve Vergisel Teşvikler: Türkiye ve Dünyadan Karşılaştırmalı Bir Bakış

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Öne Çıkanlar:

- Enerji-etkin binalar için finansal ve vergisel teşvikleri, Türkiye özelinde incelenip gelişmiş ülkeler ile karşılaştırıldı.
- Türkiye için finansal ve vergisel teşvik önerileri sunuldu.
- 2025 yılında binalarda yenilenebilir enerji kullanımına yönelik belirlenen %10'luk asgari gereklilik, en son düzenlemelere göre kademeli olarak artırılmalıdır.
- Vergi teşviklerinin önemli bir noktası, bu teşviklerin sürdürülebilir olması ve uzun vadede uygulanabilir olmaları gerektiğidir.

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Amaç:
Bu çalışma, Türkiye'deki enerji-etkin bina vergi teşviklerini incelemekte ve uluslararası örneklerle karşılaştırarak en iyi uygulamaları ve yenilikçi politikaları vurgulamaktadır.
Metot:
Çalışmada, ilk adım olarak, enerji-etkin binaların sistematik bir incelemesinin yapılmıştır. ScienceDirect, Google Scholar gibi veritabanları kullanılarak kapsamlı bir arama gerçekleştirilmiştir. Çalışmaya dâhil edilmek üzere seçilen çalışmalar, tamamen veya kısmen enerji-etkin bina teşviklerine odaklanmaktadır. "Enerji-etkin bina teşvikleri", "sürdürülebilirlik ve finansal teşvikler", "sürdürülebilir bina teşvikleri" ve "enerji-etkin bina için vergi indirimi" gibi anahtar kelimelerle yapılan aramalar sonucunda toplamda 251 yayın elde edilmiştir. Ayrıca, Türkiye'deki enerji-etkin binalara yönelik tüm finansal ve vergisel teşvik kanunları incelenmiştir.
Sonuçlar:
Türkiye'de doğrudan enerji-etkin binalara yönelik yeterli düzeyde finansal ve vergisel teşvikler mevcut değildir. Türkiye'de, binalarda enerji kayıplarını azaltmak ve enerji verimliliği sağlamak amacıyla Enerji Verimliliği Kanunu gibi bir dizi yasal düzenleme hayata geçirilmiştir. Bu tip düzenlemeler, enerji verimliliği ve sürdürülebilirlik hedeflerine ulaşılmasında önemli adımlar atmaktadır. Mevcut olarak, ihtiyaç fazlası elektrik enerjisinin satışında esnaf muafiyeti, damga vergisi kanunu gibi düzenlemeler olduğu tespit edilmiştir. Ancak, seçilen gelişmiş ülkeler özelinde yapılan karşılaştırma sonucu, Türkiye'de bu yönde atılacak somut adımların olduğunu göstermektedir. Bu adımlara örnek olarak, 2025 yılında binalarda yenilenebilir enerji kullanımına yönelik belirlenen %10'luk asgari gereklilik, en son düzenlemelere göre kademeli olarak artırılması verilebilir.
Anahtar kelimeler:
Enerji-etkin bina teşvikleri, Vergi teşvik programları, Türkiye vergi kanunları, Vergi karşılaştırması, Çevre dostu binalar

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Financial and Tax Incentives in Energy-Efficient Buildings: A Comparative View of Türkiye and the World

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Highlights:

- Financial and tax incentives for energy-efficient buildings were analyzed in the context of Turkey and compared with developed countries.
- Financial and tax incentive recommendations were presented for Turkey.
- The 10% minimum requirement for the use of renewable energy in buildings, set for 2025, should be gradually increased according to the latest regulations.
- An important aspect of tax incentives is that they must be sustainable and applicable in the long term.

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Abstract: As global concerns about climate change and environmental sustainability intensify, the energy-efficient building construction sector has emerged as a key focus for reducing greenhouse gas emissions and resource energy consumption. On the other hand, tax incentives have proven to be effective tools in promoting energy-efficient building practices, while encouraging developers, investors, and property owners to adopt sustainable construction techniques incorporating with energy-efficient technologies. To this aim, this paper reviews tax incentives for energy-efficient buildings in Türkiye and compares with international examples, highlighting best practices and innovative policies. This study also explores the scope and implementation of tax incentives programs, including property tax reductions, investment tax credits, accelerated depreciation schemes, and VAT exemptions, which aim to lower the financial barriers for energy-efficient building adoption.

The findings of this paper suggest that integrating well-structured tax incentives with broader sustainability goals can significantly accelerate the transition to eco-friendly construction practices.

Keywords: Energy-efficient Building Incentives; Tax Incentives Programs; Turkish Tax Relief; Tax Comparison; Environmental Friendly

1. Introduction

Energy-efficient buildings (EEBs) are essential for the sustainable development of nations. On the other hand, global warming, driven by the rise in greenhouse gas emissions, remains a significant challenge for governments, worldwide [1]. Hence, the design and construction of energy-efficient buildings aim to reduce the building sector's share of energy consumption. Nowadays, buildings are a major contributor, accounting for almost 30% of total green gas emissions [2]. In developing countries like Türkiye, the ratio of energy consumption in buildings is increasing compared to developed countries [3]. Therefore, to guide and encourage the building sector toward adopting green buildings, sectors should be driven by laws and legislation.

The EEB concept is defined as "*a structure designed, constructed, and operated in a way that minimizes its environmental impact and promotes sustainability*" [4]. The characteristics of "an EEB" include energy efficiency, water conservation, eco-friendly construction materials, improved indoor air quality, optimal thermal comfort, health and wellbeing, efficient land-use and biodiversity protection and resilience to global warming [5]. The LEED (Leadership in Energy and Environmental Design) certification system is an internationally recognized framework that assesses the environmental performance of buildings, encouraging sustainable construction practices by focusing on factors like energy efficiency, water conservation, and the use of renewable materials, thus serving as a crucial tool for advancing the EEB initiatives. As of 2024, there are over 195,000 LEED-certified buildings across 186 countries worldwide [6]. Figure 1 illustrates the number of LEED-certified buildings across different countries. As of recent data, Türkiye ranks among the top countries for the number of LEED-certified buildings. It is typically positioned within the top 20, with approximately 1,500 LEED-certified buildings.

