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Accessibility Analysis of nZEB Potential in Traditional Buildings: The Mihrali Bey Mansion

Hikmet ALİM[1,*], Figen BEYHAN[2]

[1] *0000-0002-5524-0015, Sivas Cumhuriyet University, Sivas Vocational School of Technical Sciences, Department of Architecture and Urban Planning, Sivas*

[2] *0000-0002-4287-1037, Gazi University Faculty of Architecture Department of Architecture, Ankara*

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Abstract

This research aims to evaluate the potential for cultural heritage buildings to achieve the nearly zero-energy building standard by improving their energy performance, using a multidimensional approach and taking the registered Mihrali Bey Mansion, located in Acıyurt Village of Ulaş District, Sivas Province, as a case study. Efforts to reduce energy consumption in the built environment should not be limited solely to technical interventions; they must also be carried out in compliance with international principles that prioritize the preservation of the building's cultural heritage quality, fabric, and identity. In practice, the four-tier intervention scale developed by the UK-based Historic England was adopted, and the mansion's current condition was comparatively analyzed against design proposals aimed at enhancing its energy performance. Both scenarios prepared within the scope of the study were tested using the DesignBuilder building energy simulation software and evaluated based on criteria such as annual energy consumption and heating/cooling requirements. Furthermore, in the proposed scenario, the roof surface was covered with photovoltaic (PV) panels to largely obtain the energy required by the mansion from renewable energy sources, thereby examining its potential to achieve nearly zero-energy building (nZEB) status. The results of the research demonstrated that energy improvements compatible with conservation awareness are feasible and applicable for high historical value buildings in terms of technical and cultural sustainability.

1. INTRODUCTION

Mihrali Bey, from the Karapapak Turks, was born in 1844 in the village of Dervaz, which was part of the Borçalı district of Tbilisi [1]. He learned to ride horses and use weapons at a young age and became known for his bravery. At the age of 17, upon the death of his father, he objected to his burial in a Christian cemetery, killed the Russian guards, buried the funeral in a Muslim cemetery, and was subsequently sought by the Russians. His fugitive life lasted until the 93 War. During the war, he wrote a letter to Kars commander Hüseyin Hami Pasha, stating his desire to fight on the Ottoman side, and joined the army with the rank of major, along with 120 men. Due to his outstanding achievements in the war, Mihrali Bey was awarded the rank of Colonel (Miralay) and the Order of the Medjidie by Sultan Abdülhamit II. After the war, he migrated with his family to Ottoman lands, settled in Acıyurt village in the Ulaş sub-district of Sivas in 1879, and built a mansion there. Mihrali Bey, who established the 40th Hamidiye Cavalry Regiment in Sivas, was assigned during the rebellion in Yemen, where he fell ill and died in 1905 [2]. In this context, the personality of Mihrali Bey, the builder of the mansion, who is associated with heroism, reinforces the symbolic meaning of the structure and deepens the social and historical function of the mansion. In this regard, the preservation of the Mihrali Bey Mansion does not only mean the conservation of an architectural structure; it also means keeping alive a historical narrative, a social value, and local memory.

In interventions aimed at increasing the energy performance of traditional buildings with cultural heritage value, not only technical efficiency but also the preservation of cultural heritage in line with international

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[*] Corresponding author: hikmetalim@cumhuriyet.edu.tr

conservation principles must be considered a fundamental priority. Within this framework, the Valletta Principles for the Safeguarding and Management of Historic Cities, Towns and Urban Areas, published by ICOMOS in 2011 [3], emphasize that energy improvement applications must be carried out in a manner that does not damage the original material, spatial arrangement, or historical character. Similarly, the Venice Charter (1964) [4] and the Burra Charter (1979-2013) [5] state that all interventions made in traditional buildings must be reversible and minimal, preserving the authenticity and documentary value of the structure. In line with these principles, applications aimed at increasing energy efficiency must be carried out without compromising the physical integrity of the structure or erasing historical traces. Furthermore, policies developed by organizations such as Europa Nostra [6] and the Council of Europe [7] also demonstrate that the preservation of cultural heritage is the primary principle in energy transition processes and that sustainability can be achieved by observing this delicate balance. The Heritage Counts 2019 report [8] also revealed within this framework that the conservation and energy-sensitive adaptive reuse of existing traditional buildings is a more sustainable approach, both environmentally and culturally, compared to new constructions. Therefore, efforts to ensure energy efficiency in traditional buildings must be addressed not only through engineering-based technical solutions but also through a holistic and multidisciplinary perspective, guided by international conservation ethics and principles.

Various academic studies have been conducted to improve the energy performance of traditional buildings. In the article titled Retrofit of an Historical Building Toward nZEB, published by Dalla Mora et al. in 2015 [9], the energy consumption of the historical Ca'S.Orsola building was reduced by 90% because of the implemented energy-efficient interventions. In the article titled Energy Efficient Improvement of Historic Buildings: A Case Study in Sinop Province, published by Genç and Beyhan in 2021 [10], the energy analyses of the selected historic building were conducted based on 4 different scenarios created using the existing condition and the Historic England intervention assessment scale, and the results were evaluated. In the article titled Historical Building Renovation and PV Optimisation Towards NetZEB in Sweden, published by Gremmelspacher et al. in 2021 [11], a 150-year-old castle located in Helsingborg, Sweden, was used to evaluate the potential for converting historic buildings in Scandinavian countries into an NZEB (Net Zero Energy Building). Within the scope of the study, energy efficiency interventions were carried out in the first phase, and in the second phase, it was determined that the building reached the NZEB standard by installing PV panels on the building. In the article titled Transformation of a Historic Building into a Nearly Zero Energy Building (nZEB), published by Romano and Mancini in 2022 [12], the energy performance of the historic Palazzo De Simone building was increased using non-destructive active and passive systems, and it was brought up to nearly zero energy building standards using PV panels. In the article titled Relationship Between Different Application Approaches and Energy Efficiency in Historic Buildings, published by Genç and Beyhan in 2023 [13], 5 different scenarios were created based on the Esma Sultan Mansion in Istanbul, and the energy efficiency levels of each scenario were evaluated. In the article titled Reconciling Heritage Buildings' Preservation with Energy Transition Golas: Insight from an Italian Case Study, published by Franco and Mauri in 2024 [14], energy-efficient improvement solutions were applied to a historic building undergoing restoration in Genoa, and the possibility of the structure approaching nZEB parameters was evaluated.

