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Article

Energy retrofitting of modern heritage in accordance with passive building standard: The case of Yenişehir Cinema

Ebru KILIÇ BAKIRHAN*, **Merve Tuna KAYILI**

Department of Architecture, Karabuk University, Karabuk, Türkiye

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ABSTRACT

Improving the energy performance of existing buildings is crucial for reducing energy demand and transitioning towards renewable energy sources in the building sector. The **Passive Building Standard** serves as a valuable guide by providing a set of strategies for achieving high energy efficiency. **Yenişehir Cinema**, an important modern heritage building, has remained vacant for nearly 12 years. Given its cultural and historical significance, integrating it back into urban life through energy-efficient retrofitting can contribute to urban sustainability.
This study aims to enhance the energy performance of Yenişehir Cinema by transforming it into a **passive building**. The proposed retrofitting strategy involves implementing a **heat recovery ventilation system, improving the building envelope, and mitigating overheating**. The energy performance of both the baseline and retrofitted scenarios was assessed using **energy models developed in Design Builder**.
The results indicate a **92% reduction in annual heating demand** and a **41.3% decrease in total carbon emissions** compared to the baseline scenario. Furthermore, the additional investment costs required for the proposed improvements can be recouped within **seven years**. However, while the overheating in the building was reduced by **40%,** this improvement remains insufficient to fully ensure **thermal comfort**.

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INTRODUCTION

The construction sector accounts for 36% of global energy consumption and 39% of carbon emissions resulting from energy use (Global Alliance for Buildings and Construction, 2020). Given this impact, the widespread adoption of passive and hybrid systems and their climate-specific optimization are among the key long-term global objectives (Global Alliance for Buildings and Construction, 2020). To reduce the dependence on fossil fuels and minimize carbon emissions, both existing and newly constructed buildings must be designed with high energy efficiency (Sharma et al., 2022). In Europe, 48% of existing buildings were constructed between 1961 and 1990 (Volf et al., 2018), highlighting the urgency of retrofitting older buildings to align with current climate conditions and the growing scarcity of resources.

***Corresponding author**
*E-mail adres: ebrukilic@karabuk.edu.tr

Reducing the energy demands of existing buildings should be achieved while maintaining occupant health and comfort (Ruparathna et al., 2016). Passive buildings are designed to have minimal energy demand for heating, yet they still provide high indoor comfort levels (Mihai et al., 2017). The EnerPHit certification system, which allows existing buildings to be upgraded to Passive Building Standard, significantly reduces their heating and cooling loads (Passive House Institute, 2023).

Extensive research has been conducted on the energy retrofitting of existing buildings. A study conducted in China applied Passive Building Standard principles by insulating the building envelope, ensuring airtightness, and integrating a high-efficiency heat recovery mechanical ventilation system. As a result, heating demand was reduced by 90% and cooling demand by 70% compared to the baseline scenario (Liu et al., 2021). Similarly, a study in Sweden demonstrated that carbon emissions could be reduced by 50% to 82% through the use of various insulation materials, facade enhancements, and window improvements (Piccardo et al., 2020). In the UK, a year-long study comparing a conventional house and a passive house found a 62.2% reduction in energy consumption and a 24% improvement in indoor temperatures. Numerical modeling further indicated that heating demand could be reduced by 80% in existing buildings through energy-efficient renovations (Liang et al., 2017).

Retrofitting historical buildings in accordance with Passive Building Standard is also critical for preserving cultural heritage while ensuring energy efficiency. A study on a historic building in Egypt found that thermal comfort levels could be increased to 66% through the implementation of hybrid passive strategies (Ibrahim et al., 2021). Similarly, a 19th-century historic building retrofitted using three passive building strategies achieved a 51.8% reduction in primary energy demand. The payback period for the implemented interventions was estimated at 18 years (Qu et al., 2021).

Türkiye, which remains heavily dependent on foreign energy resources, aims to reduce its primary energy consumption by 14% between 2017 and 2023 in accordance with the National Energy Efficiency Action Plan (Republic of Turkey Ministry of Energy and Natural Resources, 2023). The average energy consumption for heating in buildings across Türkiye is 110 kWh/m² (Allplan GmbH, 2013), whereas maximum permissible heating demand values in other countries are significantly lower: 35 kWh/m² in the UK, 34 kWh/m² in the Netherlands, and 23 kWh/m² in Denmark (Allplan GmbH, 2013). This substantial difference highlights the urgent need for stricter energy efficiency regulations and more effective enforcement mechanisms in Türkiye.

Despite the increasing emphasis on energy efficiency, a lack of legal coordination and institutional collaboration between organizations responsible for heritage protection and energy efficiency poses a significant challenge (Jahed et al., 2020).

Several studies have explored energy retrofitting strategies for historic buildings in Türkiye. Ulu & Arsan (2020) examined 22 buildings in the historic urban fabric of İzmir, demonstrating that proposed retrofit strategies could achieve up to 48% energy savings. Similarly, Timur et al. (2022) analyzed two traditional houses in Muğla, evaluating interventions such as HVAC system optimization, thermal insulation, buffer zone integration, double-glazed windows, and airtightness improvements. Their findings indicated that these measures, when applied together, could reduce annual energy consumption by up to 30%.

Since historical buildings require careful intervention to preserve their architectural integrity and cultural value, energy retrofitting must be approached with sensitivity. Ozbalta et al. (2021) assessed multiple active and passive energy efficiency scenarios for a historic building in İzmir. Their results showed that the optimal energy retrofit combination required 34% less energy compared to other alternatives.

Previous research has demonstrated that implementing Passive Building Standard in existing buildings leads to substantial reductions in energy consumption and carbon emissions, particularly in heating and cooling loads (Liu et al., 2021; Liang et al., 2017; Piccardo et al., 2020). The benefits of Passive Building Standard have also been observed in historic buildings, particularly in terms of energy savings and thermal comfort improvements (Ibrahim et al., 2021; Qu et al., 2021). Most energy retrofitting studies have focused on historical buildings in the Aegean region, primarily examining annual energy savings when passive and hybrid systems are integrated (Ulu & Arsan, 2020; Timur et al., 2022; Ozbalta et al., 2021). However, the complex interrelated parameters that influence overall energy performance are often overlooked.

