Acta Sci. Pol.
Architectura 24 (2025), 205–223

aspa.sggw.edu.pl ISSN 1644-0633 (suspended) eISSN 2544-1760 DOI: 10.22630/ASPA.2025.24.15

REVIEW PAPER

Received: 01.07.2025
Accepted: 07.08.2025

ASSESSMENT OF THE IMPACT OF COMPREHENSIVE THERMAL MODERNISATION ON THE ENERGY EFFICIENCY OF A HISTORIC BUILDING: A CASE STUDY OF A HOUSE IN LOWER SILESIA, POLAND

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ABSTRACT

The objective of this study was to evaluate the effects of comprehensive thermal modernisation on the energy efficiency of a 19th-century residential heritage building. The central hypothesis posited that a substantial reduction in primary energy demand could be achieved without compromising the building's architectural and historical integrity. The research was conducted as a case study of an existing historic structure located in the Dolnośląskie Voivodeship of Poland. The proposed modernisation strategy involved the implementation of a ground source heat pump, mechanical ventilation with heat recovery, low-temperature underfloor heating, photovoltaic panels, and the use of natural, vapour-permeable insulation materials. A comparative analysis of the building's energy performance certificates demonstrated a significant reduction in primary energy demand (from 878.9 $kWh \cdot m^{-2} \cdot year^{-1}$ to 54.6 $kWh \cdot m^{-2} \cdot year^{-1}$), thereby confirming the research hypothesis. These findings underscore the feasibility of reconciling contemporary energy efficiency requirements with the conservation of historic architecture, provided that context-sensitive, technologically appropriate solutions are employed.

Keywords: thermal modernisation, building energy performance, building renovation, historic building

INTRODUCTION

In the context of accelerating climate change and the global pursuit of sustainable development, the construction industry has come under increasing scrutiny for its significant contributions to greenhouse gas emissions, energy consumption, and resource depletion. As buildings account for a substantial portion of global energy use and material demand, the environmental implications of decisions made during their design, construction, renovation, and demolition are critical to the broader goal of environmental stewardship. Consequently, the need to adopt more sustainable construction practices has brought renewed attention to the adaptive reuse and renovation of existing buildings as a viable alternative to new construction.

A growing body of research underscores the environmental advantages of building renovation (Ferreira, Almeida & Rodrigues, 2017; Huo, Ma, Cai, Liu & Mu, 2021; Benke, Lewis, Carlisle, Huang & Simonen, 2022; Alarcón, 2023; Rybak-Niedziółka et al., 2023; Gavu & Peiser, 2024; Starzyk et al., 2024).

According to Hasik et al. (2019), refurbishing existing structures can reduce environmental impacts by 53% to 75% across multiple categories, including global warming potential, energy use, and material

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consumption. These reductions are primarily driven by the lower demand for new construction materials and the conservation of embodied energy already present in existing structures. Similar findings have emerged from studies conducted globally (Mastrucci, Marvuglia, Benetto & Leopold, 2020; Liao, Ren, Liu, 2023; Passoni, Caruso, Felicioni & Negro, 2024; Weerasinghe, Darko, Chan, Blay & Edwards, 2024; Darko, Weerasinghe, Chan & Wu, 2025; Gillett, Kalogirou, Morthorst, Norton & Ornetzeder, 2025). For instance, a Danish life cycle assessment demonstrated that renovations employing traditional materials and methods could achieve more favourable environmental outcomes than those using contemporary construction technologies (Serrano, Kampmann & Ryberg, 2022). A Canadian study further confirmed that extending the lifespan of buildings through renovation contributes to significant reductions in life-cycle energy use (Lucuik, Huffman, Trusty & Prefasi, 2010). Complementary research from China and Austria highlights the notable decrease in carbon emissions associated with renovation compared to demolition and new construction (Gao & Li, 2008).

Beyond environmental benefits, economic considerations also support the case for renovation. Although new buildings may sometimes offer more predictable energy performance over time, major retrofits often require lower initial capital investment and shorter construction timelines. In many cases, they prove to be more cost-effective, especially in urban contexts where land availability is limited and demolition may be impractical or restricted. Fleur, Rohdin and Moshfegh (2019) point out that while renovations may not always be optimal from a life-cycle cost perspective, they can still yield favourable returns when broader economic and social factors are taken into account. Additionally, renovations often enhance a building's functionality, safety, and user comfort, while also increasing its real estate value (Martinaitis, Rogoža & Bikmaniene, 2004).

RESEARCH GOAL AND HYPOTHESIS

The primary objective of this study is to assess the effectiveness of comprehensive thermal modernisation measures in enhancing the energy performance of a 19th-century single-family heritage building, without compromising its historical and architectural integrity. Drawing on existing literature and best practices in the field of sustainable heritage conservation, the following research hypothesis was formulated: *It is possible to achieve a substantial reduction in primary energy demand while preserving the architectural and historical value of the building.*

MATERIAL AND METHODS

The investigation is structured as a case study of an existing historic building located in the village of Stary Wielisław, Dolnośląskie Voivodeship, Poland. The building, listed in the municipal register of monuments, represents a typical example of rural domestic architecture from the 19th century and is characterised by traditional construction techniques, including half-timbered walls and natural building materials.

A comprehensive architectural and construction inventory was conducted as the initial step. Drawings were prepared in Autodesk AutoCAD, and a 3D model was created in SketchUp. Based on this documentation, a series of proposed modernisation interventions were developed, aiming to improve thermal performance without compromising the building's heritage character.

Energy modelling was performed to assess the energy performance of the building, and an advanced digital model was created using ArCADia-THERMOCAD software by ArCADiasoft. This building performance simulation tool enabled a thorough analysis of the thermal characteristics of the structure, taking into account:
– the physical and thermal properties of construction materials,

– the geometry and spatial configuration of the building,
– the presence and impact of thermal bridges.

Through this modelling approach, it was possible to calculate the building's energy demand both before and after the proposed retrofitting interventions. The resulting data formed the basis for a comparative analysis of energy performance certificates (EPCs) corresponding to the pre- and post-renovation states.

The overarching objective of the methodological approach was to reconcile contemporary energy efficiency standards with the conservation of historical architectural values. This was achieved through the careful selection of renovation technologies and strategies that minimise visual and structural interference with original materials and construction details.