The US Green Building Council reports that new EEBs typically experience a 10.5% reduction in operating costs during their first year [7]. Moreover, EEBs experience an average reduction in operating costs of 16.9% over a five-year period. While EEBs offer numerous benefits, the economic dimension is a critical aspect that warrants particular attention. Constructing an EEB involves various costs that can differ based on factors such as location, building type, and the level of sustainability desired. For instance, according to the Hu and Skibniewski [8], EEBs often incur an initial construction cost premium up to 10% compared to traditional buildings. Figure 2 depicts the share of the cost of constructing EEBs in terms of items. The installation of energy-efficient HVAC systems, renewable energy sources (e.g., solar panels), and advanced insulation techniques typically account for a significant share of the additional costs.

Energy consumption of Türkiye has been rising steadily each year. For example, in 2020, the country's primary energy consumption reached 147.2 million tons of oil equivalent (Mtoe), positioning Türkiye

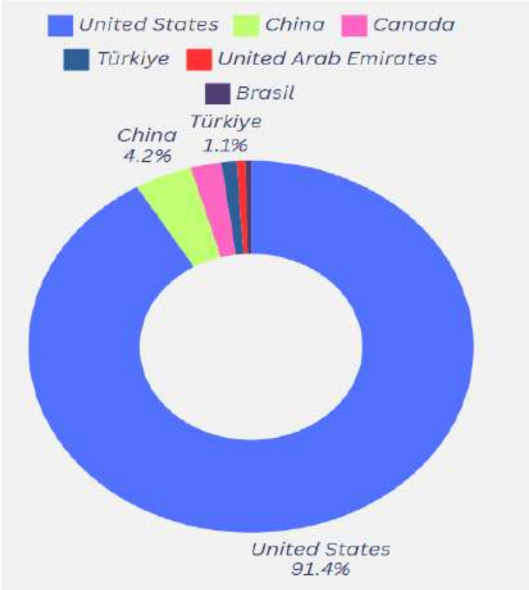

Figure 1. The share of countries according to LEED-certified buildings (adopted from US Green Building Council)

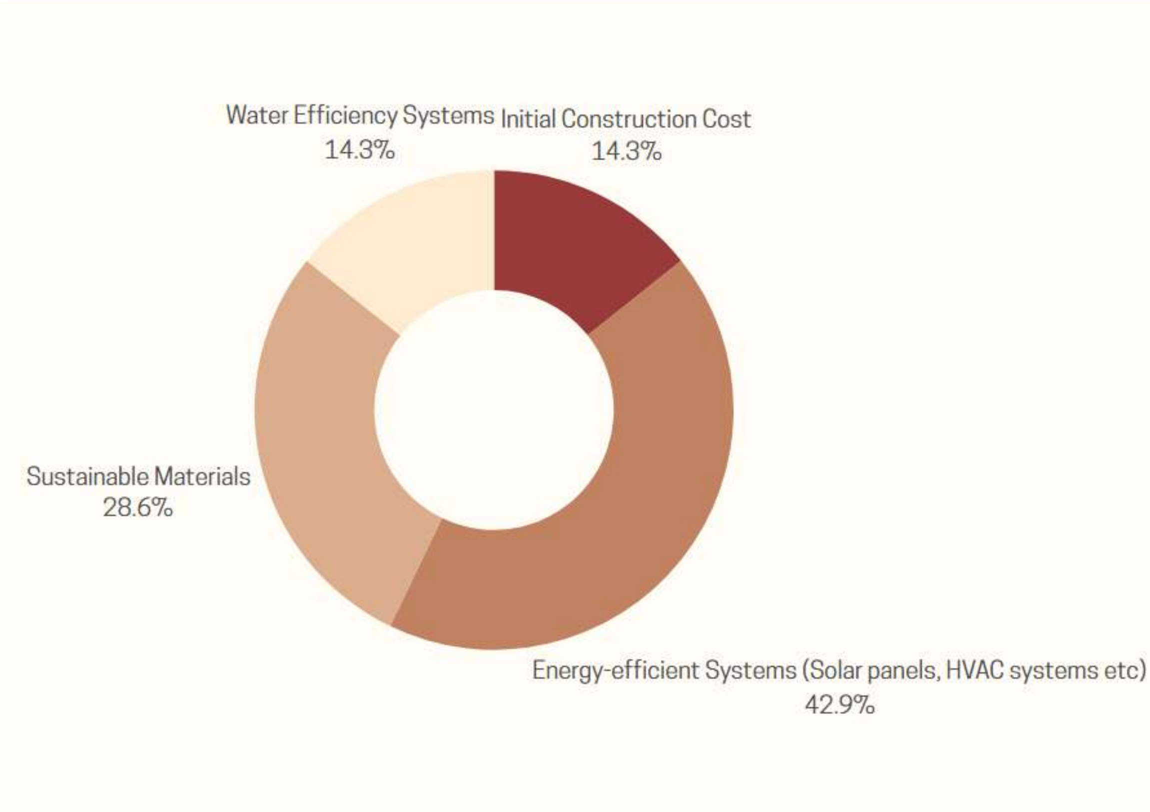

Figure 2. The share of costs for constructing EEBs [9]

among the leading countries in global energy consumption. Furthermore, energy consumption in Türkiye grew by 9% in 2021 compared to the previous year. These statistics reflect an ongoing increase in energy consumption in the country [10]. Therefore, EEBs concept may be one of the solution to decrease total energy consumption of the country. On the other hand, there are several ways to convert a building to EEB, such as adding trombe wall and integrating renewable energy like photo-voltaic panels [12] (Figure 3a) and wind turbines [13] (Figure 3b), utilizing from energy-efficient roof and walls [14] (Figure 3c) and insulating the walls [12] with changing lighting systems with more efficient ones. However, all modifications incur costs for investors, which makes effectively leveraging incentives and tax reductions essential, as this can minimize the waste of limited national resources while maximizing energy efficiency for the country.