The novelty of this study lies in its comprehensive approach, which simultaneously considers energy efficiency, carbon emissions, thermal comfort, and cost-effectiveness. The primary objective of this research is to retrofit Yenişehir Cinema—an example of modern cultural heritage—following Passive Building Standard. The target audience includes industry stakeholders, passive building practitioners, Kardemir Steel Industry Inc. (the entity holding the building's usage rights), and academics interested in energy-efficient retrofitting strategies.

MATERIAL AND METHODOLOGY

This section outlines the case study, and details the methodology applied in this research. The validation of the 3D model, software, and climate data is conducted. Following this validation, decisions regarding the energy model for the operational phase are presented. Finally, the databases and methodologies used for thermal comfort, cost analysis, and environmental impact assessment are described.

Figure 1. Master plan of Yenişehir Cinema Building (Güneş, 2017).

Case Study

The primary subject of this study is Yenişehir Cinema, located in Karabük Province, Türkiye. The building is situated in the Yenişehir Neighborhood, within an urban conservation area and a third-degree natural conservation zone. Although it was actively used as a cultural center for a period, the building itself is not officially registered as a heritage structure.

The cinema building covers a total area of 1,500 m², with three open facades and additional facilities at the rear. The net area of the building is 1,350 m², and it has a seating capacity of 750. Additionally, registered pine trees are present in the garden surrounding the cinema.

Architecturally, Yenişehir Cinema was designed by Supreme Architect Münci Tangör, a prominent figure of the Early Republican Period in Türkiye. The construction of the building took place between 1954 and 1958 (Güneş, 2017; Ulusoy, 2022).

Historically, the cinema was among the most popular and well-attended theaters in Türkiye between 1958 and 1990. Between 2008 and 2013, it continued functioning as a cultural center. However, since 2013, the building has remained closed and out of use. In 2017, restoration drawings were initiated, but the project was never implemented (Güneş, 2017). The site plan of the building is presented in Figure 1.

The historic Yenişehir Cinema, which once attracted significant public interest, has remained vacant for nearly twelve years. Yalçınkaya & Bal (2019) highlight the importance of reintegrating Yenişehir Cinema into urban life while preserving its cultural and historical significance to support urban sustainability. Similarly, Güneş (2017) emphasizes that maintaining the building's original function is essential for ensuring both social and spatial sustainability. The exterior and interior views of the building are presented in Figure 2.

Figure 2. **(a)** South facade, **(b)** East facade, **(c)** Registered trees, **(d)** Cement-based material (Authors' Archive), **(e, f)** Interiors (Güneş, 2017).

The outer walls of the building are constructed using concrete blocks. The roof structure consists of both hipped and flat sections, covered with tiles and ceramic tiles, respectively. The building system is reinforced concrete. For flooring, vinyl material is used, while most of the windows in their current state feature double glazing. The main exterior door is made of wood, contributing to the building's architectural character. The thermal properties of the existing materials are detailed in Table 1.

Methodology

The Passive Building Standard is based on five fundamental principles, which include:

1. High-level insulation (Ud<0.15 W/m²K)
2. High-performance, insulated window and door systems (Up<0.8 W/m²K)
3. Airtight building envelope (<0.6 /h @50 Pa)
4. Architectural detailing to eliminate thermal bridges
5. High-efficiency, heat recovery mechanical ventilation system (Sustainable Energy Association, n.d.).

Additionally, to comply with the Passive Building Standard, a building's annual heating and cooling demand must not exceed 15 kWh/m², and its primary energy demand should remain below 120 kWh/m². From a thermal comfort perspective, indoor temperatures must not exceed 25°C for more than 10% of the total annual hours (International Passive House Association, 2018). However, existing buildings may not fully meet these strict criteria, necessitating the development of the EnerPHit certification system, which provides two alternative compliance pathways. Meeting either of these criteria is sufficient for certification.

The first pathway focuses on building component performance, ensuring that all structural elements adhere to Passive Building Standard. The second pathway is based on energy demand, where the maximum heating load is set at 25 kWh/m² for cool-temperate climates, while the cooling demand limit remains at 15 kWh/m².

The energy demand-based approach further categorizes buildings into three classes: Classic, Plus, and Premium, based on their energy performance (Passive House Institute, 2023). In this study, the EnerPHit Standard was applied using energy demand-based criteria.

Following the Passive Building Standard, the energy retrofit process included:

- Installation of a heat recovery mechanical ventilation and heating-cooling system
- Insulation and airtight sealing of the building envelope
- Upgrading window and door systems.

Firstly, the existing building model was generated and validated. Once the climate data and building model is checked, baseline energy model is adjusted with decisions made in advance. Thereafter, energy retrofits were applied in sequence. According to the simulation results, the overheating was determined and the thermal comfort requirements were evaluated according to the (American Society of Heating, Refrigerating and Air-Conditioning Engineers) ASHRAE-14 Standard. At the conclusion of the study, economic and environmental analyses were conducted. Finally, the results were discussed on the axis of sustainable architecture (Figure 3).

As for the limitations of the study, the side and rear facades of the building are covered with rough plaster, while the entrance facade features mosaic coatings, which enhance

Table 1. Material properties of the existing structure

Building component	Material	Thickness (m)	Thermal conductivity (W/mK)	Specific heat (J/kg-K)	Density (kg/m³)	U value (W/m²K)
Wall	Plaster	0.02	0.4	1000	1000	1.88
	Concrete block	0.3	1.15	1000	1800	
	Plaster	0.02	0.4	1000	1000	
Hipped roof	Roof tile	0.025	1	800	2000	3.71
	RC	0.12	1.15	1000	1800	
Flat roof	Ceramic tile	0.018	0.85	840	1900	3.76
	RC	0.12	1.15	1000	1800	
Floor	Vinyl flooring	0.002	0.2	1000	1000	3.08
	RC	0.12	1.15	1000	1800	
Window	Double glazing	-	-	-	-	2.71
Door	Wooden					2.80

RC: Reinforced concrete.