CASE STUDY – SINGLE-FAMILY HERITAGE BUILDING IN DOLNOŚLĄSKIE VOIVODESHIP, POLAND

Historical background

The building is located in the village of Stary Wielisław, in the Kłodzko municipality, Dolnośląskie Voivodeship, Poland. It was constructed in the mid-19th century. The earliest known depiction of the building appears on a German postcard dated 1902. Initially, the building housed a post office (Fig. 1) and was later converted into a bakery (Fig. 2) following reconstruction. After 1945, the property was vacated by its German owners, who were forced to leave due to post-war border changes. Their place was taken by settlers from the eastern borderlands of the former Polish territories, resettled as part of civilian repatriation efforts after World War II. The building is listed in the local register of historical monuments.

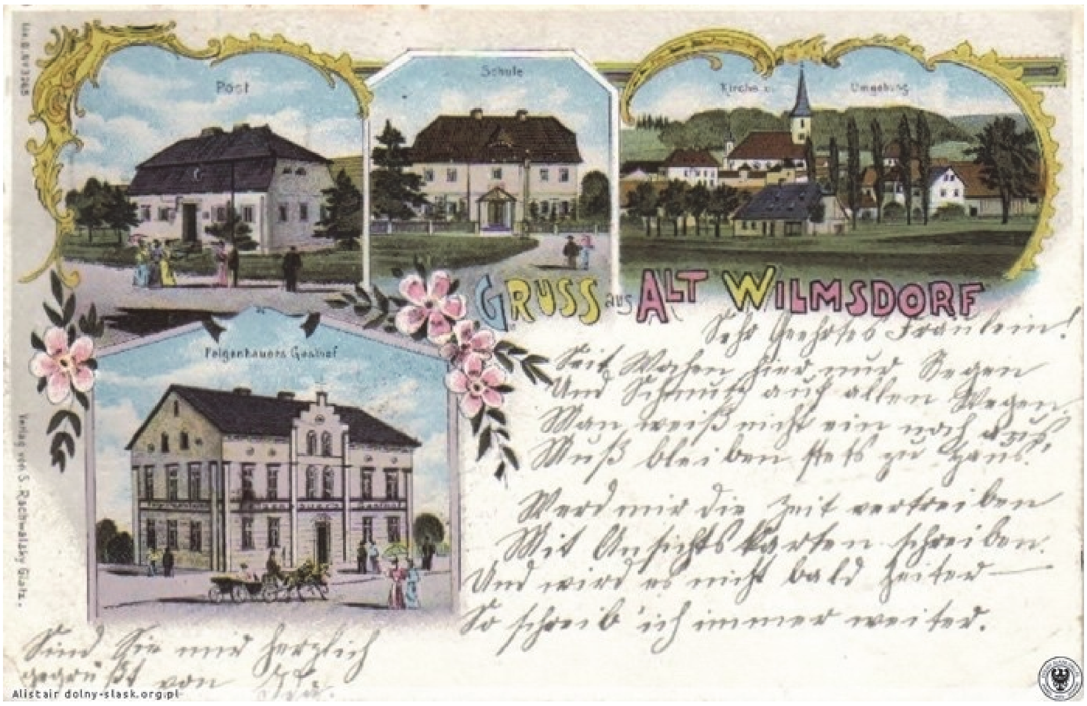


Fig. 1. German postcard with a picture of the house in the left corner described as a post office

Source: polska-org.pl.

Fig. 2. German postcard with a picture of the house described as a bakery

Source: polska-org.pl.

The architecture of Lower Silesia, especially Kłodzko Land, is characterised by a harmonious blend of Central European rural styles, shaped by centuries of Polish, Czech, and German influences. Typical for the region are solid stone or brick ground floors combined with timber-framed upper levels and steep, often corrugated roofs adapted to the mountain climate. The house exemplifies this vernacular tradition: its whitewashed ground floor, dark wooden upper story, and steep gabled roof reflect both practical needs and local building customs. Elements such as small dormer windows and simple, functional design emphasise the region's historical focus on durability and adaptation to its environment.

Building characteristics

The structure is a single-family residential building with an adjoining utility section. It comprises two usable storeys, an attic, and a partially underground basement located in the northwestern part. The foundation is primarily made of sandstone set in lime mortar. The ground-floor walls are built of brick, with the exception of the southwestern corner, which is constructed from timber logs. The upper storey is built using a half-timbered (or Prussian wall) technique, consisting of a wooden frame filled with a clay-and-chaff mixture. The attic spans the full area above the upper floor. The roof is a mansard type with gablets and three dormer windows on the northern side. It is currently covered with asbestos-cement sheets, though the original roofing material was wooden shingles. The ceilings are timber-framed and plastered from below with clay-based plaster applied on reed matting. The exterior façade is white, featuring lime plaster mixed with slag aggregate in a roughcast finish known locally as *baranek*. The main entrance consists of a double-leaf wooden door framed by a sandstone portal. The windows are traditional wooden box-type (Figs 3–7).

Fig. 3. Current state, north-east corner

Source: Authors' own photo.

Fig. 4. Current state, south-east corner

Source: Authors' own photo.

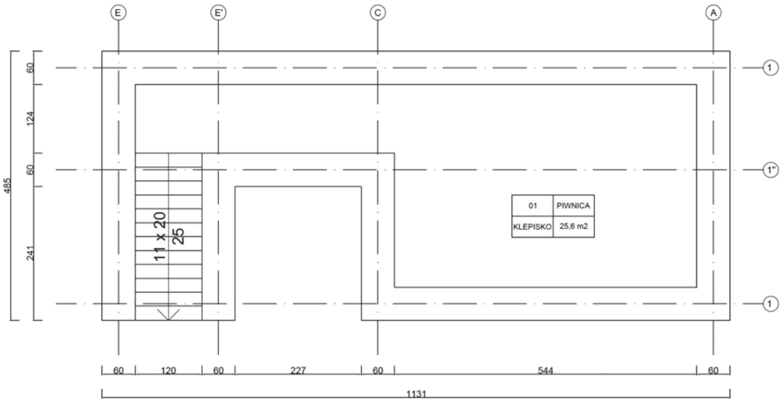


Fig. 5. Underground floor plan

Source: Authors' own photo.