As a result of the literature review conducted, while various studies exist at the international level regarding the attainability of nearly zero energy building (nZEB) or net zero energy building (NZEB) standards for traditional structures with cultural heritage value, it has been determined that studies focusing on the energy-efficient improvement of traditional structures with cultural heritage value at the national level remain limited. In this context, this study distinguishes itself from similar ones by investigating the attainability of the nearly zero energy building standard for a traditional structure with cultural heritage value at the national level.

In line with this, based on the intervention assessment scale developed by Historic England, two scenarios were constructed for the Mihrali Bey Mansion in Ulaş district of Sivas province: the existing condition and a design scenario incorporating energy efficiency improvements. Both scenarios were comparatively analyzed in terms of energy consumption performance. The DesignBuilder simulation software was used in the evaluation of the scenarios; annual heating and cooling loads and energy consumption values per unit area were calculated. The quantitative data obtained were presented through graphs and tables;

significant differences between the scenarios were demonstrated in the context of energy efficiency. Furthermore, within the scope of the design scenario, the potential for the structure to reach the “nearly zero energy” (nZEB) standard was analyzed by integrating photovoltaic (PV) panels onto the building's roof covering. This comprehensive assessment demonstrates that the building's identity and cultural value can be preserved while increasing energy performance.

2. ENERGY EFFICIENCY APPLICATIONS IN TRADITIONAL BUILDINGS WITH THE HISTORIC ENGLAND SCALE

The Historic England scale adopts a holistic approach aimed at preserving the historical, architectural, and material character of traditional structures with cultural heritage value, based on the principles of minimum intervention and reversibility in energy efficiency interventions specific to these structures. The goal of increasing energy performance is balanced with the necessity of preserving the building's originality and cultural value [15]. The intervention process begins with the analysis of the building's architectural, historical, and material characteristics, and the impact of every proposed application on these values is subject to special evaluation.

In the improvement approach for energy efficiency developed by Historic England, a detailed analysis of the existing structure is first carried out; surfaces with heat loss, moisture and condensation risk are assessed, and subsequently, each proposed intervention is tested according to conservation criteria. The prominent intervention methods in this context are [15]:

- Applications aimed at increasing the level of airtightness
- Use of solar control elements such as shutters, blinds, etc.
- Floor slab and roof thermal insulation applications
- Internal thermal insulation applications on walls
- Transparent surface applications such as secondary glazing, double glazing, low-e coating, etc.
- Integration of active systems for heating, cooling, and ventilation
- Use of renewable energy through PV panel applications

Interventions such as external facade insulation, use of PVC joinery, and synthetic paint systems are generally not recommended due to the risk of damaging the cultural heritage character of the structure.

Applications aimed at increasing the level of airtightness [16]: This is one of the simplest and most cost-effective methods for improving the thermal performance of traditional buildings. In areas with high air leakage, such as around doors and windows, reversible, non-damaging, and invisible solutions like brush or silicone-based thin seals should be applied to the original joinery. Furthermore, the balance of vapor permeability must be observed in airtightness applications.

Use of solar control elements [17]: Solar control plays a significant role in reducing energy consumption by preventing overheating, thereby decreasing the need for cooling. In this context, passive design elements such as shutters, blinds, awnings, curtains, and external shading should be implemented in a manner compatible with the traditional architectural texture of the building, reversible, and requiring minimal intervention; permanent effects must be avoided. Furthermore, preserving the visual integrity of the exterior facade and respecting the original materials and details are among the fundamental principles.

Floor slab and roof thermal insulation applications [18,19]: Roofs and floors, which are among the areas experiencing the highest heat loss, are priority intervention areas for increasing energy performance. However, when carrying out these applications, the original material structure of the building, its effect on moisture balance, and its cultural heritage value must be taken into consideration. For roof insulation, materials that do not impede the building's ventilation and do not pose a fire risk should be preferred, applied either above the slab or between the rafters, depending on whether the roof space is heated. For floor insulation, a reversible raised floor system should be constructed, and insulation placed within it, in order to protect the existing material and structure.

Internal thermal insulation applications on walls [20]: Since internal insulation applications can be risky, especially regarding moisture management, insulation systems that allow vapor permeability should be preferred in material selection. Before application, problems such as moisture, salt, and structural deterioration on the walls must be identified and rectified. During application, a reversible construction should be created on the wall surface using wooden battens or metal profiles, filled with insulation material, and then covered with appropriate material. Existing decorative interior surfaces, ornaments, or murals must be protected.

Transparent surface applications [21]: Traditional windows typically have single glazing and are air-leaking, thus constituting weak points in terms of energy loss. In this context, reversible and minimally invasive methods such as secondary glazing, low-e coating, and thermal curtains should be prioritized. Another application for energy efficiency in transparent surfaces is double glazing. Slim-profile double glazing systems adaptable to existing frames should be preferred, and to ensure visual compatibility, frames consistent with the original window design, appropriate division ratios, and the use of wooden materials must be maintained. Furthermore, technical parameters such as moisture control, risk of fogging, and balancing of indoor air must also be considered.

Active system integration [22]: When implementing active systems, preference should be given to compact, recyclable systems that can adapt to the environment in which they are placed. For heating systems, condensing boilers, low-temperature radiant panels, or underfloor systems are recommended; for cooling, passive cooling-supported solutions integrated with humidity control are suggested; and for ventilation, the use of low-energy mechanical systems supported by natural ventilation strategies is recommended, especially when aiming to remove humidity and improve indoor air quality. When placing system components, existing structural elements must be protected, damage to walls and ceilings should be minimized, and installation should be done in a recyclable manner.