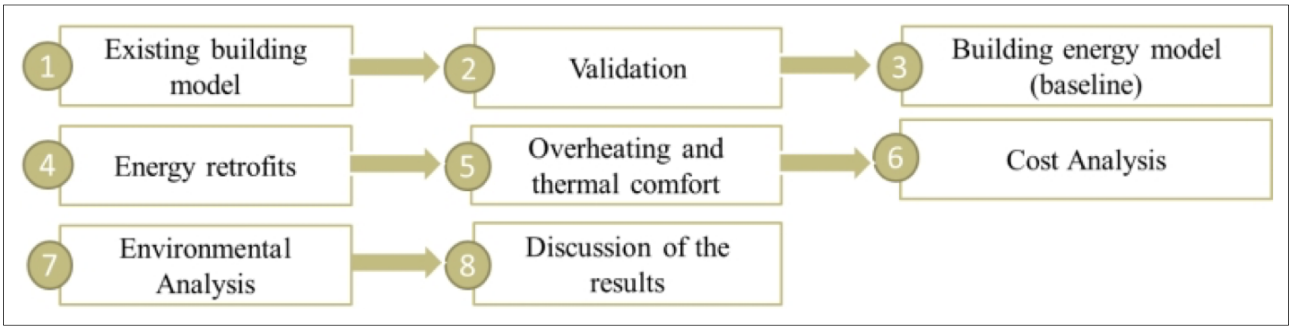

Figure 3. Methodology of the study.

its aesthetic quality. Consequently, any proposed external insulation measures would primarily impact the entrance (south) facade. However, this adjustment is beyond the scope of this study. Nonetheless, it is anticipated that the overall exterior appearance of the building will remain unaffected by the other proposed energy efficiency improvements.

Databases and Methodologies for Validation

Based on the collected data—including architectural plans, photographs, and information on building materials—a digital model of the structure was developed, and energy simulations were conducted using Design Builder v6.1 software. To ensure accurate climatic inputs, annual climate data for Karabük province was obtained from NASA's Prediction of Worldwide Energy Resources (POWER) Data Access Viewer (DAV) v.2.4.9 (NASA, n.d.).

To validate the accuracy of the simulations, real-time temperature measurements were collected using an RC-51H device, recording data at 1-hour intervals from January 3 to January 7, 2023. Due to the deteriorated state of the building, where windows are broken, measurements were limited to a single room that was as isolated as possible from external environmental influences. The selected room has no direct windows facing the outside, ensuring that the recorded indoor climate data closely represents the building's actual indoor conditions.

The ASHRAE Guideline 14 was utilized to validate the energy model, ensuring its accuracy in representing the building's actual thermal performance. Two widely used statistical methods, Mean Bias Error (MBE) and Coefficient of Variation of the Root Mean Square Error (CV(RMSE)), were employed to minimize discrepancies between the energy model predictions and the real indoor environment (Yılmaz & Oral, 2019; Guo et al., 2021; Li et al., 2021).

To validate the model, temperature measurements obtained from the indoor space were compared with corresponding simulated data generated by the energy model. Based on this comparative analysis, error margins were determined using the following equations:

$$MBE(\%) = \frac{\sum_{i=1}^{n}(Mi-Si)}{\sum_{i=1}^{n}(Mi)} \times 100 \qquad (1)$$

where MBE represents "Mean Bias Error", n denotes the number of the data, Mi stands for the measured data, and Si indicates simulation results.

$$\text{CV(RMSE)}(\%) = \frac{\sqrt{\sum_{i=1}^{n}(\frac{(Mi-Si)^2}{n})}}{M} \times 100 \qquad (2)$$

where CV(RMSE) stands for "Coefficient of Variation of the Root Mean Square Error", M denotes the mean value of the collected data in the field.

According to ASHRAE Guideline 14, for an energy model calibrated with hourly data, the margin of error between real-time measurements and energy simulations should not exceed 10% for Mean Bias Error (MBE) and 30% for Coefficient of Variation of the Root Mean Square Error (CV(RMSE)). In this study, the number of data points (n) was set to 24, corresponding to the number of hours in a day, with measurements recorded hourly.

Baseline and Retrofitted Energy Models

In the energy simulations, the baseline case was evaluated under the assumption that the building is still in use. However, since the building has been vacant for an extended period, the occupancy rate, as well as the heating and cooling setback temperatures, were determined based on assumptions.

The basement floor was excluded from the energy simulations, as such areas are typically unheated spaces (Dascalaki et al., 2011). The building's operational hours were assumed to be 08.00 am–10.00 pm, every day. The window-to-wall ratio was calculated as 5%, and some of the trees on the southwest side of the building, which are officially registered, were modeled as shading elements, as they are located along the sun-exposed facade.

Primary energy demand accounts for the total energy consumption associated with room electricity, lighting, heating, cooling, ventilation, and hot water. Historical records indicate that the building was previously heated with solid fuel and naturally ventilated during its period of use.

The baseline energy model represents the closest approximation of the building's original state when it was operational. The assumptions for both the baseline and retrofitted energy models are provided in Table 2. The building is heated and cooled with a variable refrigerant flow system with heat recovery (VRF-HR) in the retrofitted case. A VRF-HR system recovers heat from cooling zones and transfers it to heating zones, enabling simultaneous heating and cooling (Zhang et al., 2018). Additionally, a 3D model image generated in Design Builder is presented in Figure 4.

Thermal Comfort Criteria

In addition to the Passive Building Standard, the thermal conditions of the building after energy retrofits were assessed using the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) methods. These methods are designed to predict thermal comfort under steady conditions and are based on a 7-point Likert scale (Cheung et al., 2019).