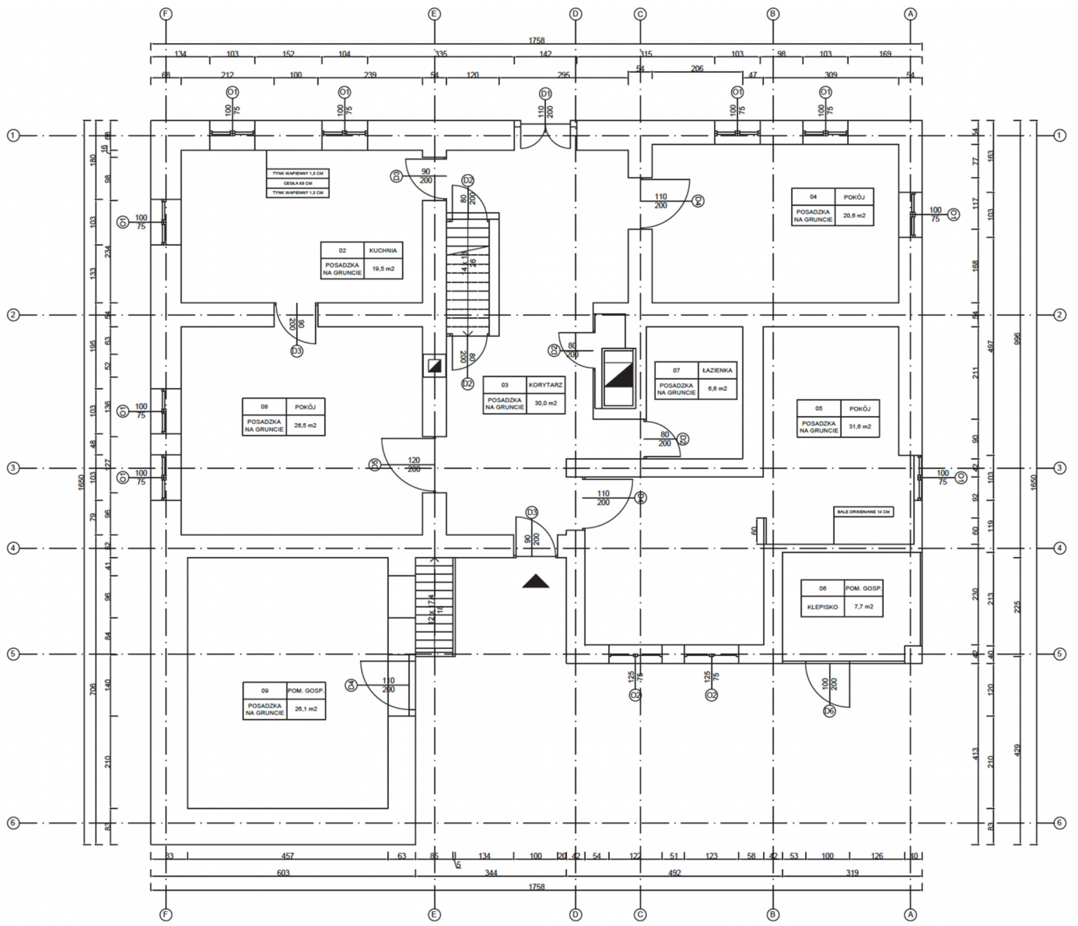


Fig. 6. First floor plan

Source: own work.

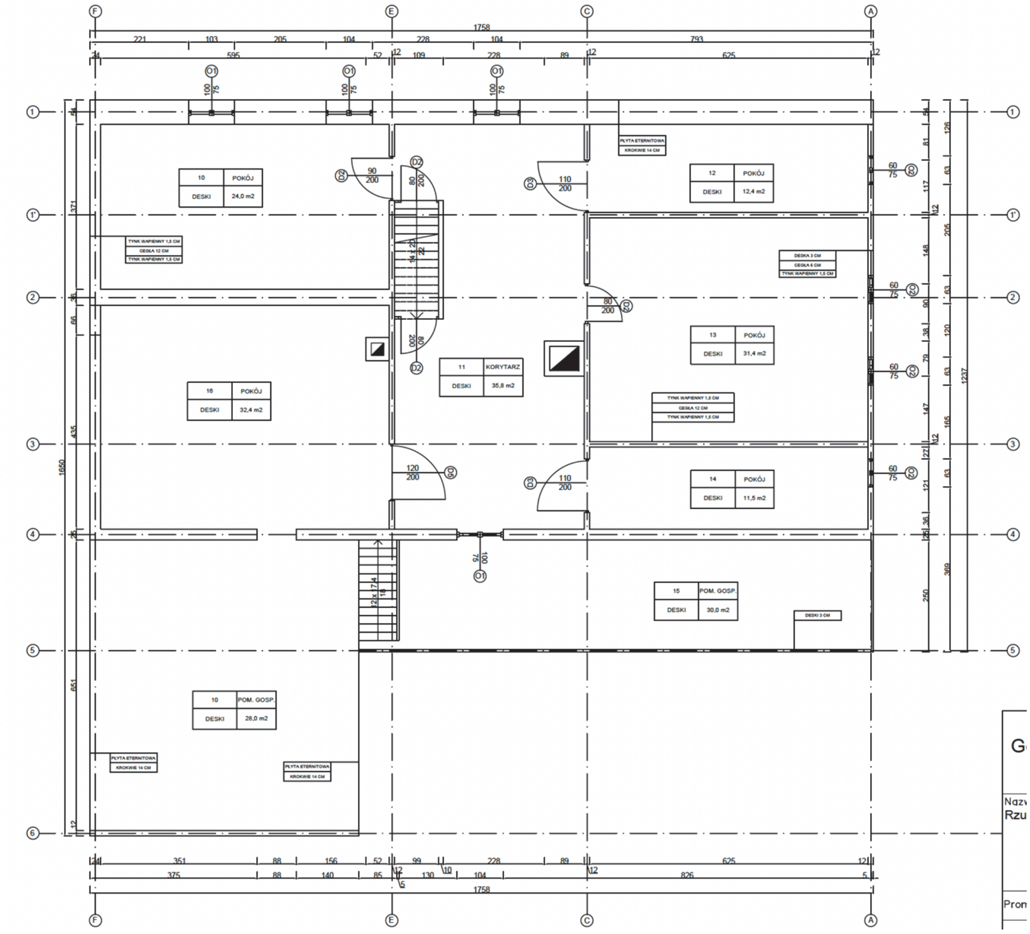


Fig. 7. Second floor plan

Source: own work.

