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The Use of Passive House Standards in Historic Buildings and Its Impact on Facade Design

Tarihi Binalarda Pasif Ev Standartlarının Kullanılması ve Cephe Tasarımına Etkisi

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Abstract: Historical buildings are offered to people with different functions in today's conditions. In these buildings, it is important to ensure the thermal comfort of the users and to reduce the heating/cooling costs with energy savings. It has been proven with examples from the world that it can be much more efficient to restore historical buildings with passive house standards, a system that has proven itself in the studies to be carried out. The restorations made in these buildings aim to investigate the effect of the possible changes to be made on the facade on the aesthetics and value of the historical buildings. The materials used and the changes to the façade are discussed in this sense. The effects of the major changes made on the façade are presented due to the examination of seventeen different buildings. The research results indicate that changes have been made in the facades of buildings to transform the interior into a more comfortable and energy-efficient space. There are many historical buildings in Turkey. Thanks to this construction concept, structures that provide comfort in terms of thermal and air quality inside and ensure energy efficiency can continue to be used. In order to achieve energy efficiency in restoration projects, a preliminary analysis can be conducted by working according to passive house rules. Thus, it is possible to renew the historical buildings that are repurposed and continue to be used in today's conditions without compromising their aesthetics. With this study, it is aimed to use passive house standards in historical buildings that are not included in the literature, and to be an example for new researches and areas to be applied.

Structured Abstract: Historical buildings can continue their activities and serve other functions as structures that continue to be used in today's conditions. The heating and cooling conditions of these buildings today are coal, natural gas, etc. It is expected that it will meet its energy needs with sustainable methods, not the way it was used in the past with fossil fuels. The reason for this is that the Passive House construction concept, which has been implemented due to the fact that fossil fuels are running out and foreign dependency exists in most countries, provides sustainable solutions in the heating and cooling systems of spaces with renewable energy and methods that can be passively included. The aim of this study is to evaluate the results of the changes in the facades by making an analysis of the transformation of historic buildings into Passive House systems

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according to the laws that allow changes to historical buildings depending on the country. The positive and negative advantages of applying the passive house concept in historical buildings as well as in every building were evaluated by discussing the damage to the historical structure or aesthetically good solutions by making changes to the facade. The absence of studies on the concept of passive houses in historical buildings in the literature also includes a preliminary study to be brought to the literature. In the study, all buildings whose construction was completed until the 1900s were selected. These buildings are seventeen in total and most of them are located in the northern European region. The changes made in the facades obtained with passive buildings are evaluated as wall material, window, roof and insulation. In some buildings, the exterior does not change at all, while in some historical buildings, there are major changes. Aesthetic concerns such as the addition of an additional structure, the enlargement of windows, the newly added material thickness expands the exterior façade and the change of exterior material have emerged. The buildings in the study were selected from the buildings with passive house certificate. With the study, when historical buildings such as those in Turkey are re-functionalized in countries where there are a lot of historical buildings, it is expected to save on heating and cooling costs and provide less energy need in buildings considered as restaurants, residences and hotels. According to the results obtained from the study;

When examining the facades of historic buildings, it is seen that solutions have been made to ensure the energy efficiency of the structure by opening additional window area or closing the structure with additional glass areas to protect the heat. However, the most common changes have been made by making changes with triple glass and low-e glass in the windows. The roof, facade mass, and building size are constant, and it has been determined that the generally restored situations are adding exterior facade paint, adding insulation material inside, increasing wall thickness, and protecting building materials. Another important point to consider is the application of insulation towards the interior or exterior. Every new material applied to the exterior disturbs the integrity of the facade and causes damage to the historical structure. In this case, even if the interior space is reduced, insulation materials must be applied to the interior and the wall thickness must increase inside. Additionally, changes have occurred in the building facades by using natural wood materials instead of materials that harm the environment. In these cases, reducing the damage to the environment has been achieved, and energy conservation in the interior space has been facilitated.

The use of photovoltaic panels on facades is not evaluated within the scope of this study. Mechanical needs such as air conditioning units, photovoltaic panels, etc. used on facades disturb the visual aesthetics of historic buildings. Their use does not create an integrated appearance in the building unless the structures are designed according to these mechanical needs. However, their use on roofs for providing energy and hot water does not have as much of an impact on the overall building appearance and aesthetics as it does on facades. Therefore, it is seen that the use of photovoltaic panels or collectors on roofs can provide energy and hot water without significantly affecting the overall form of the building.

After this study, in order to achieve energy efficiency in all restoration projects, a preliminary analysis can be conducted by working according to Passive House rules. Thus, it is possible to renew the historical buildings that are repurposed and continue to be used in today's conditions without compromising their aesthetics.

Keywords: Architecture, building aesthetics, energy efficiency, façade design, historic buildings, passive house

Öz: Tarihi yapılar günümüz koşullarında farklı işlevler ile insanların hizmetine sunulmaktadır. Bu binalarda kullanıcıların ısıl konforunu sağlamak ve enerji tasarrufu ile ısıtma ve soğutma maliyetlerini azaltmak önemli yer tutmaktadır. Uygulaması yapılmış çalışmalar ile kendini kanıtlamış bir sistem olan “Pasif Ev” standartlarında tarihi yapıların restore edilmesinin çok daha verimli olabileceği dünyadan örnekler ile kanıtlanmıştır. Bu yapılarda yapılan restorasyonlar, cephede yapılacak olası değişikliklerin tarihi yapıların estetiğine ve değerine etkisinin araştırılmasını amaçlamaktadır. Kullanılan malzemeler ve cephede yapılan değişiklikler bu anlamda ele alınmıştır. Öncelikle yapıları değerlendirebilmek için tarihi yapıların bir araya getirilmesi ile on yedi bina bulunmuştur. On yedi farklı yapının incelenmesi sonucunda cephede yapılan büyük değişikliklerin etkileri ortaya konulmuştur. Araştırma sonuçları, bina cephelerinde, iç mekanı daha konforlu ve enerji verimli bir mekana dönüştürmek için değişiklikler yapıldığını göstermektedir. Türkiye'de birçok tarihi yapı bulunmaktadır. Bu konstrüksiyon konsepti sayesinde iç mekanda ısı ve hava kalitesi açısından konfor sağlayan, enerji verimliliği sağlayan yapılar kullanılmaya devam edilebilir. Restorasyon projelerinde enerji verimliliğinin sağlanması için pasif ev kurallarına göre çalışılarak ön analiz yapılabilir. Böylece yeniden işlevlendirilen ve günümüz koşullarında kullanılmaya devam eden tarihi yapıların estetik özelliklerinden ödün vermeden yenilenmesi mümkün olmaktadır. Bu çalışma ile literatürde yer almayan tarihi yapılarda pasif ev standartlarının kullanılması, uygulama yapılacak alanlarda ve yeni araştırmalara örnek olabilmesi hedeflenmiştir.