Use of renewable energy with PV panel applications [23]: Renewable energy systems must be carefully evaluated so as not to threaten the cultural, aesthetic, and physical integrity of the structure. Placing PV panels directly on the roofs or facades of traditional buildings with cultural value can pose serious risks in terms of visual impact and structural intervention. Therefore, applications must be designed in a way that does not disrupt the building's silhouette, roof form, and material integrity. The most ideal solutions involve panel slopes being compatible with the natural structure and preferably integrating the panels into a separate structure or the surrounding land. Less conspicuous alternative technologies are also available, such as advanced thin-film panels, building-integrated photovoltaic systems (BIPV), or transparent glass modules. Furthermore, before the installation of the PV system, necessary permissions must be obtained from the relevant conservation boards, considering the building's status as an immovable cultural asset.

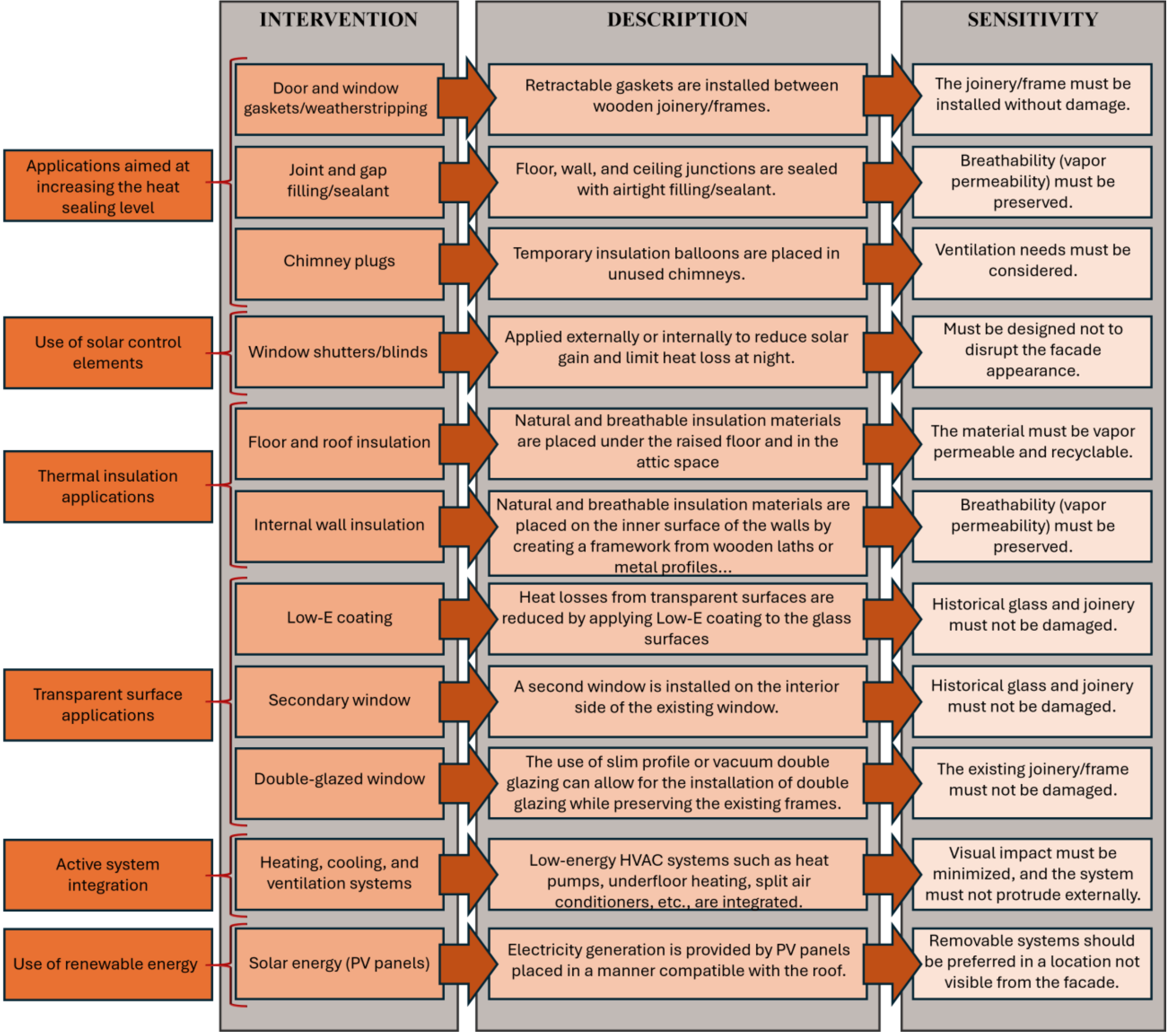
3. MATERIAL AND METHOD

This study investigates the potential for upgrading traditional buildings classified as cultural heritage to the nearly Zero Energy Building (nZEB) standard while preserving their original identity. To this end, guidelines published by the UK-based conservation organization Historic England regarding energy efficiency improvements in traditional buildings of cultural heritage value were taken as a basis. In line with these guidelines, an intervention decision matrix encompassing passive, active, and renewable energy systems applicable to traditional buildings has been developed. This decision matrix consists of three components:

(1) *Intervention: Definition of the energy improvement technique to be applied*
(2) *Description: Technical implementation method of intervention*
(3) *Sensitivity: Conservation criteria regarding the intervention's effect on the building's original texture, material, and silhouette*

The interventions were selected considering the principles of reversibility, material compatibility, vapor permeability, applicability without interfering with the load-bearing system, and preservation of facade/silhouette integrity. Thus, the suitability of every proposed improvement was evaluated not only in terms of energy performance but also in terms of the building's cultural integrity. It was specifically emphasized that in the case of applying photovoltaic (PV) panels from renewable energy systems, permission from the conservation board might be required due to the nature of external intervention (Table 1).