For the calculations, the thermal comfort tool developed by Berkeley University, which is based on ASHRAE 55 Standard, was used (Center for the Built Environment, n.d.). According to this methodology:

Table 2. Baseline and retrofitted energy model decisions

Parameters	Baseline	Retrofitted
Heating period	October-March	October-March
Heating temperature - set back	20 ºC-12 ºC	20 ºC-12 ºC
Heating system	Boiler and radiators	VRF-HR
Total efficiency	-	70%
Cooling period	-	June-August
Cooling temperature - set back	-	23ºC-28ºC
Cooling system	-	VRF-HR
Ventilation system	Natural	Mechanical with HR
Occupancy rate	08.00 am-10.00 pm	08.00 am-10.00 pm
Infiltration rate (ac/h)	0.7	0.59

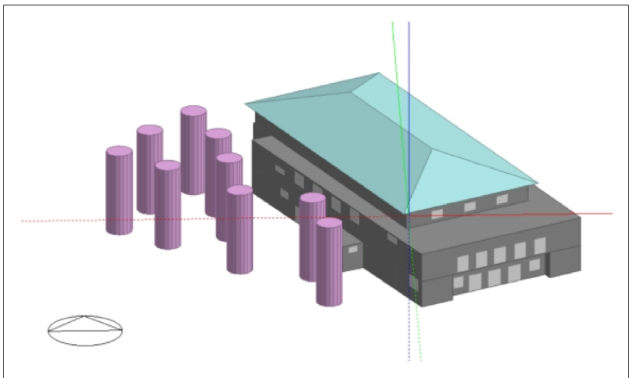

Figure 4. 3D model of the building from Design Builder.

- The clothing insulation value (clo) was set to 1.0 clo for typical winter indoor clothing and 0.5 clo for summer indoor clothing, based on operative temperatures. The metabolic rate was taken as 1 met, assuming occupants are seated quietly while watching a movie. Operative temperature and relative humidity values were determined using standard deviation and mean values, ensuring that two-thirds of the data falls within one standard deviation of the mean. Air speed was assumed to be 0.1 m/s.

Calculation of Economic Savings

At the conclusion of the study, the total costs of all energy improvement measures were calculated to evaluate the economic feasibility of the proposed interventions. This analysis aimed to determine whether the costs associated with the retrofits could be recouped within the building's remaining service life.

The unit prices for key energy efficiency components—including the VRF-HR, rockwool insulation, and low-emissivity (low-E) triple glazing system with argon filling—are detailed in Table 3. Notably, for the VRF-HR system, pricing was obtained on a per-project basis. The cost of insulating the exterior door was excluded from the calculations, as it was considered negligible in comparison to other retrofit measures. The post-retrofit service life of the building was estimated at 30 years, and the electricity tariff (kWh/₺) used in the economic analysis was sourced from the Energy Agency (n.d.). To estimate the payback period of the initial investment costs, the annual energy savings and cumulative cost recovery over time were analyzed, taking into account that electricity tariffs for the public sector in Türkiye increase by 30% annually as indicated by Energy Market Regulatory Authority (*Enerji Piyasası Düzenleme Kurumu, EPDK*) in 2024 (Dünya, 2023).

Database for Environmental Analysis

A comprehensive environmental analysis requires the assessment of both operational and embodied carbon emissions. The energy retrofits considered in this study include mechanical systems with heat recovery, insulation, and argon-filled triple-glazing window systems.

Table 3. Unit costs of proposed applications

Senarios	Unit	Unit price	Source
VRF	Per project	€200,000	Personal communication, July 24, 2024
Insulation	1 m² 1 cm	€0.6 + %18 VAT	Koca, 2023
Window	1 m²	1459.15 ₺ + 18% VAT	Yaşasan, 2024
Argon gas	1 m²	45 ₺ + 18% VAT	Yaşasan, 2024

VAT: Value added tax.

The embodied carbon of conventional buildings typically accounts for less than 20% of the total life cycle carbon (LCC). However, in low-energy buildings, embodied carbon can constitute up to 80% of the LCC (Akbarnezhad & Xiao, 2017). Given this disparity, it is crucial to evaluate both operational and embodied carbon emissions simultaneously to obtain a holistic understanding of environmental impact.

The system boundary for this study is defined as the production stage (A1–A3), while the impact category under investigation is total global warming potential (GWP-total) for embodied carbon calculations. GWP quantifies the amount of heat trapped in the atmosphere by a greenhouse gas relative to CO_2, meaning that a higher GWP indicates a stronger warming effect (U.S. Environmental Protection Agency, n.d.). GWP-total is also recognized as one of the seven key environmental impact categories outlined in the EN 15804+A2 Standard (Hill et al., 2018).

To obtain accurate embodied carbon data, this study utilizes the Environmental Product Declaration (EPD) of the selected materials, as detailed in Table 4.

The energy consumed during the operation phase of traditional buildings accounts for approximately 90% of their total energy consumption (Koç et al., 2022). To calculate operational carbon emissions, the electricity consumption point emission factors specified by the Ministry of Energy and Natural Resources were used (Republic of Turkey Ministry of Energy and Natural Resources, n.d.).

According to official data, 1 MWh of electricity consumption corresponds to approximately 0.445 tons of CO_2e. Since electrical energy is used for heating, cooling, ventilation, and all other operational activities within the building after energy retrofits, carbon emission calculations were conducted and compared for both the initial (pre-retrofit) and final (post-retrofit) states. For the environmental analysis, the service life of the building was assumed to be 30 years.

FINDINGS AND DISCUSSION

This section covers the validation and analyzes the material properties and operational energy consumption of the baseline case, followed by the energy simulation of the reference model. Energy savings are calculated based on the reference model, assessing the feasibility of retrofitting the existing building. Additionally, a comprehensive evaluation is conducted covering energy savings, overheating and thermal comfort, environmental impact, and cost analysis of the proposed interventions. The results are subsequently discussed in detail.

Validation of the Energy Model

The error margins obtained from the measured and simulated indoor temperature data were compared with the acceptable limit values defined in ASHRAE Guideline 14-2002.

For the climate and building energy model validation, the Mean Bias Error (MBE) was found to be in the range of -6.95% to -10.01%, while the Coefficient of Variation of the Root Mean Square Error (CV(RMSE)) ranged from 11.85% to 23.80% (Figure 5).