Identified problems

1. Moisture penetration in ground-floor walls

The masonry walls on the ground floor exhibit significant moisture-related degradation. The lime mortar used in the foundation walls acts as a capillary medium, drawing groundwater upwards in the absence of any horizontal or vertical damp-proof barriers. This uncontrolled moisture rise leads to saturation at the base of the walls and the gradual upward migration of water. Additionally, the application of cement-lime plaster in certain interior spaces exacerbates the problem due to its low vapour permeability. As a result, vertical capillary channels are formed, impeding the natural evaporation of moisture. In contrast, bare masonry or walls coated with high-permeability plasters facilitate faster and lower-level moisture dissipation. For an extended period, the building lacked an appropriate rainwater drainage system, causing direct exposure of the masonry to runoff from the roof. Despite prior attempts to mitigate the damage using biocidal treatments, the persistent high moisture content has led to the proliferation of microorganisms such as moulds, bacteria, algae, and yeast. These organisms actively contribute to the biological corrosion of the wall structure. Moreover, their presence poses a health risk to occupants, potentially causing allergic reactions, fungal infections, and respiratory diseases. Mycotoxins released by moulds are known to be toxic to both humans and animals.

2. Biological corrosion and degradation of timber components

The building features wooden structural elements in several key areas. The floors are constructed from timber joists supported directly on masonry walls. The first-floor walls utilise a traditional half-timbered (fachwerk) system, consisting of a wooden frame filled with a mixture of clay and chopped straw. The roof is supported by a rafter-collar beam system, without boarding, with asbestos-cement sheets mounted directly onto the purlins. The southwest corner of the ground floor is built from horizontally laid timber logs. In all these areas, the wooden components have suffered from advanced biological decay and material fatigue, primarily due to long-term neglect and inadequate maintenance. Signs of rot, insect infestation, and structural weakening are evident, threatening the building's integrity and necessitating conservation-oriented interventions.

3. Asbestos-cement roofing

The roof is covered with asbestos-cement sheets, a material widely used in Poland and former Eastern Bloc countries during the 20th century. Despite its durability, affordability, and ease of manufacture, asbestos in particulate form is highly carcinogenic. Inhalation of asbestos fibres is associated with severe health conditions, including asbestosis, lung cancer, and malignant pleural mesothelioma (O'Reilly, Mclaughlin, Beckett & Sime, 2007). In addition, the roofing material has deteriorated significantly and exhibits numerous leaks, some of which have been temporarily patched using metal sheets. According to current Polish legislation, all asbestos-cement roofing must be removed and safely disposed of by 2032.

4. South-facing extension

At some point – most likely during the building's conversion from a post office to a bakery – a series of extensions were added to the south side. These consist of a masonry ground-floor addition and timber extensions on both the ground and first floors. This annexe disrupts the original geometry of the building and significantly reduces natural light in the interior spaces due to shading effects.

Proposed architectural interventions

In response to the identified issues, a conceptual architectural design has been developed with the aim of restoring the original form of the building while enhancing its functional performance. The proposed interventions include:

- Reconstruction of the original roof shape (Figs 8–9) and replacement of asbestos-cement sheets with historically appropriate roofing materials (e.g. wooden shingles or slate).
- Preservation of historically significant features, such as wooden windows and doors, using current technology to create wooden box windows with a heat transfer coefficient of U = 1.1 $W \cdot m^{-2} \cdot K^{-1}$, as well as the distinctive timber-framed corner of the building.
- Removal of the south-facing extension, restoring the building's original massing and improving interior daylight access.
- Reconfiguration of the first-floor layout (Fig. 10) to better meet contemporary residential needs.
- Insertion of additional windows (Figs 10–11) to enhance natural lighting and ventilation.
- Creation of a dedicated technical space for the integration of thermal modernisation systems, including mechanical ventilation, insulation upgrades, and renewable energy solutions.

The proposed interventions aim to strike a balance between the preservation of cultural heritage and compliance with modern energy efficiency and comfort standards.

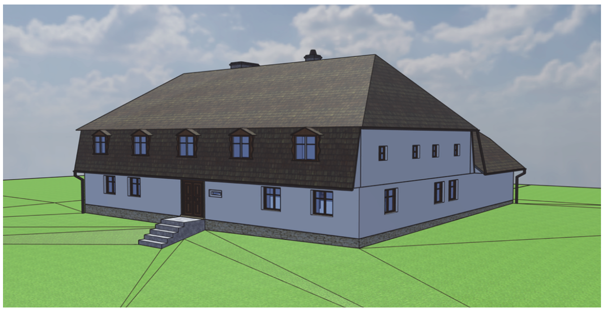


Fig. 8. 3D model of the building created in SketchUp, north-west corner

Source: own work.

Fig. 9. 3D model of the building created in SketchUp, south-east corner

Source: own work.