Table 1. *nZEB intervention decision matrix for traditional buildings of cultural heritage value*



	INTERVENTION	DESCRIPTION	SENSITIVITY
Applications aimed at increasing the heat sealing level	Door and window gaskets/weatherstripping	Retractable gaskets are installed between wooden joinery/frames.	The joinery/frame must be installed without damage.
	Joint and gap filling/sealant	Floor, wall, and ceiling junctions are sealed with airtight filling/sealant.	Breathability (vapor permeability) must be preserved.
	Chimney plugs	Temporary insulation balloons are placed in unused chimneys.	Ventilation needs must be considered.
Use of solar control elements	Window shutters/blinds	Applied externally or internally to reduce solar gain and limit heat loss at night.	Must be designed not to disrupt the facade appearance.
Thermal insulation applications	Floor and roof insulation	Natural and breathable insulation materials are placed under the raised floor and in the attic space	The material must be vapor permeable and recyclable.
	Internal wall insulation	Natural and breathable insulation materials are placed on the inner surface of the walls by creating a framework from wooden laths or metal profiles...	Breathability (vapor permeability) must be preserved.
Transparent surface applications	Low-E coating	Heat losses from transparent surfaces are reduced by applying Low-E coating to the glass surfaces	Historical glass and joinery must not be damaged.
	Secondary window	A second window is installed on the interior side of the existing window.	Historical glass and joinery must not be damaged.
	Double-glazed window	The use of slim profile or vacuum double glazing can allow for the installation of double glazing while preserving the existing frames.	The existing joinery/frame must not be damaged.
Active system integration	Heating, cooling, and ventilation systems	Low-energy HVAC systems such as heat pumps, underfloor heating, split air conditioners, etc., are integrated.	Visual impact must be minimized, and the system must not protrude externally.
Use of renewable energy	Solar energy (PV panels)	Electricity generation is provided by PV panels placed in a manner compatible with the roof.	Removable systems should be preferred in a location not visible from the facade.

Within the scope of the study, Mihrali Bey Mansion, located in Acıyurt village, Ulaş district, Sivas province, was selected as the case study building, and the structure was modeled in the EnergyPlus-based DesignBuilder v7.0.2 software. In the first stage, energy consumption, heating/cooling loads, and indoor comfort values were analyzed based on the mansion's current state. Subsequently, an energy efficiency improvement scenario was created by applying the interventions defined in the decision matrix, and a comparative analysis was performed using the same simulation parameters. In the final stage, the building's accessibility level to the nZEB standard was evaluated by integrating PV panels onto the suitable solar exposure surface of the roof.

The study, which is based on the evaluation of the building's current performance through simulation data, includes certain assumptions regarding material thermal conductivity coefficients, indoor usage profiles, and climatic data sets taken from the EnergyPlus library and ASHRAE standard scenarios used in the model. Furthermore, the applicability of the proposed interventions may vary depending on local conservation board decisions, owner preferences, and site conditions. Since photovoltaic panel applications can affect the roof silhouette and surrounding cultural perception, additional architectural adaptations may be required on site. In line with these limitations, the study acknowledges that the findings provide guidance at the principles level for buildings of similar typology, but that each application requires on-site material analysis and conservation expertise.

4. ENERGY PERFORMANCE ANALYSIS OF MIHRALI BEY MANSION

The Mihrali Bey Mansion was selected as the sample structure whose nZEB compliance potential was evaluated within the scope of this study. This section summarizes the building's plan layout, spatial organization, and construction technique; subsequently, the current energy performance based on EnergyPlus simulation results is presented. In the following subsection, the effects of the proposed improvement interventions, in line with Historic England guides, on energy performance are comparatively evaluated.

4.1. General Characteristics

Acıyurt, a village affiliated with the Ulaş district of Sivas province, is located 22 km from the Ulaş district and 59 km from the Sivas province. The village's elevation is 1320 m above sea level, and its terrain is slightly rugged [24]. According to the TS 825 Standard on Thermal Insulation Rules in Buildings, which entered into force in February 2025, the region where the village is located is defined as the 5th degree-day zone (very cold climate region) [25]. These climatic conditions necessitate high heating energy demand for buildings and make energy efficiency improvements crucial.

The Mihrali Bey Mansion was built in 1889 and is currently used as a museum. The mansion was registered as a second-group civil architectural structure and taken under protection in 1999 [29]. It underwent repairs twice, in 2006 and 2015. The two-story structure, built with a rectangular plan scheme, has a footprint of 466.87 m² and a total area of 674.64 m² (Figure 1).

Figure 1. *General View of Mihrali Bey Mansion*

There are two wooden double-leaf doors providing entry to the structure. The door on the south facade leads into the main hall (Hayat) area. The main hall area is connected to the hall (sofa), pantry (erzak), and kitchen (aşhane) areas. In the pantry area, two non-original WCs were constructed during the restoration application. The kitchen area, which is another area accessed from the main hall, contains the stove area (ocaklık) and cold storage (poyrazlık) sections, reached by ascending four steps (Figure 2).

Figure 2. *Mihrali Bey Mansion Main Hall (1), Pantry (2) and Kitchen (3) Areas*

The other door providing entry to the structure is located on the east facade. This door leads into the hall (sofa) area. From the hall, access is provided to the main hall (hayat) and rooms on the ground floor. Additionally, there is a wooden staircase in this area providing access to the upper floor areas. The upper floor features a central hall (sofa), four iwans (eyvan) on the sides, and four rooms in the corners. On this floor, there are two summer rooms and two winter rooms opening onto the hall (Figures 3, 4, 5).