Since these values remained within the acceptable thresholds specified by ASHRAE Guideline 14, the building energy model was deemed reliable. Consequently, a comparative analysis of annual energy consumption, carbon emissions,

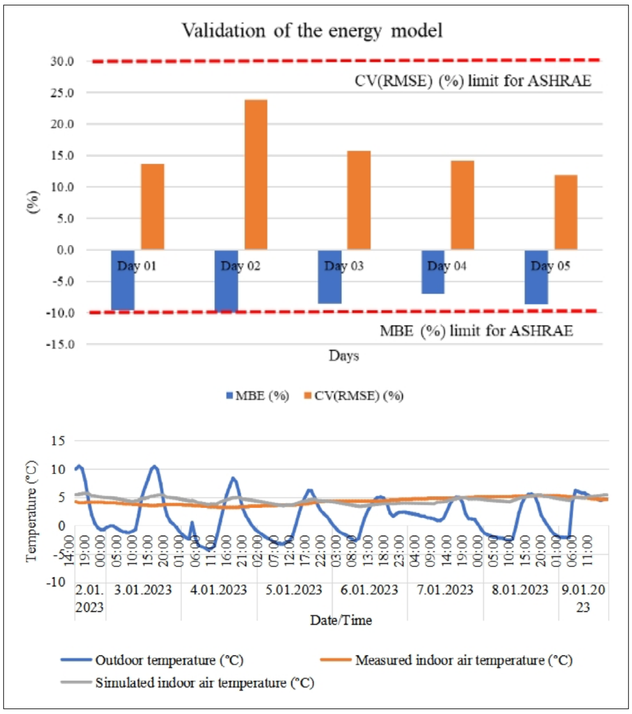

Figure 5. Validation of the building energy model (above), real-time measurements and simulation results for the indoor temperatures (below).

Table 4. Unit embodied carbon values (A1-A3) of the energy retrofits

Material/System	Unit	Embodied Carbon (kg CO_2-e)	Source
VRF-HR units	1 product	5.43E+02	Daikin, 2024
Rock wool (0.037W/mK, 60 mm, 33 kg/m^3)	1 m^2	2.62E+00	Knauf, 2021
Triple glass unit (4-12-4-12-4)	1 m^2	4.80E+01	Environdec, 2023

costs, and thermal comfort criteria was conducted for both the baseline and retrofitted scenarios, considering the in-use condition of the building.

Energy Simulations

Energy simulations were conducted based on the assumptions used to generate the building energy models. The results indicate that the heating load of the baseline energy model is 90.7 kWh/m²/year. To achieve Passive Building Standard compliance, an 83.4% reduction in heating load is required. Additionally, the primary energy demand is 163.1 kWh/m²/year, necessitating a 26.4% reduction to meet passive building criteria.

Thermal comfort analysis shows that the average indoor temperature exceeds 25°C for 17.6% of the year, while operative temperatures surpass 25°C for 16.4% of the year. According to the Passive Building Standard, these values should be reduced to below 10% to mitigate overheating risks.

The first stage of energy retrofitting involved the integration of energy-efficient HVAC units. Heating and cooling were provided using a heat recovery air conditioning unit, specifically a VRF-HR system.

As a result of this HVAC intervention:

- The heating load decreased to 58.3 kWh/m²/year, representing a 35.7% reduction.
- The primary energy demand dropped to 145.4 kWh/m²/year, achieving a 10.8% reduction.

In the second stage, rock wool insulation panels were applied to the building envelope, increasing its thermal inertia (Table 5). The thicknesses of the insulation layers were determined to ensure that the thermal transmittance of building components remains below 15 W/m²K, as required by the Passive Building Standard.

Furthermore, it was assumed that the airtightness of the structure improved, with air leakage decreasing to 0.59 air changes per hour (ac/h) following the addition of insulation layers.

As a result of the energy simulation, the heating load decreased by 87%, reaching 7.2 kWh/m²/year. Additionally, the primary energy demand was reduced by 36.1%, falling to 94.3 kWh/m²/year. These improvements successfully met the Passive Building Standard requirements for heating and primary energy demand. However, the addition of the insulation layer resulted in a 10.8% increase in cooling load.

In the third stage of the energy retrofit, windows and doors were upgraded to enhance thermal performance. The thermal transmittance (U-value) of the windows was reduced from 2.71 W/m²K to 0.78 W/m²K by installing argon-filled triple glazing. Additionally, insulation was applied to the doors, which are made of painted oak wood, reducing their U-value to 0.56 W/m²K. In addition to enhancing the window glazing, 1-meter-long shading elements made of moderately reflective metal slats were installed inside the windows. In-glass blinds were programmed to remain open during summer (June–August) to optimize thermal performance.

According to the simulation results, the heating load remained unchanged compared to the baseline case, while the cooling load decreased by 13.4%, reaching 14.1 kWh/m²/year. A 2.3% reduction in primary energy demand was achieved, resulting in an energy consumption of 92.1 kWh/m²/year.

Table 5. Improving the thermal performance of the building envelope with insulation

	Material	Thickness (m)	Thermal conductivity (W/mK)	Specific heat (J/kg-K)	Density (kg/m³)	U value (W/m²K)
Wall	Plaster	0.02	0.4	1000	1000	0.143
	Rock wool	0.24	0.037	840	33	
	Concrete block	0.30	1.15	1000	1800	
	Plaster	0.02	0.4	1000	1000	
Hipped roof	Roof tile	0.025	1	800	2000	0.148
	Rock wool	0.24	0.037	840	33	
	RC	0.12	1.15	1000	1800	
Flat roof	Ceramic tile	0.018	0.85	840	1900	0.148
	Rock wool	0.24	0.037	840	33	
	RC	0.12	1.15	1000	1800	
Floor	Screed	0.05	1.4	650	2100	0.146
	Rock wool	0.24	0.037	840	33	
	RC	0.12	1.15	1000	1800	

After implementing all energy retrofits, the study determined that a 92% reduction in heating load was achieved, while cooling load and primary energy demand fully complied with Passive Building Standard requirements. VRF-HR system contributed to a 35.7% reduction in heating load, while insulation and airtightness accounted for 88.3% of the total heating reduction. However, window retrofits had no significant impact on heating demand due to the low window-to-wall ratio.

Regarding cooling load, the impact of the VRF-HR system could not be determined, as the building did not previously have a cooling system. Floor, wall, and roof insulation, along with airtightness improvements, caused a 10.8% increase in cooling demand, while window retrofits played a 13.5% role in cooling demand reduction.