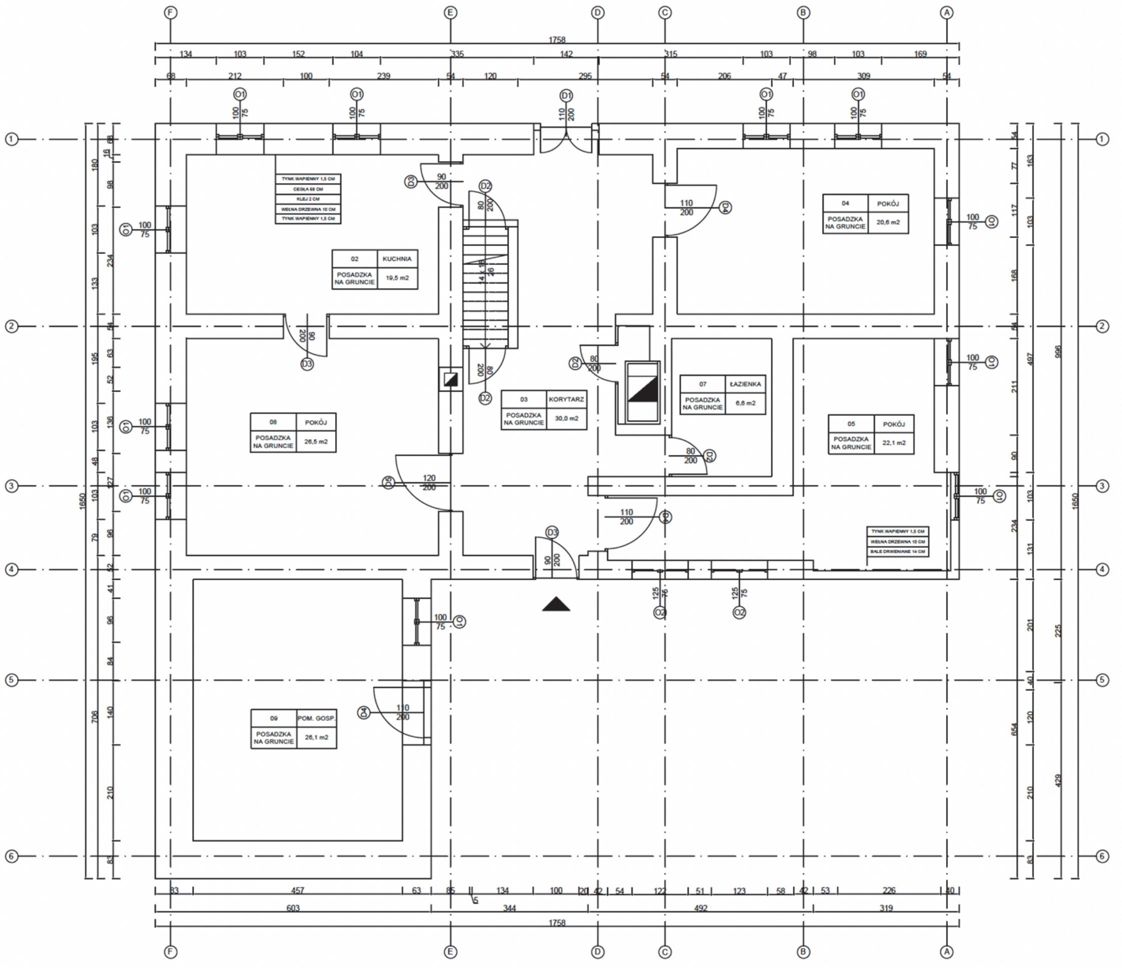


Fig. 10. First floor after renovation

Source: own work.

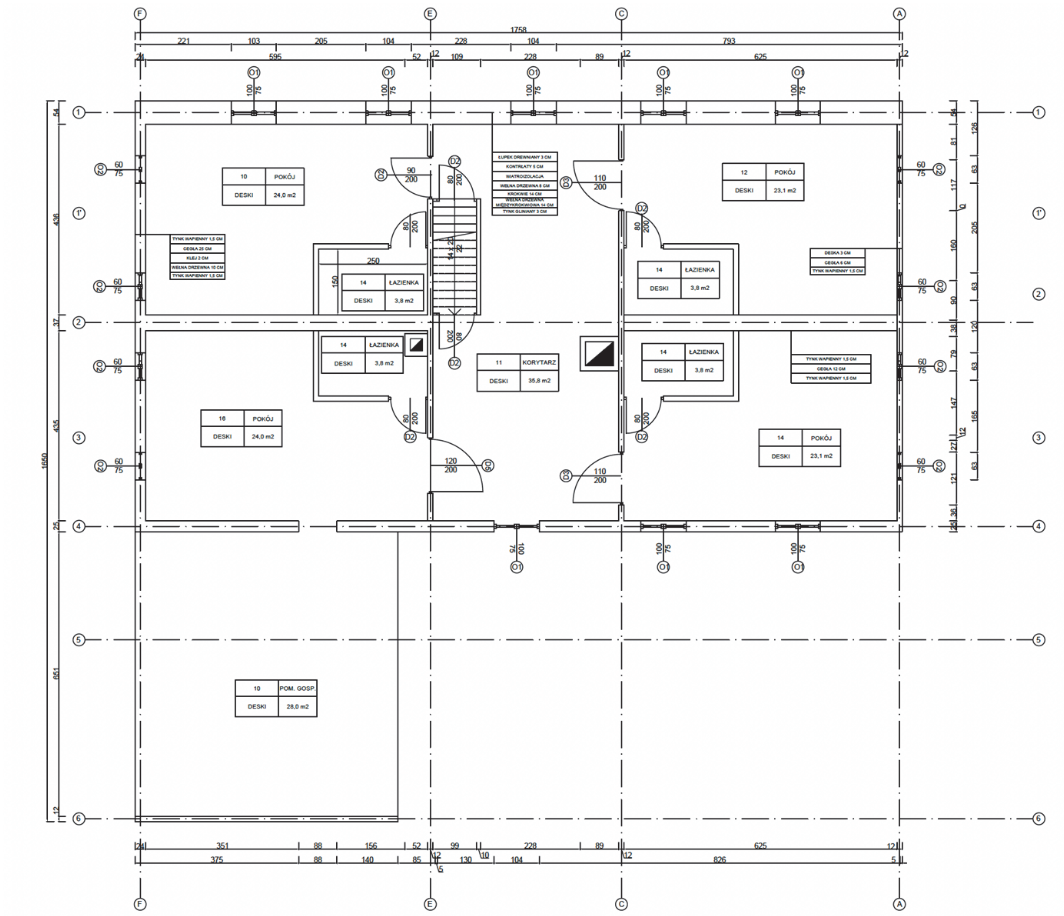


Fig. 11. Second floor after renovation

Source: own work.

Proposed technical solutions

1. Terrain regrading and an offset drainage perimeter around the building

To prevent capillary rise of moisture through lime mortar in the sandstone foundation walls, geotechnical interventions are necessary to reduce water ingress. It is recommended to implement an offset drainage perimeter that redirects groundwater away from the structure. Installing drainage directly adjacent to the foundation walls would be inappropriate due to the absence of both vertical and horizontal waterproofing layers. Excavating the foundation externally to install vertical insulation would introduce two key risks: first, the formation of a capillary chimney allowing water ingress from beneath and internally; second, disturbing the consolidated soil adjacent to the foundation, increasing its porosity and moisture absorption. Additionally, lowering the terrain on the eastern side and installing road drainage alongside the building will mitigate water runoff from the hillside, which currently contributes to the flooding and degradation of foundation walls.