Anahtar Kelimeler: Mimarlık, bina estetiği, enerji verimliliği, cephe tasarımı, tarihi binalar, pasif ev

Introduction

Passive House is a building standard created with the aim of achieving energy efficiency and comfortable indoor environments within the building. These standards prioritize material selection that is accessible to everyone, thermal conductivity values, glass selection, and low-cost choices in construction concepts. If these structures are designed during the planning stage, they can provide up to 90% energy savings for heating and cooling compared to old buildings that have been previously constructed, and up to 75% compared to standard buildings built in recent times (Passive House Institute, 2018).

Passive House standards applied in buildings have different names according to their different characteristics. However, each standard adheres to the principles of Passive House (Classic). According to the Passive House (Classic) Standards (Passive House Institute, 2015);

• To achieve a comfortable indoor environment without any mechanical system, the maximum annual heating requirement should be 15 kWh/(m²a)

• Indoor comfort criteria be met during both winter and summer seasons.

• The thermal conductivity coefficient (U value) of exterior walls be below 0.15/(m²K).

• The U-value of windows and semi-transparent elements should be below 0.8 W/(m²K).

• Window frames be well insulated and low-e glass filled with argon or krypton gas be used to prevent heat transfer.

• Windows should be designed to be openable and equipped with natural ventilation capabilities.

• There be no thermal bridges,

• After the building is constructed, an airtightness test must be performed, and during a pressure test at 50 Pascal (both pressurized and depressurized), uncontrolled leakage from gaps should be less than 0.6 times the total volume of the house per hour.

• The total demand for primary renewable energy for all household applications (heating, hot water preparation, and electricity) should not exceed 60 kWh/(m²a).

According to the Passive House Plus Standards (Passive House Plus Sustainable Building, 2022);

• Based on and adhere to all of the Passive House Standard principles.

• The Passive House Plus standard is a new certification category designed to recognize on-site renewable energy production by passive buildings. It requires a minimum of 60 kWh/m²/yr of renewable energy production along with a maximum demand of 45 kWh/m²/yr for primary renewable energy.

• It is a new energy factor developed by the Passive House Institute for a future where electricity grids are entirely powered by renewable sources. This system, which will replace the use of fossil fuels, is designed to provide additional energy production to energy efficiency by using renewable resources.

According to the Passive House Premium Standards (Passipedia - The Passive House Resource, 2021);

• Based on and adhere to all of the Passive House Standard principles.

• The Passive House Premium standard, which is an even more advanced standard, requires 120 kWh/m²/year energy production and a maximum of 30 kWh/m²/year demand for renewable primary energy.

As part of these newly added systems, the first standard known as Passive House has been renamed to Passive House Classic. This standard has a maximum primary energy demand value of 60 kWh/m²/year without the need for renewable energy production.

There may be situations where Passive House standards, which can be applied not only to newly designed buildings but also to existing buildings, are not fully implemented. This is due to thermal bridges that are difficult to prevent from escaping from walls, connection points, or corners. Due to the existence of such buildings, the Passive House Institute has developed EnerPHit for certified energy upgrades with Passive House Components. The aim is to ensure that existing buildings comply with Passive House standards and improve their performance compared to previous usage conditions. However, their performance is lower than that of existing buildings that have been retrofitted with Passive House measures.

It has been proven that the measures taken with EnerPHit, as listed below, are particularly effective and can provide significant energy savings of between 75% to 90% even in existing buildings (Bastian, 2022);

• Improved thermal insulation

• Reduction of thermal bridges

• Significantly improved air tightness

• Use of high-quality Windows

• Highly efficient heat recovery ventilation

• Efficient heat generation

• Use of renewable energy sources.

The number of renovated buildings that have been strengthened according to the Passive House standards and components in four categories is shown in the Table 1, after the implementation of the building until 2022.

Table 1: List of Renovated Buildings with Passive House Certification by 2022.

	Passive House Refurbishment	Passive House Plus Refurbishment	Passive House Premium Refurbishment	EnerPhit
Detached house	12	2	-	40
Apartment	15	1	1	30
Educational building	2	-	-	5
Sport centre	2	-	-	-
Public Building	1	-	-	2
Office	7	2	-	5
Museum	1	-	-	-
Library	1	-	-	1
Hotel	-	-	-	2
Nursing home	-	-	-	1
S.market	-	-	-	2

The total number of buildings that have undergone Passive House (Classic) renovation is thirty-three, Passive House Plus renovation is five, Passive House Premium renovation is only one, and EnerPHit retrofit is eighty-eight, all of which have been renovated to ensure indoor comfort conditions and energy efficiency.

The joint work done with renovation includes installing new insulation in the floor, walls, and ceiling of the building. First, wall insulation is done, then windows are replaced and a ventilation system is installed, and the final step is roof insulation, heating system, and other measures to achieve the EnerPHit Standard (Steiger and Vahalova, 2019). In these works, triple glazed windows are installed and low-e glass filled with argon or krypton is applied. The aim in strengthening the windows is to reduce thermal bridges and optimize solar heat gains. For changes to be made in the existing structure's facade, the facade material and windows need to be processed simultaneously, and the possibility of thermal bridges needs to be checked. According to Vahalova and Krick (2016), when a layer of insulation is applied to the outer wall on the facade, thermal bridges still exist during installation. Additional insulation is also a cost-increasing factor. However, when additional insulation is applied on the facade, it causes swelling in the walls, so the position of the windows will be more inside the facade. Especially in smaller windows, this situation turns into a factor that hinders solar gain.