In Türkiye, Erbıyık et al. [15] reviewed the LEED Certification system embedded in to green building certification as a case study. The authors stated that the defined tax for green buildings was kept fairly lower than the conventional buildings. In another study, Bahadıroğlu et al. [16] adopted the SBTool for the first time to an educational facility in Marmara/Türkiye climate for evaluation of sustainable building. The authors found that the relative performance score was assigned to “B” which means an acceptable standard for a sustainable building. On the other hand, Efe et al. [17] indicated that there was no official green or sustainable built environment evaluation system in Türkiye. The authors discussed he importance of establishing a local certification system for Türkiye.

Incentives and tax reductions are crucial not only for all sectors but for EEB sector. For example, these financial incentives foster sustainable and energy-efficient development by encouraging practices like the production of renewable energy for buildings. Additionally, they serve as an effective tool for governments to achieve their long-term energy, environmental, and climate policy goals [18]. However, incentives and tax reductions are closely related to the energy policies of countries. Therefore, the review of financial incentives is typically country-specific. For instance, Rana et al. [19] assessed the financial incentives for EEBs in Canada. The authors found significant regional variations in the availability of financial incentives for both residential and commercial buildings, even within the same country. Sebi et al. [20] compared the policy strategies of Germany, France, and the US regarding retrofitting approaches for EEBs. Liu et al. [21] reviewed policies in China for EEBs while Trencher and van der Heijden [22] followed the results of retrofit policies in existing buildings of New York, Sydney and Tokyo. Most of the review papers have focused on incentives and tax reductions in developed countries, such as those in European nations and the U.S. On the other hand, it is proven that a systematic review of existing retrofit policies on EEBs is the basis of improving the policy effectiveness [23]. Therefore, a systematic review examining the financial incentives of developing countries, with a particular focus on Türkiye, and comparing these incentives to those of developed countries, is essential. To this aim his paper reviews the EEB retrofit policies and financial incentives in Türkiye, a developing country, and compares them with those of developed countries. The importance of this paper is to explore the crucial link

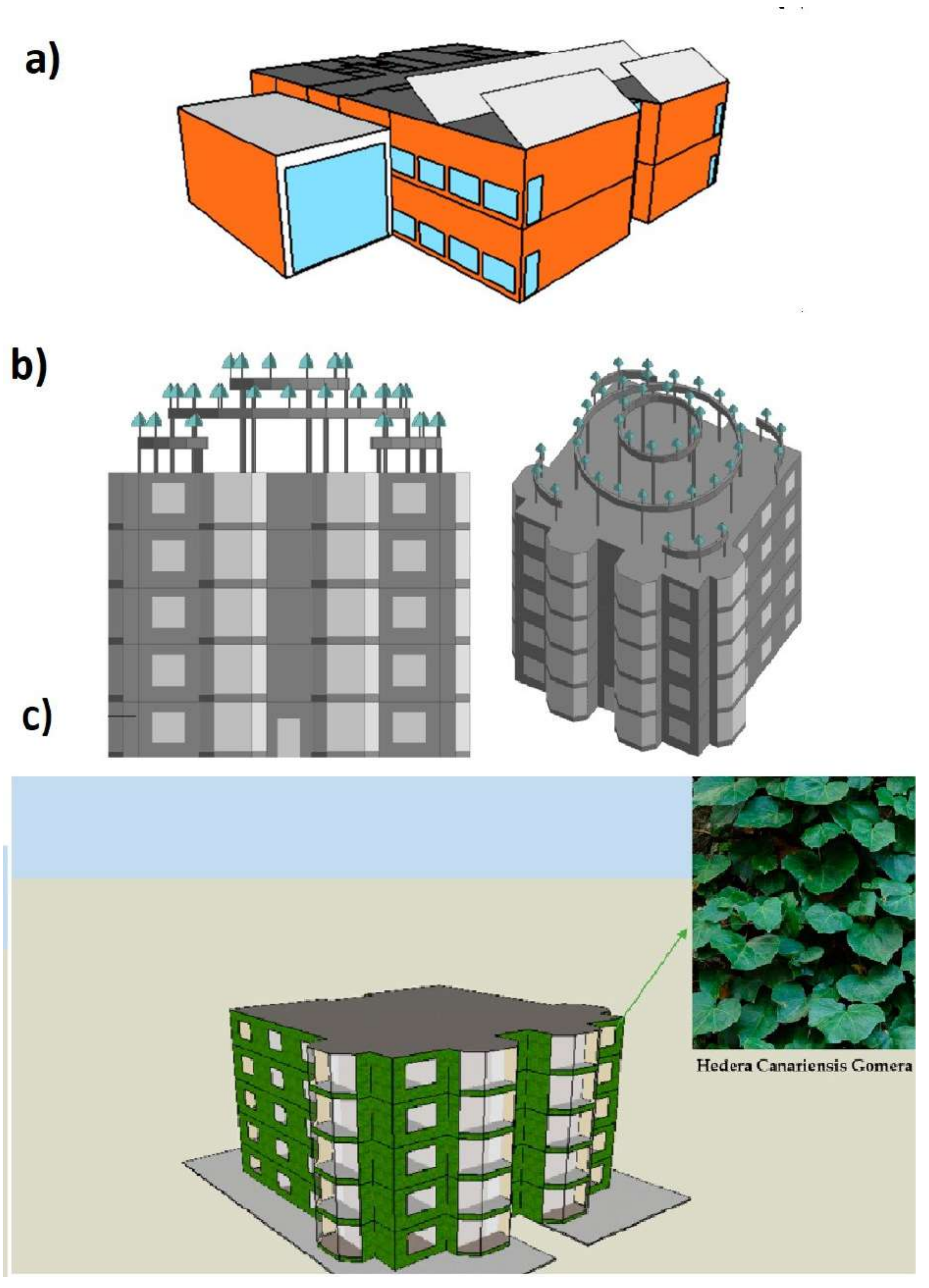

Figure 3. The simulations for EEB applications in Turkiye

between climate change, energy efficiency, and sustainable construction, offering key insights into how tax incentives can promote the adoption of energy-efficient building practices. By focusing on Türkiye, this paper provides a localized analysis while drawing comparisons to international best practices, which can help inform policy improvements and facilitate a wider shift toward sustainable construction. The study highlights the role of financial incentives—such as property tax reductions, investment credits, and VAT exemptions—in overcoming the financial challenges associated with the EEB adoption. The remainder of the paper is structured as follows: The first section examines financial incentives for EEB in Türkiye. Next, the paper compares the financial EEB incentives in Türkiye with those of developed countries. Finally, the authors propose recommendations for improving these incentives.