2. Installation of a horizontal damp-proof course between the foundation and the ground floor walls

Several methods are available for retrofitting a horizontal damp-proof course in existing buildings. Common techniques include:

– Mechanical method. Wall undercutting involves cutting through the junction between the wall and foundation using guide rail saws in a staged manner to preserve structural integrity. The gap is filled with waterproofing materials such as bituminous felt, PE/HDPE/PVC membranes, steel plates, or epoxy resin sheets. The insulation is then wedged in place, and the remaining space is filled with mortar. While durable and easy to inspect, this method is labour-intensive and invasive, with potential risks of wall cracking or settlement.
– Chemical injection methods. Injection refers to saturating the masonry cross-section with a substance that functions by one or more of the following mechanisms: blocking the capillary network, narrowing capillaries to prevent capillary action, hydrophobising the capillary walls, or a combination of the above (Monczynski, Ksit & Szymczak-Graczyk, 2019). Examples of methods using the above mechanisms are presented in Table 1.

Table 1. Chemical injection methods

Method	Method description
Crystalline injection	This technique involves drilling two horizontal rows of holes at the wall base (10–15 cm spacing, to a depth of 70% of the wall thickness), which are then filled with a mixture of portland cement, silicates, crystallisation activators, and sealing/plasticising agents. The injected material is drawn upwards by capillarity and crystallises, blocking the pores and halting vertical moisture migration. The method is minimally invasive and applicable to diverse wall types, though it lacks direct control over the efficacy and requires several weeks for full crystallisation. It was developed by Polish engineer Dr Wojciech Nawrot.
Hydrophobic injection	Based on silane or siloxane compounds, this method imparts hydrophobic properties to capillary surfaces without blocking them. Liquid water movement is prevented while vapour permeability is maintained, preserving wall breathability.
Thermal injection	An extension of crystalline/hydrophobic injection, this method incorporates thermal ventilation devices into the drilled holes, drying the wall to 4% moisture content before injecting. This accelerates drying, reduces efflorescence, and improves performance.
Pressure resin injection	Uses pressurised polyurethane, epoxy, or acrylic resins to fill pores and capillaries. This rapid method is effective regardless of initial wall dampness but may worsen structural deterioration in highly degraded masonry.

Source: own work.

– Electrokinetic method (electroosmosis). Electrodes embedded in walls and the soil alter the direction of water flow via electric current. Its effectiveness depends heavily on material composition, humidity, and pH, with mixed results reported in the literature. A known side effect is salt accumulation in walls (Franzoni, 2018).

3. Drying of ground-floor walls

After installing a horizontal damp-proof barrier, the next step is drying the damp walls. This long-term process depends on the moisture level and wall thickness. First, the extent of moisture penetration must be determined, including inside the wall section. Then, plaster should be removed up to 1 m above the damp line. Available drying methods include:

– Natural drying. Ventilation supports surface evaporation. This weather-dependent, slow process can take years. The application of porous renovation plasters helps absorb salt efflorescence caused by evaporating moisture.
– Artificial drying. Typically involves heated air and the use of condensation or adsorption dehumidifiers. An alternative is microwave drying, which heats walls to ~80°C, enabling fast and deep moisture removal. Microwaves also have a biocidal effect, making it a recommended solution.

4. Internal insulation

To preserve the building's original form and local character, interior wall insulation is proposed. A primary concern is relocating the dew point deeper into the wall, potentially raising internal humidity and causing condensation behind the insulation. Two main systems are used:
– Vapour-open systems. These systems allow moisture migration and evaporation. Common materials include wood-fibre or calcium-silicate boards, attached using full-surface adhesive to prevent voids. Finishes must be vapour-permeable (e.g. clay or lime plaster, mineral paints), making it a recommended solution.
– Vapour-closed systems. These systems use vapour barriers to prevent moisture ingress into the insulation layer. Materials include PIR, PUR, or EPS boards. Non-permeable interior finishes (e.g. gypsum board, cement plaster) may be used. However, the system is highly sensitive to execution errors: any breach in the vapour barrier can cause moisture accumulation and microbial growth.

Both systems present thermal bridging risks at junctions with other building elements. Solutions include adding 30–40 cm insulation strips on adjoining walls and floors. Mounting fixtures requires special considerations to avoid damaging the vapour barrier. Despite these challenges, internal insulation improves thermal comfort by keeping internal surfaces warm. Moreover, structural considerations for new wooden floor beams should take into account insulating the building from the inside. When installing internal insulation, increased wall moisture may adversely affect wooden floor beams embedded in the masonry, leading to wetting, freezing, and biological decay. Preventative measures include using steel or concrete spacers and leaving an air gap around beam ends to facilitate drying.

5. Restoration of the historical roofing

Due to the structural degradation of the upper floors and roof, complete replacement of the timber structure is necessary. Originally, the building had a wooden shingle roof, which may be restored with good thermal outcomes. This breathable roofing system must be installed on a lath and counter-lath grid, with a wind membrane atop vapour-open wood-fibre boards fixed to rafters. Inter-rafter spaces are also filled with insulation. The interior finish should be fibre-permeable to facilitate drying and maintain indoor air quality. Phosphorus-based fire retardants may be used to enhance fire safety and reduce smoke and heat emission (Park, Lee, Kang, Lee & Shim, 2020).