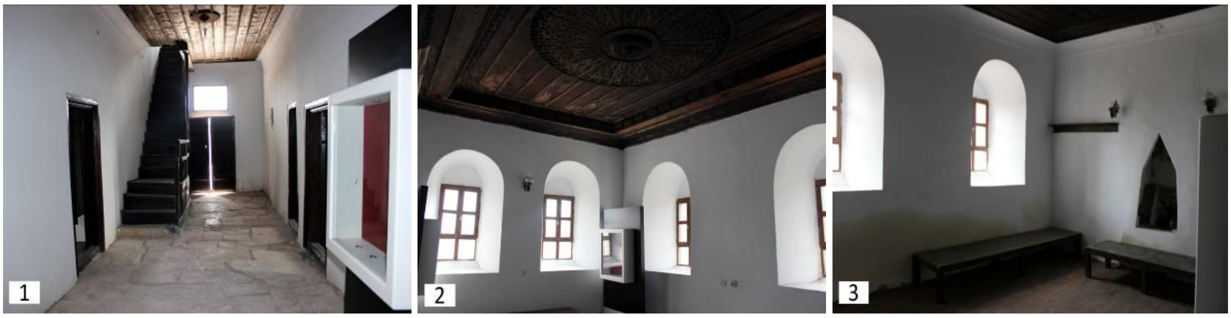


Figure 3. *Mihrali Bey Mansion Ground Floor Hall (1), Southeast (2) and Northwest (3) Room Areas*

Figure 4. *Mihrali Bey Mansion Upper Floor Hall (1), East (2) and South (3) Iwan Areas*