2. Methodology

Figure 4 presents the flowchart of the study. The first step involves conducting a systematic review of the EEB. A comprehensive search is performed using databases such as ScienceDirect, Google Scholar, and others. The studies selected for inclusion focus either fully or partially on EBB incentives. Using keyword searches, such as "EBB incentives" "sustainability and financial incentives" and "sustainable building incentives" and “tax reduction for EBB”, a total of 251 publications were retrieved for the study.

Figure 4. Flow chart of the research

However, only 93 publications are selected for this study according to 8 different financial criteria.

These financial incentive parameters for the EBBs are;

- Subsides
- Credit Incentives
- Grants
- Tax Incentives
- Exemptions
- Accelerated Depreciation
- Discounts
- Disincentives

Subsequently, these parameters are published for Türkiye and then compared with those of selected developed countries.

3. Financial Incentives for EEB in Türkiye

The concept of the EBBs, which first emerged in Türkiye in the early 2000s, has made significant progress over the years through important steps taken. During this 25-years period, Türkiye has implemented various legal regulations to support sustainability goals in the globally important fields of "Energy-efficient Buildings" and "Sustainable Structures." Government incentives, tax reductions, and financial support have played a crucial role in promoting the widespread adoption of energy-efficient building practices. In Türkiye, several legal regulations have been implemented to reduce energy losses and obtaining energy-efficiency in buildings. For instance; the "Energy Efficiency Law No. 5627 [24]", the "Thermal Insulation Regulation for Buildings [25]", the "Energy Performance in Buildings Regulation [26] ", the "Regulation on Efficient Use of Energy Resources and Energy [27]", the "Energy Efficiency Strategy Document and Buildings [28]" and the "Energy-efficient Certification Regulation for Settlements [29]".

The "National Energy-efficient Certification System (YeS-TR)," which was the first national implementation prepared for the certification of energy-efficient buildings, was implemented under the "Regulation on Energy-efficient Certification for Buildings and Settlements" published in the Official Gazette of Türkiye in June 2022. While this regulation is the only one specifically addressing EEBs, various other institutions, independent entrepreneurs, and universities in Türkiye have conducted various efforts in addition to the legal regulations. These efforts have led to the development of drafts for EEB certification systems.

On the other hand, starting from January 1, 2025, this practice will be expanded to all buildings over 2,000 square meters, and it will be mandatory for at least 10% of the energy used to be sourced from renewable energy in Türkiye. For large buildings, it has been made mandatory to construct in accordance with the nearly zero-energy building (nZEB) concept. The energy performance of buildings is required to be at least Class B.

In Türkiye, there is no direct tax incentive for EEBs. Although there is no specific regulation in Turkish tax legislation regarding EEBs, there are some regulations that cover buildings related to energy efficiency and renewable energy, which affects energy-efficient building investments.

3.1. Exemption for Tradesmen in the Sale of Excess Electricity

Under the Article 193 of the Income Tax Law (GVK), regulations are in place for the production of electricity from renewable energy sources, in line with the "Electricity Market Law" No. 6446. With the enactment of Law No. 7103, an additional subparagraph (9) was added to the first paragraph of the Article 9, which regulates the tradesmen exemption of Article 193.

The new provision states the followings:

"In accordance with the Electricity Market Law No. 6446, activities that can be carried out without a license for the purpose of generating electricity from renewable energy sources, individuals who sell excess electricity produced from a single facility with a maximum installed capacity of up to 10 kW (including 10 kW), installed on the roofs and/or facades of residential buildings they own or rent (including those installed for the common electricity needs of the main property by the co-owners) to the last-resort supply company. (The provision of the third paragraph shall not be considered in the application of this subparagraph.)".

The relevant provision is explained in the 303rd Series of the Income Tax General Communiqué, published in the Official Gazette No. 30448 on June 11, 2018.

With the Law No. 7420, published in the Official Gazette No. 32008 on November 9, 2022, which amends the Income Tax Law and certain other laws and decrees, the expression "25 kW" in paragraph (9) of the first paragraph of Article 9 of the Income Tax Law No. 193, dated December 31, 1960, was changed to "50 kW."

Moreover, those who produce excess electricity with an installed capacity of up to 50 kW (including 50 kW) on the roofs of properties they own or rent, from sources within the scope of unlicensed activities, and sell the excess electricity to the last-resort supply company are exempt from taxes.

Additionally, under the Article 17/4-a of the VAT Law, the deliveries and services made by tradesmen who are exempt from taxes according to the Income Tax Law are also exempt from the VAT.

3.2. Regulations Introduced in the Stamp Duty Law and the Fees Law Regarding Procedures for Thermal Insulation and Energy Savings in Buildings

The procedures related to thermal insulation and energy savings in buildings, outlined in the Stamp Duty Law No. 488 and the Fees Law No. 492, have been exempted from taxes on documents related to these matters.

3.3. Deduction of Thermal Insulation and Energy Saving Expenses as Business Expenses for Determining Commercial Income

In the Article 40, paragraph 1, subparagraph 7 of the Income Tax Law No. 193 titled "Deductible Expenses", following statement is valid:

"7. *(Amended: 24/12/1980-2361/29) Depreciation amounts allocated according to the provisions of the Tax Procedure Law, (Added: 24/6/1994-4008/24) (...)38 (Additional provision: 15/7/2016-6728/14) (Expenses related to thermal insulation and energy-saving measures that increase the economic value of the property included in the business can be directly deducted in the year they are incurred.)*"

The principles of this regulation were outlined in the Income Tax General Communiqué No. 295 published in the Official Gazette No. 29927 on December 23, 2016.