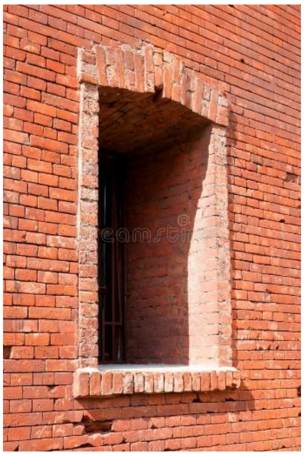

Figure 1: An example of a window being positioned on the inside due to the thickness of the building element in the facade (Dreamstime, 2023).

According to the EuroPHit project, which won an award in 2015, it is recommended to permanently seal the gaps that will occur when windows are installed at the same level as the exterior wall in the integrated frames of the windows. This recommendation suggests using windows with U values recommended for Passive Houses instead of standard frames (Krick, 2015).

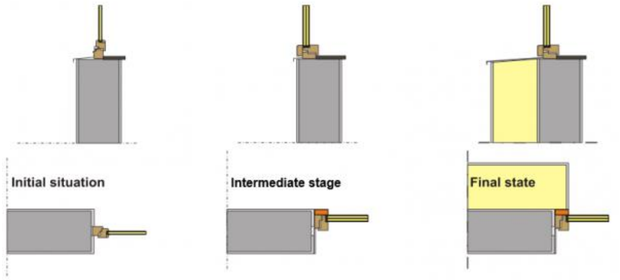

Figure 2: Detail of material thickness of the insulation material (Vahalova and Krick, 2016).

According to Krick, the method currently used of aligning windows to the middle of the wall results in the presence of thermal bridges, difficulty in sealing, and high costs for air tightness.

Another important factor is air tightness, which is caused by uncontrolled heat losses. Joints, areas where two materials meet, and other similar areas can cause unwanted heat losses. This problem also occurs in building facades when there is a significant difference between indoor and outdoor temperatures, causing heat losses. This lost air cannot be recovered, which is why it is also known as uncontrolled ventilation.

Air tightness has the following advantages (Passive House Institute, 2022):

• Prevention of building damages caused by moisture.

• Prevention of high heat losses due to infiltration.

• Improvement of sound insulation

• Improved indoor air quality

Adequate air tightness is based on the following:

• Use of demand-controlled ventilation

• The effectiveness of thermal insulation without air flow

According to Feist (2003), a study conducted in Nuremberg, in a cold climate, showed that a building renovated to Passive House standards achieved 85% energy efficiency. The modifications made to the building included using insulation materials in the roof and walls, replacing windows, and installing a solar collector system. The study demonstrated that the building did not experience significant leakage when compared to its previous state, achieving good results from an air-tightness report. Another study was carried out in Spain, a hot climate region, on the Centón house where renovation and reinforcement were made. The changes made to the building included:

• Reinforcement and insulation of foundation under the basement

• Roof improvement, including building, insulation, and air sealing.

• Improvement of external wall insulation and mitigation of thermal bridging.

• Installation of Passive House windows and their connection to the walls.

• Installation of a mechanical ventilation heat recovery system.

• Creating specifications for using interior spaces as a workplace or office.

• Replacing an old coal boiler with a heat pump.

The next step in the renovation plan is to implement renewable energy sources. The analyses conducted as a result of all these applications demonstrate that the heating demand has decreased by approximately 93% (Antón et al., 2016).

According to European Commission (2022), in order to achieve the energy reduction targets defined by the European Union for 2020 and 2030, all new building energy enhancements across Europe, including Turkey, must be strongly encouraged to achieve the EnerPHit energy efficiency level. Currently, structures such as factories, residences, offices, hospitals, and educational buildings continue to use depleted sources such as fossil fuels, including oil, coal, and natural gas, for energy, creating an energy source shortage in countries like Turkey. It is necessary to reduce external dependence and create a clean and sustainable environment by increasing the use of both Passive House standards and renewable energy sources in buildings. Moreover, there are examples of historical buildings that are still in use and can be renovated to create more useful and healthy spaces while achieving energy efficiency.

Passive House in Historic Buildings

A passive house is a type of home design that emphasizes energy efficiency and uses natural resources to minimize energy consumption. These homes are designed with factors such as building materials, window placement, and insulation quality in mind, in order to increase energy efficiency. Historic buildings are often not suitable for passive house standards because old building materials have low insulation efficiency and window placement can decrease energy efficiency. However, it is possible to apply passive house practices to historic buildings. Measures that can be taken include adding insulation, installing energy-efficient windows, utilizing natural heat sources, and installing energy-efficient hot water systems.

The techniques that can be applied to implement passive house practices in historic buildings include:

1. Insulation: The walls, roof, and floor of historic buildings should be retrofitted with insulation to increase energy efficiency and reduce vulnerability to outdoor weather conditions.

2. Windows: Energy-efficient windows should be installed in historic buildings, which will reduce heat loss and allow natural light to enter.

3. Natural heat sources: Historic buildings can take advantage of natural sources such as sunlight, wind, and humidity. Sunlight can provide natural heat and light to the interior of historic buildings.

4. Energy-efficient hot water systems: Energy-efficient hot water systems should be installed in historic buildings to save energy and reduce utility bills.

5. Ventilation systems: Suitable ventilation systems should be installed in historic buildings, which will help control humidity and pollution, and improve air quality.

These techniques can be implemented to increase the energy efficiency and comfort of historic buildings. In addition, aesthetic solutions that preserve the original features of historic buildings can also be found.

Insulation is one of the most important techniques among passive house practices for historic buildings. The following techniques can be applied to increase the insulation of historic buildings:

1. Wall insulation: The walls of historic buildings should be replaced with insulation on both the interior and exterior sides. This will reduce heat loss through the walls and minimize the impact of outdoor weather conditions.

2. Roof insulation: The roofs of historic buildings should be replaced with insulation on the interior side. This will reduce heat loss through the roof and minimize the impact of outdoor weather conditions

3. Floor Insulation: The ground of historical buildings should be modified by adding insulation underneath. This will reduce heat loss from the ground and minimize the impact of external weather conditions.

4. Double-glazed windows: Double-glazed windows should be installed in historical buildings. This will reduce heat loss and allow sunlight to enter the building.

These techniques can be applied to improve the energy efficiency of historical buildings. In addition to these, aesthetic solutions that preserve the original features of historical buildings can also be found. Using old building materials to add insulation, in particular, will help maintain the original appearance of historical buildings.

The materials used for insulation in historical buildings should be selected considering their characteristics and construction dates. The following materials can be used for insulation in historical buildings:

1. Adhesive Materials: Insulation materials added to the inside of walls and roofs with an appropriate adhesive provide insulation without damaging the original structure of historical buildings.