Figure 5. *Mihrali Bey Mansion Upper Floor Winter (1) and Summer (2) Room Areas*

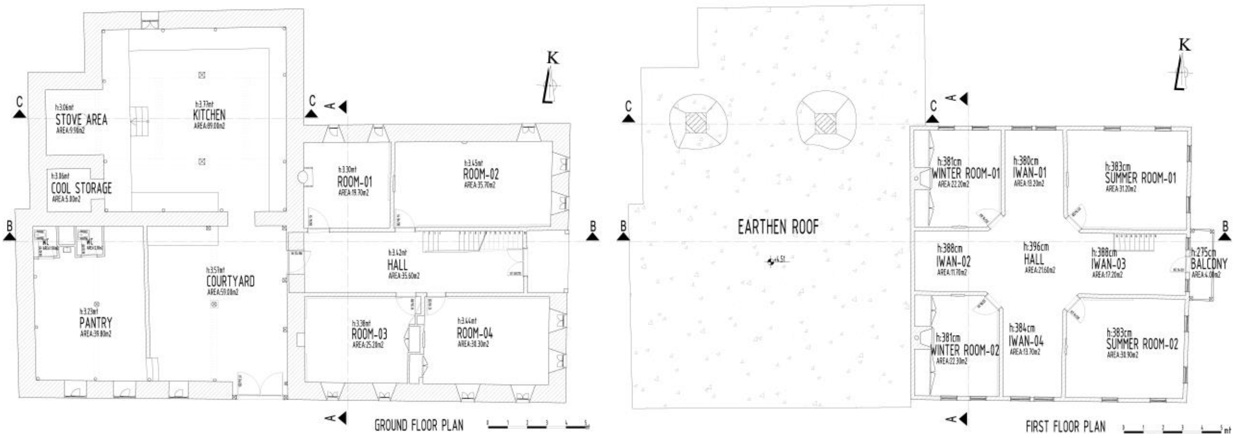


Figure 6. *Mihrali Bey Mansion Floor Plans*

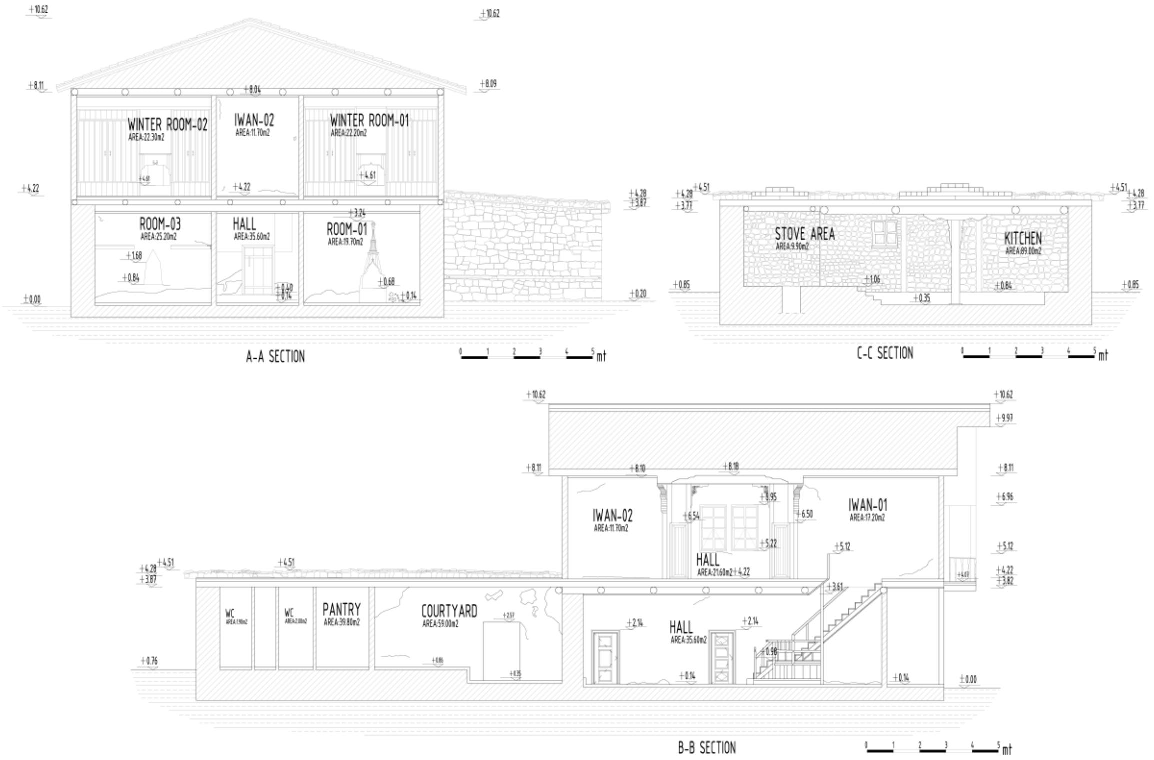


Figure 7. *Mihrali Bey Mansion Sections*

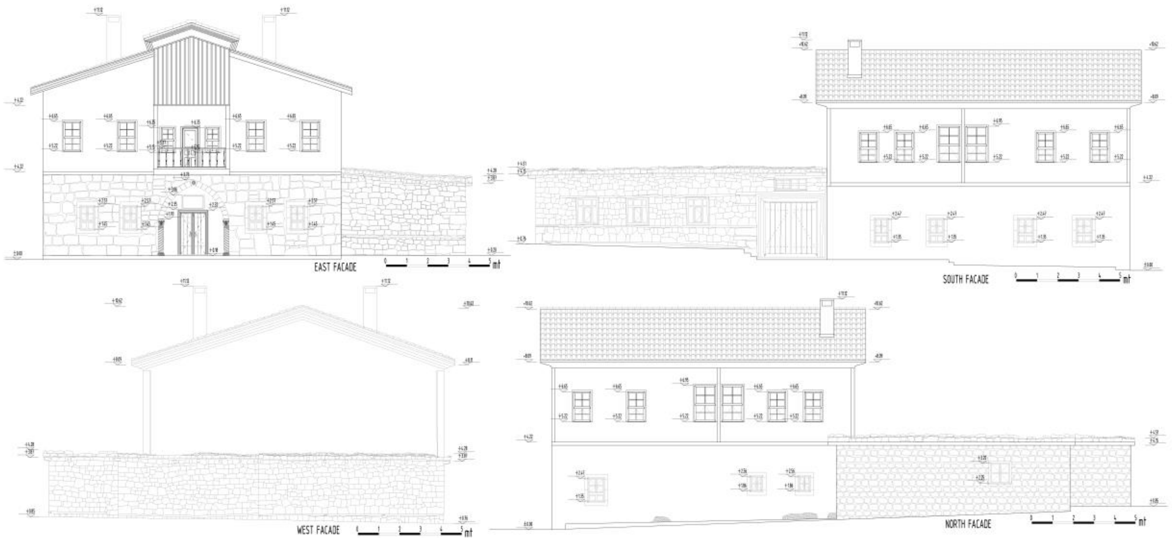


Figure 8. *Mihrali Bey Mansion Facades*

4.2. Construction Technique and Material Properties

The Mihrali Bey Mansion was constructed with a rubble stone masonry system on the ground floor and a timber framed wall system with adobe infill on the first floor. The mass containing the hall (sofa) and rooms on the ground floor was built using ashlar stone in a masonry system, while the mass containing the kitchen (aşhane), pantry (erzak), and main hall (hayat) areas was built using roughhewn stone in a masonry system. The hall and rooms are separated by timber framed walls with adobe infill, and their surfaces are plastered with earth plaster and fine lime plaster. The floor of the hall area is flagstone paving, and the ceiling is strip wood paneling. In the rooms facing the northeast, southeast, and southwest, the floor is wooden flooring, and the ceiling is strip wood paneling. In the room facing the northwest, the floor is flagstone paving, and the ceiling is strip wood paneling. The walls of the main hall area located on the ground floor are plastered with earth plaster and fine lime plaster. The other walls of the pantry area and the walls of the kitchen area are unplastered. Although the floors of the main hall, pantry, and kitchen areas were originally flagstone, they were covered with travertine floor covering during the restoration application. The ceilings of all three areas are timber joist ceilings.

All walls on the upper floor of the mansion were constructed from wood-framed adobe infill walls, plastered with earth plaster and fine lime plaster. In the upper floor hall area, the floor is wooden decking, and the ceiling is a wooden suspended ceiling with wooden laths and a wooden central boss. In the balcony, rooms, and iwans located on this floor, the floor is wooden decking, and the ceiling is a wooden suspended ceiling with laths. While the roof of the mass containing the hall and rooms in the mansion is a hip roof covered with Ottoman tiles, the roof of the mass encompassing the kitchen, main hall, and storage areas is a traditional earth roof.

This construction system creates a wall character with high vapor permeability, regionally differentiated heat storage capacity, and sensitive moisture behavior; therefore, material compatibility and reversibility are critically important in the proposed interventions.

4.3. Energy Analyses and Results

The energy analyses of the building were carried out using DesignBuilder v7.0.2 software, based on EnergyPlus 9.4. The Sivas province TMYx (2009-2023) set was used as climate data; this set reduces the effect of extreme annual fluctuations in the building's energy performance assessment because it represents the average meteorological values over many years. The year 2024 was preferred for the simulation since the year 2025 is not yet complete. In the program, the building modeling was first performed, and the building envelope components were defined. Subsequently, two separate scenarios were created by applying the existing condition and the energy-efficient improved condition (interventions applied according to the developed Decision Matrix) and energy analyses were conducted. The building envelope layers and U-values for the scenarios are provided in Table 2.

Table 2. *Building envelope layers and U-values (Existing condition and improved condition)*

	Current Status		Energy Efficient Improved Status	
Shell Element	Layers	U Value (W/M2-K)	Layers	U Value (W/M2-K)
External Wall (Ground floor)	Rough cut stone wall	0,781	Rough cut stone + 30 cm rock wool + 2 cm gypsum board + lime plaster	0,10
	Lime plaster + rough cut stone + lime plaster	0,737	Lime plaster + rough cut stone + 30 cm rock wool + 2 cm gypsum board + lime plaster	0,104
External Wall (1st floor)	Lime plaster + adobe filling wall between wooden frame + lime plaster	1,661	Lime plaster + adobe filling wall between wooden frame + 30 cm rock wool + 2 cm gypsum board + lime plaster	0,108
Interior walls	Lime plaster + adobe filling wall between wooden frame + lime plaster	1,661	Lime plaster + adobe filling wall between wooden frame + lime plaster	1,661
Ground flooring	Compressed soil + wooden flooring	1,741	Compressed soil + 10 cm rock wool + wooden flooring	0,312
	Compressed soil + flagstone flooring	2,443	Compressed soil + 10 cm rock wool + flagstone flooring	0,329
	Compressed soil + travertine flooring	2,574	Compressed soil + 10 cm rock wool + travertine flooring	0,331
Intermediate floor	Wooden flooring + wooden beams + lath wood suspended ceiling	1,337	Wooden flooring + wooden beams + lath wood suspended ceiling	1,337
Attic flooring	Wooden flooring + wooden beams + lath wood suspended ceiling	1,337	Wooden flooring + 20 cm rock wool + wooden beams + lath wood suspended ceiling	0,167
Soil roof	Soil roof layer + wooden flooring + wooden beams	1,003	Soil roof layer + 20 cm rock wool + wooden flooring + wooden beams	0,160
Glass type	Frame: Wood Glass: 6mm single glass	5,7	Frame: Wood Glass: Low-e 6mm single glass (secondary glass application)	1,428
Air tightness level	0,7 a/h		0,5 ac/h	