With this legal amendment, the phrase "*Expenses related to thermal insulation and energy-saving measures that increase the economic value of the property included in the business can be directly deducted in the year they are incurred*" was added to the article on deductible expenses in the Income Tax Law. This change allows these expenses, which were previously added to the property cost and depreciated over time, to now be directly deducted as an expense in the year they are made.

3.4. Deduction of Expenses Related to Thermal Insulation and Energy Saving Measures in Determining the Net Amount of Real Estate Income

In the Income Tax Law No. 193, under Article 74 - Expenses:

"Expenses: Article 74 – (Amended first paragraph: 24/12/1980-2361/51) In order to determine the net income, expenses listed below are deducted from gross income, excluding those related to exempt gross income according to Article 21:

6. Depreciation of leased property and rights (The depreciable value, if known, is the cost price; if unknown, for buildings and land, it is the tax value, and for other assets, it is the market value determined according to the third item of Article 267 of the Tax Procedure Law), and expenses made by the lessor that are aimed at increasing the economic value of the real estate, such as thermal insulation and energy-saving measures (If these expenses exceed the limit set in Article 313 of the Tax Procedure Law within a calendar year, they may be considered as part of the cost)."

When the real expense method is selected for the declaration of real estate income, thermal insulation and energy-saving expenses, which enhance the economic value of the property, can be added to the property's cost and depreciated over time.

With the amendments introduced by the Law No. 6745, the change in Article 74 of the Income Tax Law allows for these expenses, provided they do not exceed the depreciation limit specified in Article 313 of the Tax Procedure Law. In this case, the entire amount of the expenses, excluding those related to exempt gross income, may be directly deducted as an expense in determining the net income.

However, if the expenses exceed the depreciation limit specified in Article 313 of the Tax Procedure Law, the entire amount of the expenses, excluding those related to exempt gross income, may either be directly written off as expenses or added to the property's cost and depreciated.

4. Comparison of Financial Incentives with the Developed Countries

This section summarizes financial incentives in developed countries and compares these incentives with the Türkiye.

4.1 United States of America

Looking at the global scene, it is evident that the United States offers the most incentives for energy-efficient buildings. Different states in the U.S. have various incentive programs.

For example, New York and Maryland have legal provisions that include tax deductions for energy-efficient buildings. In Maryland, energy-efficient building owners receive an 8% income tax deduction. In New York, both public and private sector buildings are incentivized through a "energy-efficient building grant" program, aimed at making buildings more energy-efficient and environmentally friendly. Additionally, building owners and tenants who meet specific energy-efficient building criteria enjoy advantages such as corporate tax, income tax, and insurance tax deductions. One of the key criteria is that energy consumption in new buildings should not exceed 65% of the permitted level, while for renovated buildings, it should not exceed 75% [30].

In Oregon, energy-efficient building incentives are offered in the form of exemptions from property taxes. The support is provided through a credit fund to help cover the building costs in the region.

In Cincinnati, Ohio, newly constructed buildings certified at the LEED Silver level are exempt from property taxes for 15 years. Renovations also enjoy up to $500,000 in exemptions for 10 years. For LEED Platinum-certified buildings, there is no upper limit on the tax exemption.

4.2. United Kingdom

The United Kingdom, a country with heavy rainfall, aimed to turn this situation into an advantage by enacting the "BS-8515" standard in 2009. This law covers the design, installation, and maintenance of rainwater harvesting systems, which allow rainwater to be added to household water supplies. In the first year, a 100% tax deduction is applied to this system. Additionally, a 5% tax deduction is offered for solar panels. There are also benefits for individuals who generate electricity. Those with solar panels on their roofs can sell the excess energy they produce to companies.

From the beginning of 2022 until March 31, 2027, the UK aims to provide approximately £280 million in tax incentives to improve residential energy efficiency. To achieve these goals, the government plans to apply a reduced Value Added Tax (VAT) rate for materials that improve energy efficiency in residential buildings. Specifically, energy-saving materials such as insulation, heat pumps, and solar panels will be subject to a 0% VAT rate until March 31, 2027. Additionally, the stamp duty paid for a home will be adjusted based on its energy efficiency performance. As a result, homes with better energy performance will have lower stamp duty [31].

4.3. Australia

In Australia, there is an organization called GBCA (Energy-efficient Building Council of Australia) that examines and certifies energy-efficient buildings. One of its primary roles in the energy-efficient building process is setting standards for energy-efficient buildings using various rating tools. To establish these standards, the GBCA developed the Energy-efficient Star rating system in 2002. Today, the Energy-efficient Star rating system continues to maintain its popularity and is becoming increasingly widespread in the construction industry.

Currently, there is no systematic approach for tax exemptions specifically for energy-efficient buildings in Australia. However, federal tax systems provide tax exemptions for activities related to environmental protection [32].

4.4. France

In France, various measures have been implemented to encourage households to carry out energy efficiency renovations. These measures include tax reductions, subsidies, and zero-interest bank loans. The tax credit system allows taxpayers to deduct part of the renovation costs from their income taxes. The discount rate varies depending on the equipment used; for example, it is 15% for double glazing, 25% for roof and wall insulation, 25% for heating system modernization, 40% for renewable energy use, and can vary based on the number of individuals in the household [30].

The French government introduced the sustainable development tax credit in 2005 to enhance energy efficiency in private residences. This tax advantage was later restructured as a tax credit for energy transition. The program allows private homeowners in France to benefit from this tax credit, offering up to 30% reimbursement of their expenses if they opt for energy efficiency renovations or heating system modernization. In practice, the tax authorities apply these credits based on documentation of the expenses incurred. However, this tax advantage cannot be used for a second home and is limited to 30% of the total expenses for energy renovation works. This amount should not exceed 8,000 euros per person in the household, and 16,000 euros for couples. Additionally, an extra 400 euros can be reimbursed for each child in the household. This tax credit can also be applied to investments in new buildings and can be used for improvements to insulation and/or heating systems.