2. Surface Mounting Materials: Insulation materials that can be mounted on the exterior surface of historical buildings in a way that is not visible, enhance insulation and do not compromise the original appearance of historical buildings.

3. Natural Materials: Natural materials such as straw, felt, and glued fabric can be used in a way that preserves the aesthetic appearance of historical buildings.

4. New Technological Materials: New technological materials with very high insulation properties can be used to increase the energy efficiency of historical buildings. However, their potential to compromise the original appearance and cause harm to historical buildings should be considered.

The most suitable insulation material for each historical building should be determined based on its characteristics, construction date, and energy efficiency needs. In addition, local building codes may also determine the suitability of insulation materials.

The following materials may be used as insulation materials that can be installed on the exterior surface of historical buildings in a way that is not visible:

1. Spray Insulation: Spray insulation is applied to the wall and roof surfaces without interfering with the structural integrity of the building. When applied to the exterior surface, it enhances insulation and does not compromise the original appearance of historical buildings.

2. Panel Insulation: Panel insulation refers to insulation materials in the form of plastic panels that are mounted on the exterior surface. Panel insulation is not visible on the exterior surface of the building and does not compromise the original appearance of historical buildings.

3. Insulating plaster: Rendered insulation can be applied to wall and roof surfaces in the form of a plaster layer. Insulating plaster provides insulation without compromising the original appearance of historical buildings.

The most suitable insulation material for each historical building should be determined based on its characteristics, construction date, and energy efficiency needs. In addition, local building codes may also determine the suitability of insulation materials.

Energy-efficient windows for historical buildings are window systems that not only increase the energy efficiency of historical buildings but also preserve their original appearance. The following techniques can be used for energy-efficient window applications in historical buildings:

1. Natural Glass: Natural glass can be used to improve energy efficiency without compromising the design of the original window systems in historical buildings. It allows sunlight to pass through, thus increasing energy efficiency.

2. Insulated Glass: Insulated glass is a type of glass added to the window systems of historic buildings to improve energy efficiency. Insulated glass reduces heat loss and improves energy efficiency.

3. Low-E Glass: is an energy-efficient type of glass that can be added to historic building window systems. Low-E glass helps to reduce heat loss and improve energy efficiency.

For each historic building, the most suitable window system should be determined based on the building's characteristics, construction date, energy efficiency needs, and local building codes. In addition, custom-designed window systems can also be used to improve energy efficiency without compromising the original appearance of historic buildings.

Natural heat sources can also be used in passive house applications for historical buildings. The following techniques can be used for natural heat source applications in historical buildings:

1. Solar Energy: Solar energy can be used as a natural source of heat for historical buildings by utilizing energy-efficient window systems and open floor plans.

2. Geothermal Energy: Geothermal energy systems can be used for historical buildings by extracting heat from underground hot water sources.

3. Wind Energy: Wind energy systems can be utilized for historical buildings through wind turbines mounted on the building.

4. Geothermal Energy: Geothermal energy systems can be used for historical buildings by extracting heat from underground hot water sources.

The most suitable natural heat source for each historical building should be determined based on the building's characteristics, energy efficiency needs, and local building codes. Implementing natural heat sources provides an environmentally friendly and sustainable approach, in addition to increasing the energy efficiency of historical buildings.

Energy-efficient hot water systems can be used for historical buildings to increase their energy efficiency and reduce energy costs. The following techniques can be applied in the implementation of energy-efficient hot water systems for historical buildings:

1. Collector Systems: Solar collectors, which are among the energy-efficient hot water systems for historical buildings, produce hot water using solar energy.

2. Geothermal Hot Water Systems: Geothermal hot water systems for historical buildings produce hot water from underground hot water sources.

3. Combined Systems: Combined systems, which are among the energy-efficient hot water systems for historical buildings, produce hot water by combining natural heat sources.

The most suitable energy-efficient hot water system for each historical building should be determined based on the building's characteristics, energy efficiency requirements, and local building codes. Implementing energy-efficient hot water systems provides an environmentally friendly and sustainable approach, in addition to increasing the energy efficiency of historical buildings.

Suitable ventilation systems for historical buildings can be used to improve the energy efficiency, indoor air quality, and health of the interior space, in addition to preserving the historic structure. The following techniques can be applied in the implementation of appropriate ventilation systems for historical buildings:

1. Mechanical Ventilation Systems: Mechanical ventilation systems are designed to draw in outdoor air and expel stale air from indoor spaces.

2. Natural Ventilation Systems: Natural ventilation systems aim to expel air from indoor spaces by utilizing the natural features in the design of historical buildings.

3. Controlled Ventilation Systems: Controlled ventilation systems can be used to improve air quality and energy efficiency in addition to mechanical ventilation systems.

The most suitable ventilation system for each historical building should be determined based on the characteristics of the structure, energy efficiency needs, and local building codes. The implementation of appropriate ventilation systems improves the energy efficiency of historical buildings, as well as enhances the quality and health of the indoor environment.

Controlled ventilation systems, similar to mechanical ventilation systems, aim to draw in outdoor air and expel stale air from indoor spaces. However, in these systems, air flow is controlled and can be used to improve air quality and energy efficiency. Controlled ventilation systems allow for the control of air flow, humidity, temperature, and other characteristics using multiple sensors and smart control systems. These systems can be used instead of open windows or regularly opened and closed ventilation ducts in areas that require ventilation, and they improve energy efficiency as well as the quality and health of the indoor environment. The use of controlled ventilation systems can be implemented to regulate the humidity and air quality of the indoor environment, thus providing a healthy indoor environment and improving energy efficiency for historical buildings.

The aim of this study is to evaluate the changes made in existing historical buildings, common problems of historical buildings, and the results obtained after renovation. In this way, sustainable methods that may be needed in the renovation of many historical buildings in Turkey are brought together. The studies aimed at positioning photovoltaic panels on the façade, which are seen in other renovation works, can be applied to increase energy production and reach the Passive House Premium standard. However, this study will not be evaluated within the scope since its implementation is not aesthetically pleasing for historical buildings.

Material & Method

Before starting the study, the construction years of the buildings to be selected are investigated and the oldest buildings are taken into consideration. In order to identify the changes in the façades of these buildings and to examine the change, the following flow chart will be applied.