6. Heating system replacement

Currently, the building is partially heated via a solid-fuel stove in the kitchen with a water heat exchanger and a tiled top. This system is inefficient, labour-intensive, and causes thermal bridging due to unheated zones. To improve energy performance, reduce operating costs, and minimise environmental impact, a new system is proposed:
– Ground source heat pump (GSHP). GSHPs utilise underground glycol-filled collectors (horizontal or vertical) to extract heat. Glycol is vapourised in an evaporator, then compressed to increase

its temperature. The hot gas heats water via a condenser. This highly efficient system achieves a coefficient of performance (COP) of up to 4.9 in winter and 2.3 in summer (Desideri, Sorbi, Arcioni & Leonardi, 2011).
- Heat recovery ventilation (HRV). HRV systems recover heat from exhaust air, supplementing the GSHP. Over time, the ground temperature around the collector drops, reducing efficiency. Supplementing the glycol loop with heat from exhaust air stabilises ground temperature and enhances system performance (Ya-Su, Fahlen & Lindholm, 2007).
- Low-temperature underfloor heating. In the case of heating the building using a ground-source heat pump, low-temperature heating systems are preferable due to the increased efficiency of the heat pump operating at lower supply temperatures. Although underfloor heating systems have higher thermal inertia, they enable an even distribution of heat throughout the building volume. Moreover, they help maintain the temperature of wooden floor structures, thereby preventing moisture accumulation in the beams resting on internally insulated walls.
- Photovoltaic installation. By supplying the heat pump with electricity generated by photovoltaic (PV) panels, it is possible to achieve up to a 40% reduction in life-cycle operating costs and a 30% decrease in carbon dioxide emissions (Wang, Quan, Zhao, Rosengarten & Mojiri, 2025). In order to preserve the architectural and historical integrity of the renovated building, it is proposed that the PV panels be installed on the roof of the adjacent barn. Importantly, the southern slope of the barn roof is not visible from the street, minimising visual impact. The system's capacity should be sized appropriately to meet the energy demands of the installations described above.
- Energy storage system. To fully capitalise on the potential of the photovoltaic installation, the integration of an energy storage system (battery bank) is recommended. This would allow the surplus energy generated during the day to be stored and used during nighttime hours. Such a solution contributes to further reductions in the consumption of primary energy required for the operation of the building.

RESULTS

Energy modelling and performance improvement

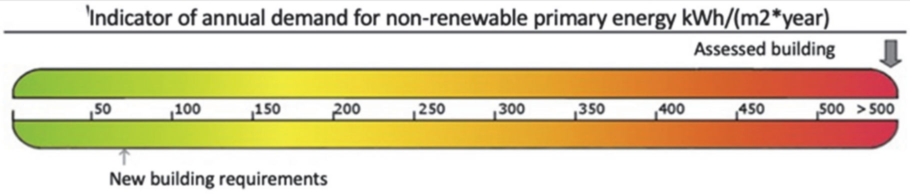
The building was modelled using ArCADia-THERMOCAD software developed by ArCADiasoft. Utilising specialised energy performance modelling software enables comprehensive energy analysis by accounting for building geometry, material properties, and thermal bridging.

As a result of the proposed thermal retrofitting measures, the building's primary energy demand was reduced from 878.9 $kWh \cdot m^{-2} \cdot year^{-1}$ to 54.6 $kWh \cdot m^{-2} \cdot year^{-1}$ – a more than sixteenfold decrease (Tables 2–3). Following the renovation, this over one-hundred-year-old structure now meets contemporary energy performance standards while offering improved indoor comfort and long-term operational cost savings for future users.

Equally significant is the elimination of the solid fuel boiler, which previously contributed to the emission of harmful gases and particulate matter detrimental to human health. The integration of renewable solar energy systems – coupled with energy storage capabilities – further reduces reliance on primary energy sources and enhances the sustainability of the building.

Table 2. Assessment of the energy performance of the building before renovation

Building under review		
Building Type 2)	Residential	
Purpose of the building 3)	House	
Building address	57-313 Stary Wielisław 183	
Building referred to in Article 3(2) of the Act 4)	No	
Year of completion of the building 5)	1910	
Method for determining energy performance 6)	calculation method for the accepted mode of use and standard climatic conditions	
Area of rooms with adjustable air temperature (heated or cooled area) Af [m2] 7)	294.10 m2	
Usable area [m2]	294,10 m2	
Valid until (yyyy-mm-dd) 8)	15.06.2035	
A weather station according to which data is determined 9)	Kłodzko	
Assessment of the energy performance of the building 10)		
Energy Performance Indicators	**Building under review**	**Requirements for a new building according to the technical and construction regulations** 11)
Indicator of annual demand for useful energy	EU= 382.8 kWh/(m2·year)	
Indicator of annual final energy demand 12)	EK= 798.1 kWh/(m2·year)	
Indicator of annual demand for non-renewable primary energy 12)	EP= 878.9 kWh/(m2·year)	EP= 70.0 kWh/(m2·year)
Unit CO2 emissions	ECO2= 0.28244 t CO2/(m2·year)	
Share of renewable energy sources in annual final energy demand	UOZE= 0.00 %	



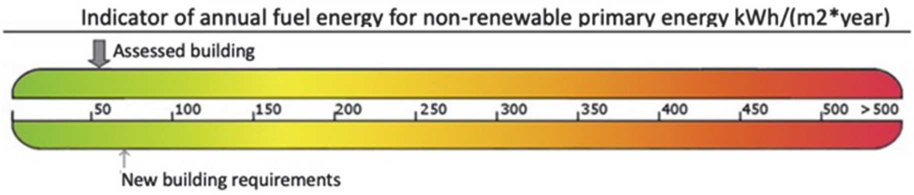
Calculated annual amount of energy carrier or energy consumed by the building13)			
Technical system	**Type of energy carrier or energy**	**Amount of energy carrier or energy**	**Unit/(m2·year)**
Heating	Local energy generation in a building - Hard coal	108,15	kg/(m2·year)
	System power grid - Electricity	0,57	kWh/(m2·year)
Domestic hot water preparation	Local energy generation in a building - Hard coal	20,19	kg/(m2·year)
	System power grid - Electricity	0,11	kWh/(m2·year)
Cooling	--	--	--
Built-in lighting system 11)	--	--	--

Source: own work.