Regarding total energy savings, the contributions of individual retrofit measures were as follows: the VRF-HR provided a 10.8% reduction in primary energy demand, insulation and airtightness contributed to a 35.1% reduction, and window improvements resulted in a 2.3% reduction. These combined efforts led to a total energy saving of 43.5% (Figure 6).

Overheating and Thermal Comfort

After the energy improvements, the operative temperature, which serves as an indicator of thermal comfort and is calculated as the arithmetic average of the radiation temperature and indoor dry-bulb temperature, was analyzed to assess overheating, a key criterion of the Passive Building Standard. According to the passive building requirements, the operative temperature should not exceed 25°C for more than 10% of the hours in a year. The results indicate that the operative temperature exceeds this threshold for 9.8% of the annual hours, demonstrating compliance with the standard. The implemented measures resulted in a 40.2% reduction in overheating hours per year (Figure 7).

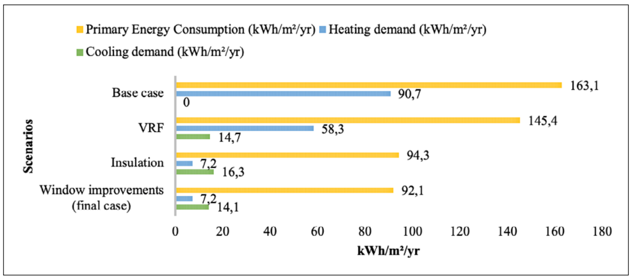

Figure 6. The effects of the improvements on the energy performance of the building.

Additionally, the average indoor temperature range between 19.4°C and 27.8°C, which falls within the comfort range specified by ASHRAE Standard 55-2017. The average indoor humidity remains between 40% and 60%, meeting the required comfort conditions. These findings confirm that the retrofitting measures not only improved energy efficiency but also prevented the building's overheating (Table 6).

The thermal comfort conditions were also evaluated using the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) methods, in accordance with ASHRAE 55-2023 (Center for the Built Environment, n.d.). The results confirmed that overheating alone is not a sufficient criterion for ensuring user thermal comfort. Instead, a comprehensive assessment of is necessary.

The PMV-PPD analysis revealed that only two of the datasets met the thermal comfort criteria. During the summer period, up to 87% of users are likely to experience discomfort (cool) when the operative temperature is below average (Table 7). This suggests that the current conditions may not be optimal for occupant comfort.

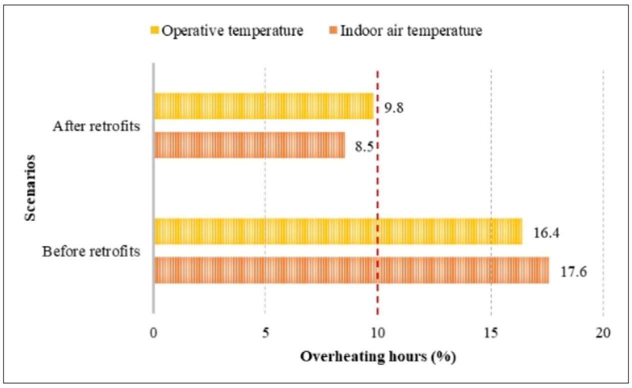

Figure 7. Overheating before and after the retrofits.

Table 6. Overheating hours of the building during the year after improvements

Overheating status	Average indoor air temperature	Operative temperature	Relative humidity	Outside dry-bulb temperature
Minimum	15.1	17.1	10.2	-9.7
Maximum	31.5	29.9	78.7	38.6
Mean	21.9±2.1	22.4±2	43.8±12.5	13±9
Hours above 25°C (uncomfortable)	741	860		
Total hours in a year	8760			
Uncomfortable hours (%)	8.5	9.8		

Table 7. Thermal comfort based on PMV/PPD method

Operative temperature (°C)	Relative humidity	Clothing level (clo)	PMV	PPD (%)	Sensation
20.4	31.1	0.5	-2.25	87	Cool
20.4	56.3	0.5	-2.09	81	Cool
20.4	31.1	1.0	-0.89	22	Slightly cool
20.4	56.3	1.0	-0.73	16	Slightly cool
24.4	31.1	0.5	-0.77	18	Slightly cool
24.4	56.3	0.5	-0.57	12	Slightly cool
24.4	31.1	1.0	0.16	6	Neutral
24.4	56.3	1.0	0.36	8	Neutral

However, adjusting the operative temperature to above average during winter conditions significantly improves thermal comfort. Under these conditions, the percentage of users experiencing discomfort is reduced to only 6-8%, ensuring that the thermal comfort threshold is met (Figure 8). These findings indicate that careful temperature regulation is necessary to maintain an optimal indoor environment throughout the year.

Cost Analysis

Following the completion of the energy retrofits, the initial investment costs and payback periods of the applied measures were calculated to evaluate their feasibility within the scope of the project. In addition, the total costs were determined by incorporating both initial investment costs and 30-year operating expenses.

For accurate cost assessment, foreign exchange transactions for Euro (€) to Turkish Lira (₺) were based on the Indicative Exchange Rates of the Central Bank of the Republic of Türkiye as of 24.07.2024 at 15:30 (Table 8). This ensures that cost evaluations reflect real-time currency values, enhancing the reliability of the economic analysis.

After calculating the costs, the annual energy savings were determined by comparing the baseline annual energy consumption with the total annual energy consumption of retrofitted case. This corresponds to a total energy saving of 142,000 kWh per year.

As a result of the calculations, it was determined that:

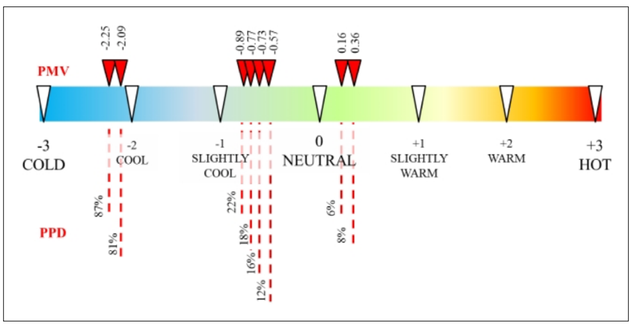

Figure 8. PMV/PPD results and thermal comfort assessment.