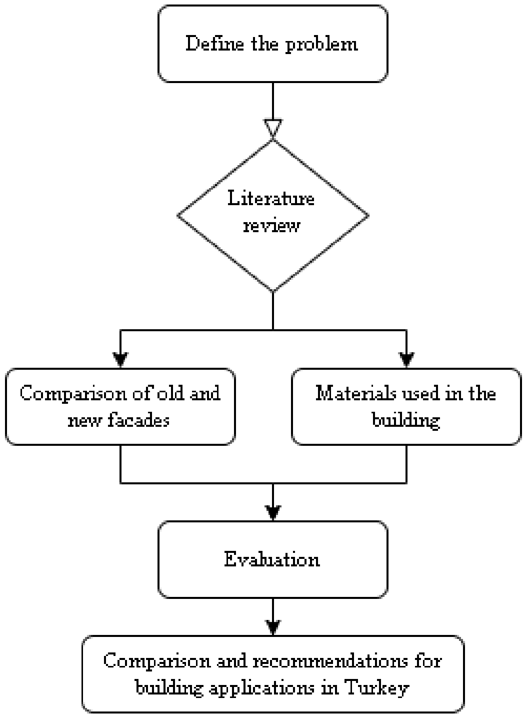

Figure 3: Flow chart

This study aims to examine historical buildings that underwent renovation until 2022 and the studies conducted for the aesthetic concerns of the building with changes in façade design. In this literature review study, the Passive House database is used to analyze the materials used on the exterior façade and their effects after renovation. A total of seventeen buildings constructed between 1850-1938 are examined in this study.

Table 2: Location, function, construction and renovation years of the examined seventeen buildings.

Building Code	Location	Function	Year of construction	Year of Refubrishment	Floor Area (m²)	Construction type
B-1	Neuendorf / Usedom (Mecklenburg-Vorpommern)	Hotel	1905	2005	256	Mixed
B-2	Hamburg-Harburg (Hamburg)	detached house	1909	1950	141	Mixed
B-3	Hjørring (Nordjylland)	two family house	1920	2009	221	Masonry
B-4	Hemmingen OT Harkenbleck (Niedersachsen)	two family house	1850		254	Mixed
B-5	Dallgow-Döberitz (Brandenburg)	multi family dwelling	1910		357	Masonry
B-6	Barcelona (Cataluña)	terraced house	1918	2012	68	Mixed
B-7	Möhrendorf (Bayern)	detached house	1935		100	Masonry
B-8	Neusäß-Steppach (Bayern)	semi detached house	1938		83	Mixed
B-9	Phoenicia (New York)	Public building	1890	2011	237	Timber

B-10	BROYE (Bourgogne-Franche-Comté)	detached single family house	1900	1970	170	Masonry
B-11	Palacio de Ardisana, Llanes (Asturias)	Hotel	1916	2018	275	Mixed
B-12	8TH Manchester (North West England)	semi detached house	1894	2018	374	Mixed
B-13	Brooklyn NY (New York)	terraced house	1900	2012	249	Masonry
B-14	Neulengbach (Niederösterreich)	detached single family house	1876	2013	119	Masonry
B-15	London (Greater London)	terraced house		2013	139	Masonry
B-16	Burgos (Castilla y León)	school	1891	2015	386	Masonry
B- 17	Sain Bel (Auvergne-Rhône-Alpes)	detached single family house	1900	2018	156	Mixed

Results or Findings

The common features of the seventeen examples examined generally include the ability to utilize heat from the sun, the use of operable windows for natural ventilation, the use of insulation materials to prevent energy loss in the interior space, and the use of triple-glazed windows at the forefront of renovation work.

Table 3: Applied materials of seventeen selected buildings (Passive House Database, 2023).

	Building Facade	Wall	Roof	Window
B-1	 ID:1745	Internal plaster, 38cm brick wall, 36cm additional wooden bulkheads insulation cellulose with plaster Wood wool lightweight panels or soft wood fiber panels and wall-integrated thermal solar system U-value=0,11 W/(m²K)	Plasterboard battens and roof beams uninsulated, Renovation: 38cm OSB bulkheads and cellulose insulation 1.5cm soft wood fiber board U-value =0,1 W/(m²K)	Triple glazing, Ug-value =0,62 W/(mK) g-value=47%
B-2	 ID:1910	15mm internal plaster 105mm sand-lime brick 60mm core insulation 220mm sand-lime brick 300 FJI system insulated with cellulose 22mm planking 60mm wood fibre board 15mm exterior plaster U-value=0.091 W/(m²K)	12.5mm gypsum board 400mm FJI system insulated with cellulose 35mm wood fibre board U-value =0.098 W/(m²K)	Triple glazing, filling: argon Ug-value =0.6 W/(m²K) g-value=54%

B-3	 ID:6239	Wall type 1: Plaster, 10mm Existing wall, 108mm Air, 94mm Existing wall, 108mm Insulation, 350mm U-value=0.103 W/(m²K) Wall type 2: Plasterboard, 26mm Insulation, 50mm Insulation, 250mm Woodboard, 25mm Insulation, 350mm Plasterboard, 20mm U-value=0.059 W/(m²K) Wall type 3: Plasterboard, 26mm Insulation, 100mm Insulation, 250mm Woodboard, 25mm U-value=0.110 W/(m²K) Wall type 4: Plasterboard, 26mm Insulation, 45mm Insulation, 390mm Woodboard, 25mm U-value=0.09 W/(m²K)	Roof type 1: Plasterboard, 26mm Insulation, 45mm Insulation, 250mm Woodboard, 25mm Insulation hard, 180mm Insulation hard, 120mm U-value=0,061 W/(m²K) Roof type 2: Plasterboard, 26mm Insulation, 45mm Insulation, 390mm Woodboard, 25mm Insulation, 135mm U-value =0.066 W/(m²K)	Triple glazing Ug-value =0.52 W/(m²K) g-value=53%
B-4	 ID:1334	EG-solid wall U-value 0.13, External insulation, plaster 20mm solid brick 300mm Blown-in cellulose insulation 275mm Heraklith BM plate 35mm Mineral plaster 20 mm Upper floor - half-timbered wall U-value 0.11, External insulation, larch shell Clay plaster 20 mm solid brick 120 mm Blown-in cellulose insulation up to 360 mm Wood fiber board 20 mm U-value =0.12 W	Sloping roof Plasterboard 12.5mm Mineral fiber insulation 180mm U-value =0.31 W/(m²K)	Ug-value =0.6 W/(m²K) g-value=55%