4.5. Spain

Since 1990, Spain has implemented various normative and financial measures aimed at improving energy efficiency in all types of housing, including single-family homes. In some municipalities, when solar energy systems are installed in homes (except new ones), property tax rates are reduced by up to 50%. Additionally, buildings or facilities that include solar energy-based heating or electrical systems benefit from up to 95% tax reductions on building, infrastructure, and installation taxes, with these tax reductions being applied by local governments. Local authorities also offer property tax reductions for buildings that include solar energy or photovoltaic systems.

The Spanish government also provides personal income tax credits for residential energy efficiency renovations. This tax credit mechanism contributes financially to housing energy efficiency initiatives under the existing national regulations. The contribution is available for homeowners, with this advantage applied to no more than 30% of the total expenses for energy efficiency renovations. The maximum amount for each person in the household is set at 8,000 euros, and for couples, it is 16,000 euros. Additionally, an extra 400 euros can be reimbursed for each child in the household. Furthermore, in addition to energy renovation works, Spain offers a 20% additional tax reduction for improvements to insulation and heating-cooling systems in buildings.

4.6. Germany

Hamburg, Germany's second-largest city, became the first to develop a comprehensive energy-efficient roof strategy to mitigate the effects of climate change. A budget of 3 million euros was allocated for the development and implementation of this strategy. The program, launched in 2015, was originally set to end in 2019 but has been extended until 2024. It aims to increase the surface area of energy-efficient roofs using various tools. The program covers up to 40% or more of the construction costs for energy-efficient roofs between 20 and 100 square meters. For non-residential buildings, a maximum of 50,000 euros per roof is provided. Hamburg also plans to provide up to 100,000 euros in support for energy-efficient roofs on school buildings. In 2019, Hamburg allocated 7.5 million euros for the construction of energy-efficient roofs on schools.

To increase energy efficiency in buildings, the German government has offered tax advantages to homeowners, which can be recognized as tax deductions on income tax returns. This regulation, which came into effect in 2020, targets homeowners of properties older than 10 years. The deductions are reflected in income tax returns. However, in order to benefit from this deduction, the homeowner must reside in the property. Additionally, the efficiency improvements must be completed by January 1, 2030, at the latest.

Under this incentive, homeowners can benefit from tax deductions when they replace or renovate windows, doors, heating systems, update ventilation equipment, insulate walls, roofs, floors, and ceilings, or install a digital system to optimize energy performance. The tax deduction is limited to 20% of the total expenses for these activities. The right to the deduction is spread over three years, with 7% applied in the first year, 7% in the second year, and 6% in the following year. Additionally, there is a cap of 40,000 euros for the maximum deduction amount. If the property is rented out or assigned to someone else for free, the tax deduction cannot be claimed. The German government expects these tax incentives to save 3.4 million tons of carbon by 2030 [30].

4.7. Canada

In Canada, various energy-efficient building incentives are provided by the Canada Mortgage and Housing Corporation (CMHC), banks, public utilities (such as the Power Smart Home Loan provided by FortisBC), and municipalities, with most of the incentives being 5-year loan programs. These loans are available for the construction of new homes, renovations of commercial buildings, and upgrading of individual systems. For example, in Manitoba, there is a Residential Earth Power Loan for cold climate air-source heat pumps.

Tax incentives in Canada are generally based on exemption models rather than discounts. For instance, British Columbia (BC) offers a 100% property tax exemption for certain devices and energy upgrades. Quebec (QC) offers the RenoVert tax credit for energy renovations in homes. Among the various financial incentives, tax incentives have been found to be the most effective method in terms of both environmental and economic impact.

In Canada, there are numerous grants available at both the provincial and municipal levels. Most of these grants are provided through public utility companies in different provinces. In the residential sector, discounts offered by municipalities in Alberta (AB) are common. In provinces such as BC, QC, ON, and Newfoundland and Labrador, public utilities more widely provide discounts [19].

4.8. Norway

Norway is another country that has developed a energy-efficient building certification system. In the early 2000s, Norway used the EcoProfile certification system, but it has since been replaced by BREEAM-NOR, which was developed in 2011. BREEAM-NOR is the national adaptation of the BREEAM rating system that originated in the United Kingdom.

In addition to being a safe and livable country, Norway stands out for its ambitious renewable energy goals and efforts to achieve these targets. Some of the key renewable energy incentives implemented in Norway include indirect taxes, energy funds, carbon dioxide taxes, and premiums for energy-efficient certification schemes, tariff guarantees, and other exemptions.

Norway offers various incentives aimed at energy conservation. The Norwegian Investment Support combines investment subsidies and financial incentives to promote renewable energy sources for electricity generation. Wind and biomass (heat production) investments can benefit from subsidies, which can reduce total investment costs by up to 25% and 100%, respectively. Wind energy promotion projects can receive subsidies covering up to 100% of the investment costs. Additionally, wind energy investments are exempt from both investment taxes and energy production taxes [32].

Table 1 summarizes financial incentives for energy-efficient buildings in selected developed countries and Türkiye.

5. Suggestions

Energy efficiency and renewable energy regulations related to buildings in Türkiye are currently limited, highlighting the need for new policies that provide financial advantages for energy-efficient buildings, in alignment with global best practices. Therefore, this section presents several suggestions for Türkiye.

- Energy-efficient-certified or LEED-certified buildings or complexes could be granted the right to receive free advertising through public channels.