Table 8. Total quantity and price calculation of the applications proposed for the project

Scenarios	Total amount	Total cost
VRF-HR	20 high static pressure concealed ceiling type indoor units (ducting, copper piping and installation)	200,000 €+18% VAT =8,413,400 ₺
Insulation	3310 m² 24 cm	47,664 €+18% VAT =2,005,062 ₺
Window (with argon gas)	50.26 m²	73,336 ₺+18% VAT =86,536 ₺
		2,261 ₺+18% VAT =2,668 ₺
Total		10,507,666 ₺

- Window replacement costs (86,536₺) can be fully recovered within the first year.
- Insulation costs (2,005,062₺) can be covered within the first three years.
- VRF-HR costs (8,413,400₺) will be recouped within seven years.

The findings indicate that the proposed energy retrofitting measures are financially viable, with relatively short payback periods, making them a cost-effective solution for improving building energy efficiency.

Finally, the additional investment costs and 30-year operating costs were evaluated together to determine the overall economic feasibility of the proposed retrofitting measures. The annual primary energy demand in the final scenario was calculated by accounting for inflation-driven increases in energy costs and compared with the operating costs of the baseline case.

According to the results, the total initial investment and 30-year operating costs of the proposed passive building were found to be 43.4% more economical compared to the operating costs of the baseline case alone (Table 9).

Table 9. Calculation of operating and investment costs

Years (2024-2053)	Baseline	Passive building
Operational cost (₺)	12,957,131,748	7,316,688,130
Additional cost (₺)	-	10,507,666
Total cost (₺)	12,957,131,748	7,327,195,796
Saving (%)	-	43.45

These findings highlight that, despite the initial capital investment, transitioning to a Passive Building Standard yields significant long-term financial benefits, making it a cost-effective and energy-efficient solution.

Environmental Impact

Both embodied carbon emissions and operational carbon emissions were assessed to evaluate the overall environmental impact of the proposed energy retrofits. The total embodied carbon emissions resulting from the retrofits were calculated based on Environmental Product Declaration (EPD) data sheets. According to these calculations:

- VRF-HR system contributed 10,860 kg CO_2-e,
- Insulation accounted for 34,689 kg CO_2-e,
- Windows contributed 2,412 kg CO_2-e,
- Leading to a total embodied carbon footprint of 47,961 kg CO_2-e.

The total annual operational carbon emissions were calculated based on annual energy consumption. The energy-to-carbon conversion factor from the Ministry of Energy and Natural Resources (n.d.) was used, where 1 MWh of energy consumption corresponds to 0.445 tons of CO_2-e.

In the baseline case, with an annual energy consumption of 163.1 kWh/m^2/year, the corresponding operational carbon emissions were 72.6 tons CO_2-e per square meter per year. After implementing the retrofits, with an annual energy consumption of 92.1 kWh/m^2/year, the operational carbon emissions were reduced to 41 tons CO_2-e per square meter per year. As in the cost analysis, the operational period for environmental analysis was considered as 30 years. Over this period, the total operational greenhouse gas (GHG) emissions would have been 2,177 tons per square meter in the baseline case. After the retrofits, this value decreased to 1,230 tons per square meter. When embodied carbon emissions from the production stage (A1-A3) were included, the total emissions after retrofits amounted to 1,277 tons per square meter.

As a result, the GHG emissions from operational energy consumption were reduced by 43.5%, while the total carbon emissions decreased by 41.3% compared to the baseline scenario, demonstrating the significant environmental benefits of the energy-efficient retrofits (Figure 9).

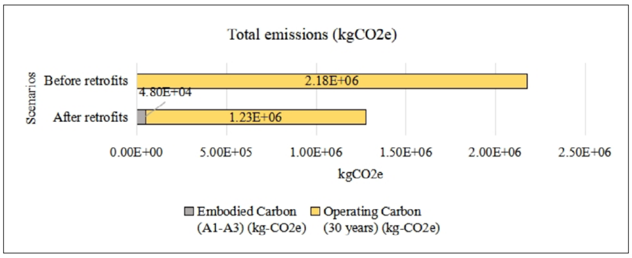

Figure 9. Environmental impact of the energy retrofits.

Assessment of the Results

This study aimed to promote sustainability in the architectural domain by retrofitting Yenişehir Cinema in accordance with Passive Building Standard requirements. Additionally, the project envisions reintegrating Yenişehir Cinema into urban life as a passive building, ensuring both economic and environmental sustainability. Economic sustainability is achieved through applicable energy-efficient solutions, while environmental sustainability is targeted by reducing the building's carbon footprint. To accomplish these goals, passive building strategies were systematically implemented, fulfilling all required conditions.

The desired thermal transmittance values for walls, doors, and windows were successfully achieved, and a heat recovery ventilation unit was integrated into the building. As a result, the heating, cooling, and primary energy demands were reduced to below threshold values, and the overheating level of the building was significantly minimized.

Comparing the baseline case with the retrofitted case, the results indicate a 43.5% reduction in annual primary energy demand, while heating demand decreased by 92%. Although the overheating issue was reduced by 40%, further improvements are required to ensure optimal thermal comfort for users.

The proposed retrofits are financially feasible, with a total payback period of 7 years. Furthermore, the total carbon emissions of the building were reduced by 41.3%, demonstrating the environmental benefits of energy-efficient interventions. Consequently, the study has successfully achieved ecological, economic, and social improvements, paving the way for Yenişehir Cinema to be reintroduced into urban life as a retrofitted passive building (Figure 10).