B-5	 ID:1190	Brick cavity wall with perlite fill and thermal insulation composite system U-value=0.15 W/(m²K)	Roof truss doubled, 33 cm blown-in cellulose insulation with moisture-variable vapor barrier U-value=0.13 W/(m²K)	Triple thermal insulation glazing with krypton filled Ug-value =0.5 W/(m²K) g-value=47%
B-6	 ID:2650	Plasterboard, 15mm Neopor 0,032 W/(m² K)+KVH (3%), 160mm interior plaster Brickwork, 290mm Exterior plaster U-value=0.195 W/(m²K)	Fermacell 15mm, Insulation 0.042 W/(m²K)+battens (16%), 240mm Fibreboard, 22mm air gap Under construction, 20mm XPS insulation 0.032 W/(m²K) 40mm U-value =0.159 W/(m²/K)	Double glazing, (4-16-4 argon) Ug-value =1.1 W/(m²K)g-value=58%
B-7	 ID:821	3cm interior plaster 30cm sandstone/brick - inventory 26cm ETICS 1cm external plaster U-value=0.12 W/(m²K)	14cm insulation between rafters 16cm above-rafter insulation U value=0.11 W/(m²K)	Ug-value=0.66 W/(m²K) g-value=55%
B-8	 ID:1567	30cm of cellulose between FJI carriers 6cm soft wood fiber boards with counter battens, rhombus formwork made of larch existing plaster, 25cm hollow concrete blocks, new clay plaster inside U-value=0.12 W/(m²K)	Plasterboard, osb board, 12cm cellulose between existing rafters, formwork (old), new airtight membrane, 24cm cellulose between FJI carriers, 6cm soft wood fiber panels with counter battens, brick battens, clay roof tiles U-value=0.11 W/(m²K)	Triple thermal insulation glazing Ug-value =0.5 W/(m²K) g-value=49%
B- 9	 ID:6368	Lightweight timber construction with PIR insulation. U-value=0.141 W/(m²K)	Lightweight timber construction with PIR insulation. U-value =0.075 W/(m²K)	Ug-value =0.55 W/(m²K) g-value=47%

B-10	 ID:6764	Stone wall, coating, Cellulose 310mm, wood fiber. Ventilated facade in burnt wood U-value=0.123 W/(m²K)	OSB floor Cellulose 600mm U-value=0.066 W/(m²K)	Ug-value =0.53 W/(m²K) g-value=53%
B-11	 ID:5819	600mm- Stone masonry Wall 40+40mm mineral woold Air stop barrier 40mm mineral woold 18mm interior pasterboard U-value=0.249 W/(m²K)	Ventilated cover of ceramic tile Waterproof barrier 50mm wood fibre panel 22mm osb board 100mm mineral wool insulation between beams Air stop barrier 40mm mineral wool insulation 15mm interior plasterboard U-value=0.201 W/(m²K)	Argon filled. Ug-value =0,5 W/(m²K) g-value=53%
B-12	 ID:5807	Front walls: 110mm Victorian facing brick, 38mm cavity, 13mm Fermacel, 145mm Steico I-joists with Steico Floc blown cellulose in between, 80mm Steico Protect Dry, 10mm Thermalime plaster. U-value=0.175 W/(m²K) Side walls: 14mm Therma lime render, 80mm Steico Protect Dry, 240mm Steico I-joists with Steico Floc blown cellulose in between, 250mm double layer of Victorian wire cut bricks with finger cavity, 10mm Thermalime plaster. U-value=0.116 W/(m²K) Outrigger walls: Organowood cladding, Facade membrane, 300mm Steico I-joists with Steico Floc blown cellulose in between, Proclima Intello Membrane, 15mm gypsum plasterboard & skim. U-value=0.132 W/(m²K)	Hook fixed slate on battens, Siga Majcoat, 60mm Steico Special Dry, 145mm - 300mm Steico I-joists mounted on 75mm original rafters with Steico Floc blown cellulose in between, Siga Majrex membrane, 15mm gypsum plasterboard & skim. U-value: 0.108-0.148 W/(m²K) U-value =0.108 W/(m²K)	Ug-value =0.45 W/(m²K) g-value=1%

B-13	 ID:4364	Front masonry wall insulated with dense fill cellulose. U-value=0.332 W/(m²K)	Flat roof insulated with both dense fill cellulose and EIFS insulation U-value =0.083 W/(m²K)	Ug-value =0.5 W/(m²K) g-value=53%
B-14	 ID:3352	2.0cm plaster 49.0cm VZM 2.0cm plaster 35.0cm straw 3.6cm rough formwork 1.5cm Fermacell HD 0.3cm fine plaster U-value=0.12 W/(m²K)	14.0cm double wood 10.0cm bed 6.0cm air cushion wood 5.0cm screed, old 35.0cm straw insulation 2.0cm gypsum fiber 2 layers U-value =0.12 W/(m²K)	Ug-value=0.6 W/(m²K)
B-15	 ID:4044	230mm existing solid brick wall 30mm ventilated cavity 100mm phenolic insulation 15mm OSB Grade 3 (airtightness layer) taped with airtightness tape 12.5mm plasterboard U-value=0.173 W/(m²K)	Existing uninsulated roof 80mm phenolic insulation between rafters 50mm phenolic insulation under rafters 15mm OSB Grade 3 (airtightness layer) taped with airtightness tape 12.5mm plasterboard U-value =0.14 W/(m²K)	Triple glazing with two low-e coatings and argon filled U g-value =0.58 W/(m²K) g-value=55%
B-16	 ID:4727	Main layer Preexisting masonry wall 62cm Insulation Polyurethane foam 10cm airtightness Plastic membrane interior layer Plaster board panelling 2,6cm U-value=0.264 W/(m²K)	Roof: ceramic roof tiles+new sealing membrane+wood table open air chamber insulation glass-wool blanket 30cm airthightness OSB close air chamber (installation ducts) interior finished plaster board suspended ceiling U-value =0.133 W/(m²K)	Ug-value =0.5 W/(m²K) g-value=42%

B-17	 ID:6051	Stone 2.0 W/(mK) 450mm Cellulose wadding 0.042 W/(mK) 280mm Glasswool 0.037 W/(mK) 45 mm BA13 0.325 W/(mK) 13mm U-value=0.139 W/(m²K)	Glasswool 0.04 W/(mK) 260mm Glasswool 0.04 W/(mK) 260mm BA13 0.325 W/(mK) 13mm U-value=0.079 W/(m²K)	Ug-value=0.53 W/(m²K) g-value=54%

- B – 1 (Building 1):

The aim of adding photovoltaic panels to the facade of Building 1 in Neundorf, Germany was to meet the building's energy needs through electricity production. Based on information from the energy calculation using PHPP, it was assumed that passive heat recovery from the ventilation system was 70%. A central water heating area of 20 m² was prepared using solar collectors on the eastern side of the building. The building continues to be used as a hotel today.