Table 1. Financial Incentives for Energy-efficient Buildings in Selected Developed Countries and Türkiye

	Subsides	Credit Incentives	Grants	Tax Incentives	Exemptions	Accelerated Depreciation	Discounts	Disincentives
Türkiye	✓	NC	✓	✓	NC	NA	✓	NA
US	✓	✓	✓	✓	✓	✓	✓	✓
UK	✓	✓	✓	✓	✓	✓	✓	✓
Australia	✓	✓	✓	✓	✓	✓	✓	✓
France	✓	✓	✓	✓	NC	NC	✓	✓
Spain	✓	✓	✓	✓	✓	NA	✓	NC
Germany	✓	✓	✓	✓	✓	✓	✓	NC
Canada	✓	✓	✓	✓	✓	✓	✓	✓
Norway	✓	✓	✓	✓	✓	✓	✓	✓

NA: Not available and NC: Not common

- There is a need for regulations that will provide directly financial advantages for energy-efficient buildings, taking into account practices from other countries.
- The requirement for the use of renewable energy in buildings, currently set at a minimum of 10% in 2025, could be gradually increased in accordance with the latest regulations.
- The exemption for buildings rented out as residential under Article 21 of the Income Tax Law could be extended and amended to include energy-efficient buildings by expanding its scope and limits.
- Similar to the LEED certification system, VAT reductions could be applied for the use of regional materials in construction, and insurance discounts could be provided for employing local workers.
- Individuals undertaking or owning the construction of energy-efficient buildings can benefit from exemptions provided for buildings constructed under Investment Incentive Certificates.
- Under the Real Estate Tax Law No. 1319, tax reductions, exemptions, and tax credits for energy-efficient buildings could be introduced by considering the practices of other countries.

- To encourage compliance with energy efficiency improvements, disincentives such as carbon taxes could be applied to those who do not meet established standards. Additionally, higher rates of environmental and cleanliness taxes could be applied to non-compliant parties.
- The exemptions provided for buildings constructed under the Investment Incentive Certificate could be extended to individuals involved in the construction of energy-efficient buildings.
- In technology development zones, the incentives for the exemption of income from software and R&D activities could also be applied to energy-efficient building construction to promote sustainable buildings.
- Under the Value Added Tax Law, VAT exemptions could be granted on new machinery and equipment used for R&D, innovation, and design activities related to energy-efficient building construction, which would further encourage energy-efficient building investments.
- Other potential incentives include providing tax relief on energy, water, and renewable resources for projects that use them efficiently, reducing environmental and cleanliness taxes for projects that recycle waste materials, VAT exemptions on energy sources and equipment used in construction, applying low or no tax on imported building materials, income and corporate tax reductions for investors, and providing workforce support for construction projects.
- A key point in tax incentives is that these incentives must be sustainable and applicable in the long term.

6. Conclusion

This paper presents an in-depth comparative analysis of the financial and tax incentives available for energy-efficient buildings in Türkiye and across the globe. It emphasizes the growing significance of adopting energy-efficient building practices as a means of addressing climate change and supporting sustainable development goals. While numerous developed countries provide a wide range of incentives, such as subsidies, tax exemptions, low-interest loans, and grants, Türkiye has made commendable progress in promoting energy-efficient building practices through similar measures, though some challenges remain.

Developed countries like Germany, Spain, and Canada have implemented extensive financial mechanisms to advance energy-efficient buildings, aligning these efforts with broader climate policies. In contrast, Türkiye is gradually increasing its support in this area. The results indicate that the success of these incentives is not only influenced by their diversity and accessibility but also by the degree of awareness and active participation from both governmental and private sectors.

For Türkiye to further promote sustainable construction, it could benefit from expanding its financial incentives, introducing more robust tax incentives, and ensuring better synchronization between public policy and industry requirements. As energy-efficient building practices continue to develop, it is crucial for policymakers worldwide to collaborate and exchange knowledge in order to establish a conducive environment for sustainable construction.

In conclusion, this paper highlights the importance of sustained investment in financial and tax incentives as key drivers for energy-efficient building adoption. By improving the accessibility and breadth of these incentives, countries can accelerate their transition to a more sustainable and environmentally-friendly built environment.

References

[1] C. Turhan, S. Simani, and G. Gokcen, "Development of a personalized thermal comfort driven controller for HVAC systems," Energy, vol. 217, p. 121568, 2021, doi: 10.1016/j.energy.2021.121568.

[2] C. Turhan and G. Gokcen-Akkurt, "Assessment of thermal comfort preferences in Mediterranean climate: A university office building case," Thermal Science, vol. 22, no. 5, pp. 2177–2187, 2018, doi: 10.2298/TSCI171231267T

[3] S. Yildiz, "Determining wind energy potential using geographic information system functions: a case study in Balıkesir, Turkey," Applied Sciences, vol. 13, no. 16, p. 9183, 2023, doi: 10.3390/app13169183.

[4] A. M. Fathy, M. I. Abdelhady, and F. Juma, "The architectural tools in reducing energy consumption of residential buildings in hot countries," Int. J. Appl. Eng. Res., vol. 15, pp. 135–143, 2020, Doi: 10.1556/Pollack.8.2013.3.15

[5] T. Liu, L. Chen, M. Yang, M. Sandanayake, P. Miao, Y. Shi, and P.-S. Yap, "Sustainability considerations of energy-efficient buildings: A detailed overview on current advancements and future considerations," Sustainability, vol. 14, no. 21, p. 14393, 2022, doi: 10.3390/su142114393.

[6] A. O. Adewolu, "LEED-certified building: Advancing sustainable development goals through energy-efficient design," Int. J. Sci. Acad. Res., vol. 5, no. 2, pp. 6964–6971, 2024. [Online]. Available: https://www.scienceijsar.com/article/leed-certified-building-advancing-sustainable-development-goals-through-energy-efficient-design

[7] K. R. Kareem and R. K. Pandey, "Cost effectiveness of energy-efficient buildings," Int. J. Curr. Eng. Technol., vol. 3, no. 4, pp. 1522–1527, 2013. [Online]. Available: http://inpressco.com/category/ijcet

[8] M. Hu and M. Skibniewski, "Energy-efficient building construction cost surcharge: An overview," J. Archit. Eng., vol. 27, no. 4, p. 04021034, 2021. doi: 10.1061/(ASCE)AE.1943-5568.0000506

[9] C.-Y. Sun, Y.-G. Chen, R.-J. Wang, S.-C. Lo, J.-T. Yau, and Y.-W. Wu, "Construction cost of energy-efficient building certified residence: A case study in Taiwan," Sustainability, vol. 11, no. 8, p. 2195, 2019. doi: 10.3390/su11082195

[10] O. T. Bişkin and A. Çifci, "Forecasting of Turkey's electrical energy consumption using LSTM and GRU networks," BSEU J. Sci., vol. 8, no. 2, pp. 656–667, 2021. doi: 10.35193/bseufbd.935824

[11] Republic of Türkiye Ministry of Energy and Natural Resources. (2022).