* The thickness values used in interventions such as internal insulation and roof/ground insulation in this study were modeled under ideal conditions in a simulation environment to demonstrate the potential level of improvement in terms of energy performance. However, since internal insulation applications require sensitivity, especially regarding moisture movement, condensation risk, and vapor diffusion, the final material selection and insulation details must be determined during the application phase through on-site material analysis and building physics assessments. Therefore, this study aims to evaluate the attainability of the nZEB standard in traditional buildings at a principles level, rather than providing a direct implementation prescription. The field applicability of the interventions must be adapted in line with local conservation board decisions, the existing physical condition of the structure, and the unique material characteristics.

To accurately perform energy analyses in the program, certain data regarding the building's usage must be entered. Although the structure is currently used as a museum, due to the lack of a standardized profile regarding the internal space usage continuity and internal heat gains of museums, the residential function, which is the original use scenario, was taken as the basis for energy simulations. This approach is consistent with the principles of comparability and performance assessment consistency proposed in EN 16883:2017 for energy improvements in traditional structures of cultural heritage value. Therefore, the study results should be evaluated not as a consumption measurement for the current museum use, but as an analysis of the building's energy efficiency potential.

Spaces defined according to residential usage profiles were determined by function as bedroom, living room, kitchen, etc., and activity patterns were specified. It was assumed that a total of 10 people lived in the mansion. Occupants' clothing levels were accepted as 1 clo for winter months and 0.5 clo for summer months. The indoor temperature for the heating period was set at 21 °C, and the upper limit value at which the heating system maintains the indoor temperature was determined as 12 °C. For the cooling period, the indoor temperature was assumed to be 25 °C, and the upper limit value at which the cooling system maintains the indoor temperature was 28 °C [30]. LED fixtures were chosen as the lighting system, and a radiator distribution system with a condensing boiler (CoP=0.85) was preferred as the heating system. There is no mechanical ventilation system in the building, which uses a natural ventilation scenario.

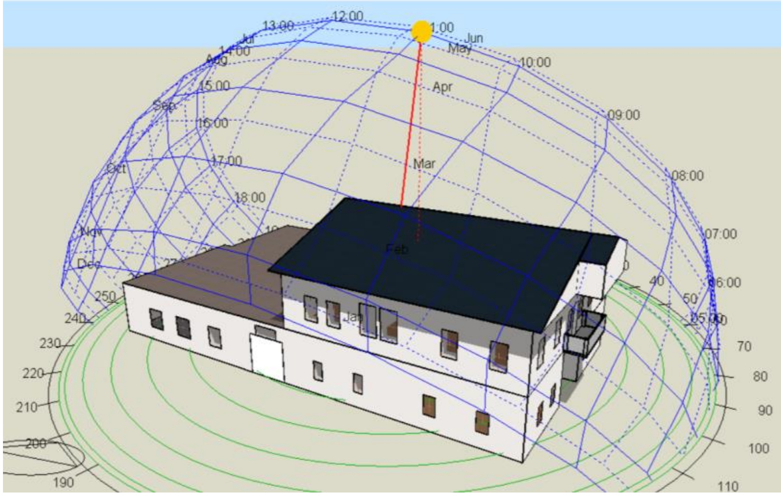


Figure 9. *Mihrali Bey Mansion Simulation View*

Table 3. *Comparison of energy consumption data for the existing condition and energy-efficient improvement scenario*

Parameters	Existing condition	Energy efficient improved condition
Annual total energy consumption	77977,56 kWh	38758,47 kWh
Electricity consumption per total area	139,58 kWh/m2	69,37 kWh/m2
Annual total heating load	56002,14 kWh	18768,09 kWh
Heating load per total area	100,24 kWh/m2	33,59 kWh/m2
Ratio of heating load to total energy consumption	%71,82	%48,42
Highest monthly heating load	12440,05 kWh (Ocak)	4295,01 kWh (Ocak)
Annual total energy generation		31451,32 kWh
Annual total energy requirement after energy production	-	7307,15 kWh
Total energy requirement per area after energy production	-	13.08 kWh/m²
Note: Heating load ratios were calculated by dividing the annual heating energy requirement by the total annual energy consumption. Heating Load Ratio (%) = (Annual Heating Energy (kWh) / Total Annual Energy Consumption (kWh)) X 100		

The results in Table 3 show that the interventions applied according to the decision matrix significantly reduced the building's heating energy demand. The heating load, which constituted 71.82% of the total energy consumption in the existing condition, decreased to 48.42% in the improved scenario. This reduction is associated particularly with the lowering of the heat transfer coefficient in the wall and roof components and the improvement of airtightness. The reduction of the building's annual energy demand to 13.08 kWh/m² after PV panel integration indicates that the structure can technically approach the nearly zero energy building standard. However, the nearly Zero Energy Building (nZEB) standard is defined based on primary energy performance rather than final energy consumption. Therefore, the annual heating and electricity consumption values based on the simulation outputs were recalculated using the primary energy factors proposed in the EPBD. Furthermore, the production values of the PV system were evaluated by considering its effect on the building's energy exchange with the grid. Thus, the building's energy performance was addressed based on "primary energy consumption" instead of "net energy demand," consistent with the nZEB approach. The results of this conversion are presented in Table 4.