Figure 4: B-1, Neundorf/Germany, before and after (Passive House Database, 2023).

- B – 2 (Building 2):

The insulation used in Building 2 consists entirely of ecological materials that do not harm the environment, made only of cellulose and wood fibers. It is still used as a residence today.

Figure 5: Front and Rear Elevations of B-2, Hamburg/Germany (Passive House Database, 2023).

- B – 3 (Building 3):

It is still used as a residence today.

Figure 6: Old and New Facade Views of B-3, Hjørring/Denmark (Passive House Database, 2023).

- B – 4 (Building 4):

Building-4, used as a farmhouse, has been modernized using passive house components. As seen in the facade, the attic floor has been converted into a balcony with large windows. During the modernization process, additional windows were added and the window openings were made larger, leading to a redesign of the facade views.

Figure 7: Old and New Facade Views of B-4, Hemmingen/ Germany (Passive House Database, 2023).

External insulation has been applied to the exterior walls of the facade, with the lower half of the walls covered in plaster and the upper half covered in wooden cladding. Ecological solutions have been preferred for the facade of Building-4.

- Cellulose insulation material
- Recycled insulation material
- Facades made of locally sourced untreated black pine/Douglas fir

In addition, it is aimed to provide hot water through solar energy by using collectors on the roof and to collect rainwater from the roof for water conservation.

- B – 5 (Building 5):

Building-5, originally an apartment building in Brandenburg, has been renovated to meet passive house standards, transforming it into a sustainable and modern residential building. The facade of the building was restored with a contemporary design, different from other buildings in the city. Cellulose insulation was used to provide benefits such as keeping the interior space somewhat insulated from the cold in winter, protecting from the heat in summer, and reducing noise from the nearby train tracks.

Figure 8: Old and New Facade Views of B-5, Brandenburg/ Germany (Passive House Database, 2023).

A 13 m² area of the roof has been allocated for the use of collectors to provide hot water through renewable energy sources. An heat recovery ventilation system with approximately 85% rainwater usage has been installed, and eco-friendly, recyclable cellulose roof insulation has been used.

- B – 6 (Building 6):

The aim of renovating a house built in 1918 in Barcelona in 2012 was to provide thermal comfort and energy efficiency in the interior. The renovation process, which lasted for 4 months, aimed to create a home with energy performance and reduce environmental impact by using ecological materials. The materials used on the facade consist of natural Scots pine and thermally treated pine. With the presence of large windows, it is possible to make the most of daylight in the interior and benefit from natural ventilation. After completion, the heating demand of the house was reduced from 170 kWh/m²/year to 17 kWh/m²/year. The project also won an Isover Energy Efficiency Award.

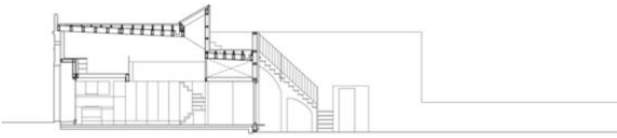

Figure 9: Section of the roof window opened after the renovation (Inhabitat, 2013).

A roof window was added to the roof, which was redesigned to allow for redirection due to the house's orientation towards the northeast. This was done to enable the roof to receive more sunlight during the winter months and provide warmth.

- B – 7 (Building 7):

Building 7 is a residential building located in the Bavarian state of Germany, which was restored from a structure built in 1935 to continue functioning as an energy-efficient residential building today. The heating energy demand has been reduced by approximately 90% by adding insulation materials for heat gain and by using photovoltaic panels on the roof to generate electricity.


Figure 10: B-7, Front and Back Façade Appearances, Möhrendorf, Germany (Passive House Database, 2023).

The roof of the building, located in the city center, features solar panels that can generate a total of 123 kWh/m² electricity and also meet the hot water demand. The aim is to continue using the building while preserving its historical characteristics. Replacing the windows with triple-glazed ones aims to prevent heat loss.

- B – 8 (Building 8):

Renovation works have started on a semi-detached house in Bavaria, Germany, with the aim of improving its energy efficiency and creating healthier living conditions. The biggest changes have been made to the façade, particularly the windows. The roof window has been made larger to passively harness more sunlight. The windows on the ground and first floors have also been expanded lengthwise to increase solar gain.


Figure 11: Old and New Facade Views of B-8, Bayern / Germany (Holzbau Deutschland Leistungspartner, 2008).

Solid wood, wood-based materials, and wood fiber insulation materials were used wherever possible. As part of the renovation, the asbestos-containing panels on the south facade were removed and replaced with wooden panels.


Figure 12: The facade originally contained panels that contained asbestos, but they have been replaced with new wooden panels (Passive House Database, 2023).

All current windows have triple insulated glass. The use of cellulose as insulation in the walls has provided a recycled and ecological solution. The thickness of the walls insulated with cellulose is 36 cm.

- B – 10 (Building 10):

A detached house has been visually transformed by cladding it with wood as part of its passive renovation. The house, which was originally built with stone, is now intended to meet passive house standards with the addition of wood cladding and cellulose insulation. Additionally, renewable energies are used in the building to generate 4 kWh/(m² a) of energy.


Figure 13: Old and New Facade Views of B-10, Phoenicia NY / USA (Passive House Database, 2023).

- B – 11 (Building 11):

Villa Marta is a 102-year-old house that has been renovated with the goal of preserving almost the same facade. The only major change to the facade was the replacement of the window with insulated glass. The renovation also respected and preserved the features of Indian architecture, reducing the heating demand of the house by 90%. The facade of the house is made of stone walls, and there are glass balcony protrusions on the east and west facades outside the thermal envelope. The intermediate floors and roof have a wooden structure, as is typical of traditional Asturian architecture.