Türkiye National Energy Plan. Retrieved from https://www.enerji.gov.tr.

[12] C. Turhan and S. Ghazi, "Energy consumption and thermal comfort investigation and retrofitting strategies for an educational building: Case study in a temperate climate zone," J. Build. Des. Environ., vol. 2, no. 2, p. 16869, 2023. doi: 10.37155/2811-0730-0201-7

[13] Y. A. S. Saleh, G. G. Akkurt, and C. Turhan, "Reconstructing energy-efficient buildings after a major earthquake in Hatay, Türkiye," Buildings, vol. 14, no. 7, p. 2043, 2024. doi: 10.3390/buildings14072043

[14] C. Turhan, C. Carpino, M. A. C. Austin, M. F. Özbay, and G. G. Akkurt, "Impact of energy-efficient wall and roof applications on energy consumption and thermal comfort for climate-resilient buildings," in 19th SDEWES Conference Proceedings, Rome, 2024. [Online]. Available: https://iris.unical.it/handle/20.500.11770/372798.

[15] H. Erbıyık, T. Çatal, S. Durukan, D. G. Topaloğlu, and Ü. Ünver, "Assessment of Yalova University Campus according to LEED V.4 certification system", ERT, vol. 4, no. 1, pp. 18–28, 2021, doi: 10.35208/ert.812339.

[16] A. Bahadiroğlu, A. Y. Koç, E. Parlak, N. Larsson, W. Kujawski, and U. Unver, "Sustainable building evaluation: a case study," Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, vol. 44, no. 2, pp. 3149–3163, 2022, doi: 10.1080/15567036.2022.2061646.

[17] O. Efe, R. Özdemir, S. Işik, İ. Durmuş, and Ü. Ünver, "Assessment of the Yalova University Engineering Faculty Building using the B.E.S.T. green building certification system," Int. J. Sustainable Energy, vol. 41, no. 11, pp. 1759–1777, 2022, doi: 10.1080/14786451.2022.2109027.

[18] J. Ye, F. Yang, J. Wang, S. Meng, and D. Tang, "A literature review of energy-efficient building policies: Perspectives from bibliometric analysis," Buildings, vol. 14, no. 9, p. 2607, 2024. doi: 10.3390/buildings14092607

[19] A. Rana, R. Sadiq, M. S. Alam, H. Karunathilake, and K. Hewage, "Evaluation of financial incentives for energy-efficient buildings in Canadian landscape," Renewable and Sustainable Energy Reviews, vol. 135, p. 110191, 2021. doi: 10.1016/j.rser.2020.110191

[20] C. Sebi, S. Nadel, B. Schlomann, and J. Steinbach, "Policy strategies for achieving large long-term savings from retrofitting existing buildings," Energy Efficiency, vol. 12, no. 1, pp. 89–105, 2019. doi: 10.1007/s12053-018-9661-5

[21] G. Liu, Y. Tan, and X. Li, "China's policies of building energy-efficient retrofit: A state-of-the-art overview," Building and Environment, vol. 191, p. 107558, 2020. doi: 10.1016/j.buildenv.2020.107558

[22] G. Trencher and J. van der Heijden, "Instrument interactions and relationships in policy mixes: Achieving complementarity in building energy efficiency policies in New York, Sydney, and Tokyo," Energy Research & Social Science, vol. 54, pp. 34–45, 2019. doi: 10.1016/j.erss.2019.03.002

[23] U. G. D. Madushika, T. Ramachandra, G. Karunasena, and P. A. D. S. Udakara, "Energy retrofitting technologies of

buildings: A review-based assessment," Energies, vol. 16, no. 13, p. 4924, 2023. doi: 10.3390/en16134924

[24] Republic of Turkey. (2007). *Energy Efficiency Law No. 5627*. Official Gazette No. 26510, dated May 2, 2007. Retrieved from https://www.mevzuat.gov.tr/

[25] Republic of Turkey Ministry of Environment and Urbanization. (2008). Thermal Insulation Regulation for Buildings. Official Gazette, Issue No. 27019. Retrieved from https://www.resmigazete.gov.tr/eskiler/2008/11/20081105-5.htm

[26] Republic of Turkey Ministry of Environment and Urbanization. (2010). Energy Performance in Buildings Regulation. Official Gazette, Issue No. 27425. Retrieved from https://www.resmigazete.gov.tr/

[27] Republic of Turkey Ministry of Energy and Natural Resources. (2008). Regulation on Efficient Use of Energy Resources and Energy. Official Gazette, Issue No. 27035. Retrieved from https://www.resmigazete.gov.tr/

[28] Republic of Turkey Ministry of Energy and Natural Resources. (2012). Energy Efficiency Strategy Paper 2012–2023. Official Gazette, Issue No. 28215. Retrieved from https://www.eie.gov.tr/

[29] Republic of Turkey Ministry of Environment, Urbanization and Climate Change. (2022). *Regulation on Energy-efficient Certificates for Buildings and Settlements*. Official Gazette, Issue No. 31864. Retrieved from https://www.resmigazete.gov.tr/eskiler/2022/06/20220612-2.htm

[30] Ş. A. Koç and A. Çevik, Eds., Issues on sustainability, economics & history, 1st ed. IJOPEC Publication Limited, 2023. [Online]. Available: https://www.ijopec.co.uk.

[31] O. Avcı, "Energy-efficient building tax incentives: Selected country cases and implications for Türkiye," in Issues on sustainability, economics & history, 1st ed., Ş. A. Koç and A. Çevik, Eds., IJOPEC Publication Limited, 2023, pp. 71–90. [Online]. Available: https://www.ijopec.co.uk.

[32] S. Özdemir, "Seçilmiş bazı ülkelerde yeşil bina vergi teşvikleri çerçevesinde Türkiye için öneriler," Vergi Raporu, no. 290, pp. 70–85, Kasım 2023.

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