CONCLUSION AND RECOMMENDATIONS

The depletion of non-renewable resources and the ongoing challenges posed by climate change present significant obstacles to the sustainability of existing buildings. As a result, it is crucial to enhance the energy performance of such buildings to ensure their continued viability. The Passive Building Standard provides a comprehensive range of solutions to address this challenge. According to the

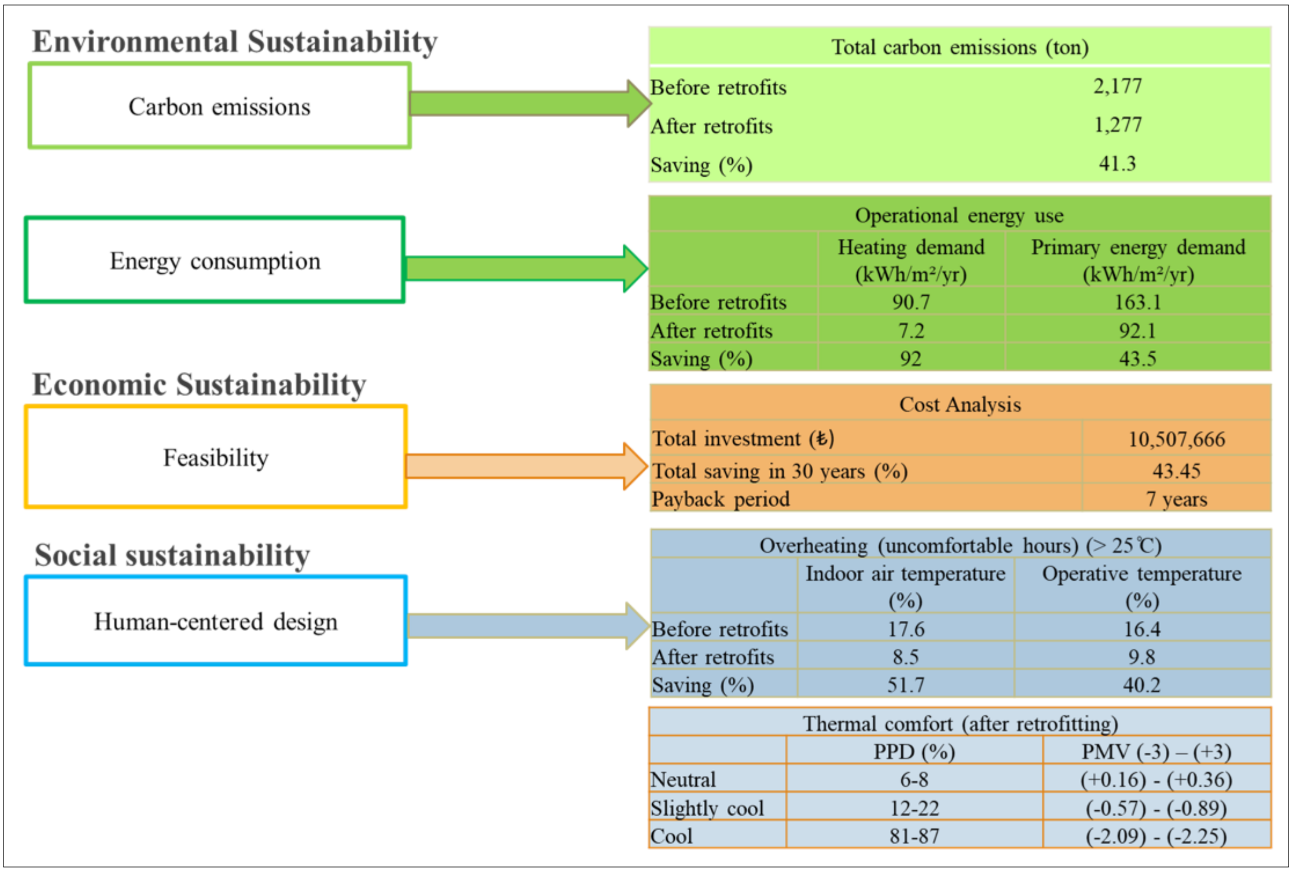

Figure 10. Interpretation of the results in the perspective of sustainable architecture.

standard, energy demands should be balanced to maintain user comfort throughout the year, and the integration of hybrid systems is recommended to optimize performance.

Yenişehir Cinema, a notable modern architectural building, holds significant value in the collective memory of the community. Currently, the building is vacant, but it is believed that the structure can be successfully retrofitted using the principles of the Passive Building Standard and reintegrated into urban life. In alignment with the EnerPHit certification system, the thermal performance of the building envelope was enhanced by incorporating active air conditioning systems, adding insulation, and improving transparent surfaces. One of the major barriers to energy efficiency and comfort was the lack of insulation in the building envelope. Consequently, 35.1% of energy savings in primary energy consumption were achieved solely through improvements to insulation and airtightness. Additionally, the installation of a heat recovery ventilation system prevented heat losses, resulting in a 10.8% reduction in energy consumption. However, due to the building's low transparency, the improvements to windows and doors contributed the least to energy performance, accounting for only 2.3% of the total energy savings. As a result, all requirements to achieve the EnerPHit certification system have been completed.

From an economic standpoint, the window improvements can be covered within the first year, insulation applications within three years, and the VRF-HR system within seven years.

By ensuring thermal comfort, it is possible to create a user-oriented interior space, fostering an environment where social interactions can thrive. The study found that while overheating can be prevented according to the Passive Building Standard, this alone is insufficient to ensure the required thermal comfort. The PMV/PPD method demonstrated that additional measures are necessary to achieve and maintain optimal thermal comfort. While implementing these measures, passive approaches, such as Trombe walls and innovative insulation materials, should be considered to prevent the building from consuming excessive energy during the use phase while ensuring thermal comfort.

Although the proposed improvements led to an increase of 48 tons in the embodied carbon of the building, the overall total carbon emissions decreased by approximately 41% due to the reduction in carbon emissions during the operational phase. This indicates that the retrofitting measures yield positive environmental sustainability outcomes.

Increasing legal regulations and financial support mechanisms that encourage passive building conversions in Türkiye will contribute to the sustainable transformation of the existing building stock. Projects promoted through public-private partnerships would help similar practices to become widespread and YES-TR certificates to be obtained.

Future research can focus on advanced technologies and innovative materials that can be applied to heritage buildings. A comprehensive approach that addresses the energy-carbon-cost triangle is essential for achieving long-term sustainability. Similar passive building transitions can be tested in different climate zones to assess the applicability of passive building strategies in various climatic conditions in Türkiye. Further research can be conducted on how to optimize energy efficiency strategies in different geographical regions. Furthermore, in addition to thermal comfort, visual comfort, acoustic comfort, and the indoor air quality should be considered to ensure the creation of a truly sustainable built environment.

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