Figure 14: Old and New Facade Views of B-11, Bourgogne-Franche-Comté / France (Villa Marta, 2023).

- B – 12 (Building 12):

By using photovoltaic panels in the building envelope, 11 kWh/m² of electricity can be generated. To passively maximize solar heat gain, windows have been placed angled towards the sun. The world's first breathable, smart membrane structure has been created, inspired by biomimicry, for the roof.


Figure 15: Old and New Facade Views of B-12, Asturias / Spain (On the market, 2023).

- B – 13 (Building 13):

Due to the cultural importance of the terraced house, which was first used in the early 1900s, significant changes were made to the facade during its restoration. An interior, breathable insulation was added to the front load-bearing wall. This project has been approved by the Passive House Institute.


Figure 16: Old and New Facade Views of B-13, Manchester/ United Kingdom (Passive House Database, 2023).

This building, which has different front and back facades in the picture, continues to be used as a residential building while achieving energy efficiency today.

- B – 14 (Building 14):

The materials used for insulation in the building consist of locally sourced materials. An ecological solution was sought by using straw, wood, and oak sticks found in the surrounding area. The aim was to balance moisture by replacing the previously moldy walls with renewed ones and adding insulation.

Figure 17: Old and New Facade Views of B-14, Brooklyn NY/ United States (Passive House Database, 2023).

In its new state, it can be observed that the window openings on the facade are fixed, and the colors have changed. If compared to the old state, there has been no change in the shape of the roof, but the material has been renewed. It is clear that the wall thickness has increased, and as a result, the area where the door is located is more recessed.

- B – 15 (Building 15):

The building located in London has been updated to meet EnerPHit standards by implementing some passive house components. In order to preserve the facade and not create a difference from its old appearance, insulation has been used on the inner walls. Due to its historical significance, external wall insulation was not permitted in the area, so the only change made was the replacement of the windows with triple glazed windows for thermal insulation. Structural insulation has been used to reduce heat loss and eliminate some structural thermal bridges in certain areas.

- B – 16 (Building 16):

In this historic building, the goal was to renovate without changing the exterior appearance, so the renovation was focused on the interior walls and the exterior facade was left untouched. Since it was impossible to change parameters such as building orientation or window size, no changes were made to the facade.

Figure 18: B-16, façade, London/ United Kingdom (Passive House Database, 2023).

However, ecological aspects were not taken into account in the new materials to be added, and only energy efficiency of the building was targeted. Mechanical systems have been added to the structure, which is currently used as a university campus, to generate additional electricity.

- B – 17 (Building 17):

The building, which was previously used as a barn in France, had a lot of air leaks due to the inadequate insulation and open surroundings, as well as improper orientation. Therefore, the aim was to apply all possible Passivhaus standards in the building.

Figure 19: Old and New Facade Views of B-17, Sain Bel / France (Passive House Database, 2023).

The first goal is to increase the openings where the windows are located on the façade and thus enable passive use of daylight. The windows are kept wide to be able to use natural light and also to benefit from the sun for heating. Especially the windows opening to the areas that are open to the environment are designed to be proportional and in accordance with their historical characteristics (BE&CO, 2019).

Conclusions

Passive house practices have an important place in energy-efficient and environmentally friendly construction activities. These practices aim to maximize energy efficiency, reduce energy demand, and cause less harm to the environment. Implementing passive house practices contributes to the widespread adoption of energy-efficient and environmentally friendly construction activities. These practices promote the efficient use of energy resources worldwide and contribute to solving global environmental problems. By using natural resources such as daylight, natural heat sources, and ventilation systems, energy savings are achieved. In addition, technological solutions such as insulation, energy-efficient windows, and hot water systems aim to increase energy efficiency. Furthermore, passive house practices contribute to the preservation and restoration of historic buildings. These practices can be implemented to make historic buildings energy-efficient and provide an environmentally friendly indoor environment. In conclusion, passive house practices have an important place in energy-efficient and environmentally friendly construction activities, promoting the efficient use of energy resources, less harm to the environment, and the preservation of historic buildings.

When examining facades of historic buildings, it is seen that solutions have been made to ensure the energy efficiency of the structure by opening additional window area or closing the structure with additional glass areas to protect the heat. However, the most common changes have been made by making changes with triple glass and low-e glass in the windows. The roof, facade mass, and building size are constant, and it has been determined that the generally restored situations are adding exterior facade paint, adding insulation material inside, increasing wall thickness, and protecting building materials. Another important point to consider is the application of insulation towards the interior or exterior. Every new material applied to the exterior disturbs the integrity of the facade and causes damage to the historical structure. In this case, even if the interior space is reduced, insulation materials must be applied to the interior and the wall thickness must increase inside. Additionally, changes have occurred in the building facades by using natural wood materials instead of materials that harm the environment. In these cases, reducing the damage to the environment has been achieved, and energy conservation in the interior space has been facilitated. Energy efficiency varies according to climate, but research has proven that at least 70% energy efficiency can be achieved.

The use of photovoltaic panels on facades is not evaluated within the scope of this study. Mechanical needs such as air conditioning units, photovoltaic panels, etc. used on facades disturb the visual aesthetics of historic buildings. Their use does not create an integrated appearance in the building unless the structures are designed according to these mechanical needs. However, their use on roofs for providing energy and hot water does not have as much of an impact on the overall building appearance and aesthetics as it does on facades. Therefore, it is seen that the use of photovoltaic panels or collectors on roofs can provide energy and hot water without significantly affecting the overall form of the building.

There are many historical buildings in Türkiye, and there are buildings that continue to be used by repurposing them without losing their historical structure, especially in restored buildings. Thanks to this construction concept, structures that provide comfort in terms of thermal and air quality inside and ensure energy efficiency can continue to be used. In order to achieve energy efficiency in restoration projects, a preliminary analysis can be conducted by working according to passive house rules. Thus, it is possible to renew the historical buildings that are repurposed and continue to be used in today's conditions without compromising their aesthetics.

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1. Araştırmacıların katkı oranı beyanı / Contribution rate statement of researchers:

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    2. Yazar/Second author % 50.

2. Yazarlar tarafından herhangi bir çıkar çatışması beyan edilmemiştir (No potential conflict of interest was reported by the authors).