Table 4. *Primary Energy Calculations - Improved Scenario (Post-PV)*

Item	Value (kWh/year)	Description
Heating demand (heat supplied to the space)	18.768,09	Simulation output
Boiler efficiency (η)	0,85	Model assumption
Natural gas final consumption	22.080,11	18.768,09 / 0,85
Electricity final consumption (pre-PV)	16.678,36	38.758,47 − 22.080,11
PV production	31.451,32	Model output
Net imported electricity after PV	0	PV covered internal building consumption
Total primary energy (Conservative)	22.080,11	Natural gas * 1.0 (no electricity import)
kWh/m²·year (primary)	32,7	22.080,11 / 674,64
Footnote: Primary energy factors: Electricity = 2.50, Natural Gas = 1.00 (EPBD compliant assumptions). In the conservative approach, primary energy credit was not given for PV production supplied to the grid.		

5. FINDINGS AND DISCUSSION

This study demonstrates that traditional buildings can achieve the Nearly Zero Energy Building (nZEB) standard, provided that the building identity and cultural authenticity are preserved. The improvement scenario implemented according to the decision matrix reduced the total annual energy consumption of Mihrali Bey Mansion by approximately 50%, achieving a significant drop particularly in heating energy demand. The reduction of the heating load—which currently constitutes 71.82% of the total annual energy consumption—to 48.42% in the improved state indicates that passive interventions (wall and roof insulation, air tightness, and secondary window applications) are highly effective in terms of energy performance (Table 3). The decrease in energy demand per unit area to 13.08 kWh/m² following PV panel integration shows that the building can technically approach the nearly zero energy standard. However, since nZEB assessment must be conducted based on primary energy, the study results were recalculated using primary energy factors, revealing that the building's annual primary energy consumption decreased to 32.7 kWh/m²-year. This value signifies a substantial level of improvement for a traditional stone-adobe masonry building located in a 5th-degree day region characterized by harsh winter conditions.

Nevertheless, the study results point to significant limitations that must be considered during the implementation phase. Since interventions such as internal wall insulation and roof insulation pose risks, particularly regarding moisture movement and vapor diffusion, the insulation thicknesses used during the simulation phase were designed to demonstrate ideal performance; the necessity for on-site material analysis, moisture behavior modeling, and building physics assessment before field application was acknowledged. Furthermore, because PV panel applications may impact the roof silhouette and the perception of the cultural landscape, such interventions must be treated as site-specific applications requiring conservation board approval. Consequently, the study does not offer a direct implementation prescription but rather proposes a holistic assessment framework that provides guidance at the principles level for the nZEB target in traditional buildings.

In these respects, the study provides a concrete example within the Turkish context of the increasingly widespread approach in international literature regarding the “integration of cultural heritage and energy sustainability”; it demonstrates that the traditional building stock can be repositioned not as a passive asset but as an active sustainability component in the fight against climate change.

6. CONCLUSION

This study reveals that traditional buildings classified as cultural heritage can achieve an energy performance level approaching the Nearly Zero Energy Building (nZEB) standard when their original identity and conservation principles are respected. The interventions developed for Mihrali Bey Mansion, based on the Historic England approach, allowed for both the preservation of the building's original material and spatial character and a significant improvement in energy performance. The findings indicate that traditional buildings can substantially reduce their energy loads through passive strategies such as insulation, transparent surface improvements, and increased air tightness; and that the net energy demand can be significantly lowered through renewable energy integration. Contrary to the common belief that traditional buildings of cultural heritage value should be excluded from sustainability goals, this demonstrates that cultural heritage can be addressed in harmony with energy transition processes.

However, the applicability of the proposed interventions depends on detailed building physics analyses concerning moisture and condensation behavior, on-site assessment of material compatibility, and institutional approval processes regarding the visual and monumental impact of PV integration. Therefore, the study offers a methodological framework for the decision-making and evaluation process rather than a specific implementation recipe.

In conclusion, the scenario developed using Mihrali Bey Mansion demonstrates that it is possible to treat the traditional building stock as a resource capable of contributing to nZEB targets, providing a practical example of the increasingly strengthening integrated approach between the fields of conservation and energy efficiency.

In line with the developed approach and the findings obtained, the following recommendations are presented for energy efficiency improvements in traditional buildings:

Recommendations Regarding Application and Restoration Processes

Materials with vapor-permeable structures should be preferred for thermal insulation applications; especially in adobe and timber structural components, thick insulation layers should not be applied without conducting moisture transfer analyses. Roof and floor insulation solutions should be implemented using reversible systems; the original structural details of the building should be preserved as much as possible. For transparent surface improvements, thin-profile double glazing or secondary glazing systems that preserve the original joinery and division ratios should be preferred. The effects of PV panel integration on the building's silhouette and environmental perception should be evaluated on-site by conservation boards, and if necessary, separate support structure / ground integration should be preferred.

Recommendations Regarding Policy and Legislation

In the energy performance assessments of traditional buildings with cultural heritage value, existing standards (such as TS 825, Building Energy Performance Regulation, etc.) need to include building-specific evaluation criteria rather than singular reference values. Joint evaluation protocols should be established among conservation boards, municipalities, and energy efficiency consultants for energy improvements in cultural heritage buildings. Incentive models for BIPV (Building Integrated PV) and low-visibility technologies should be developed for renewable energy integration.

Recommendations for Future Research

This study presented a model-based assessment for the existing building; it is recommended that model validation be performed in the future using on-site thermal camera measurements, indoor humidity balance monitoring systems, and long-term comfort analyses. Similar research applied to different climate zones and different traditional building typologies will contribute to the development of typology-based intervention guides. Furthermore, user-focused visual perception studies evaluating the effects of PV integration on the cultural landscape perception in traditional buildings with cultural heritage value have been identified as a significant missing area to support decision-making processes.

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