Table 3. Assessment of the energy performance of the building after renovation

Building under review		
Building Type 2)	Residential	
Purpose of the building 3)	House	
Building address	57-313 Stary Wielisław 183	
Building referred to in Article 3(2) of the Act 4)	No	
Year of completion of the building 5)	1910	
Method for determining energy performance 6)	calculation method for the accepted mode of use and standard climatic conditions	
Area of rooms with adjustable air temperature (heated or cooled area) Af [m2] 7)	294.10 m2	
Usable area [m2]	294.10 m2	
Valid until (yyyy-mm-dd) 8)	15.06.2035	
A weather station according to which data is determined 9)	Kłodzko	

Assessment of the energy performance of the building 10)		
Energy Performance Indicators	**Building under review**	**Requirements for a new building according to the technical and construction regulations** 11)
Indicator of annual demand for useful energy	EU= 176.0 kWh/(m2·year)	
Indicator of annual final energy demand 12)	EK= 93.2 kWh/(m2·year)	
Indicator of annual demand for non-renewable primary energy 12)	EP= 54.6 kWh/(m2·year)	EP= 70.0 kWh/(m2·year)
Unit CO2 emissions	ECO2= 0.00738 t CO2/(m2·year)	
Share of renewable energy sources in annual final energy demand	UOZE= 52.71 %	



Calculated annual amount of energy carrier or energy consumed by the building13)			
Technical system	**Type of energy carrier or energy**	**Amount of energy carrier or energy**	**Unit/(m2·year)**
Heating	On-site energy generation in a building - Solar energy	34,75	kWh/(m2·year)
	System power grid - Electricity	16,95	kWh/(m2·year)
Domestic hot water preparation	On-site energy generation in a building - Solar energy	36,59	kWh/(m2·year)
	System power grid - Electricity	4,88	kWh/(m2·year)
Cooling	--	--	--
Built-in lighting system 11)	--	--	--

Source: own work.

Although calculations based on a computer model are precise and reliable, high-quality, structured data is crucial. There is also a risk of oversimplification and making too many assumptions, which can lead to a loss of accuracy. This can apply to historic buildings, which are made from various materials and can be surprisingly heterogeneous.

Effectiveness of the thermal modernisation

To assess the effectiveness of the planned thermal modernisation, the analysis of thermal resistance of external partitions and roof layers was performed (Tables 4–7).

Table 4. Layers of external wall before modernisation

Layer	Material	Dimension [m]	Heat conduction coefficient (λ) [-]	Thermal resistance [$m^2 \cdot K \cdot W^{-1}$]
1	lime plaster	0.015	0.700	0.021
2	solid brick	0.680	0.780	0.872
3	lime plaster	0.015	0.700	0.021

Source: own work.

Table 5. Layers of external wall after modernisation

Layer	Material	Dimension [m]	Heat conduction coefficient (λ) [-]	Thermal resistance [$m^2 \cdot K \cdot W^{-1}$]
1	lime plaster	0.015	0.700	0.021
2	wood-fibre boards	0.100	0.038	2.632
3	solid brick	0.680	0.780	0.872
4	lime plaster	0.015	0.700	0.021

Source: own work.

Table 6. Layers of the roof before modernisation

Layer	Material	Dimension [m]	Heat conduction coefficient (λ) [-]	Thermal resistance [$m^2 \cdot K \cdot W^{-1}$]
1	asbestos boards	0.020	0.700	0.029

Source: own work.

Table 7. Layers of the roof after modernisation

Layer	Material	Dimension [m]	Heat conduction coefficient (λ) [-]	Thermal resistance [$m^2 \cdot K \cdot W^{-1}$]
1	lime plaster	0.015	0.700	0.021
2	wood-fibre boards	0.220	0.038	5.789
5	foil	0.002	0.300	0.007
6	air void	0.050	×	0.180
7	wooden roofing	0.030	0.160	0.188

Source: own work.

As a result of the thermal modernisation, the heat transfer coefficient for the external wall has decreased by a factor of over three, and by over 36 for the roof. Results like this are excellent and mean that far more energy is being saved.

DISCUSSION

This study aimed to reconcile contemporary energy efficiency requirements with the conservation of architectural heritage by employing context-sensitive and technically appropriate interventions. The analysis demonstrates that, when guided by a carefully planned and integrated strategy, it is possible to attain a high level of energy performance without undermining the historical character or cultural significance of the building.

Importantly, the renovation of historic and traditional architecture plays a crucial role in preserving cultural heritage and identity. Historic buildings serve not only as material artefacts of architectural and construction practices but also as markers of the sociocultural, economic, and environmental narratives of their time. Their continued existence enables intergenerational transmission of knowledge, values, and aesthetics that might otherwise be lost (Nassir, 2020). In regions with complex and often turbulent histories – such as many areas of Central and Eastern Europe – heritage preservation becomes especially significant. In the face of global homogenisation and the proliferation of standardised architectural forms, the conservation and adaptive reuse of historic buildings offer a means of maintaining local distinctiveness and cultural continuity (Nguyen & Khuat, 2024).

Nevertheless, the process of renovating historic buildings is not without challenges. Renovators must often navigate conflicting priorities between improving energy performance and adhering to heritage preservation standards. Regulatory frameworks may impose restrictions that limit the extent to which energy upgrades can be implemented, while technical difficulties associated with integrating modern systems into old structures further complicate renovation efforts. As Mazzarella (2015) notes, a balanced and context-sensitive approach is required – one that recognises the value of cultural heritage while striving to meet contemporary environmental performance goals.

CONCLUSIONS

In the context of rapid advancements in building technologies and mounting global pressure to reduce the carbon footprint of the construction sector, the renovation of historic buildings has emerged as a key challenge for engineers, architects, and conservation specialists. This case study demonstrates that, with a carefully planned and context-sensitive approach, it is possible to achieve high energy performance standards without compromising the architectural integrity or cultural value of heritage structures.

The integration of vapour-open (diffusion-permeable) materials and assemblies ensured balanced moisture transfer through the building envelope, thereby preventing the accumulation of condensation, protecting the structural integrity of timber-framed elements, and promoting a healthy indoor microclimate. At the same time, the implementation of a low-temperature underfloor heating system in conjunction with a ground-source heat pump, mechanical ventilation with heat recovery, and a photovoltaic installation – including an energy storage system – enabled a radical reduction in primary energy demand. These interventions not only enhance user comfort but also eliminate local emissions from fossil fuel combustion, contributing to cleaner air and improved public health.

The use of advanced energy modelling software (ArCADia-THERMOCAD) allowed for a precise assessment of thermal performance, taking into account geometric features, material properties, and thermal bridges. The result was a dramatic reduction in the building's primary energy demand – from 878.9 $kWh \cdot m^{-2} \cdot year^{-1}$ to 54.6 $kWh \cdot m^{-2} \cdot year^{-1}$ – without altering its external appearance or internal spatial character. As the house is heated just partially, using solid fuel and tiled stoves, there is no reliable data on its actual energy consumption.

This example reinforces the idea that appropriately executed energy retrofitting of historic structures does not conflict with their conservation; on the contrary, it can reinforce their value. Through the extension of the building's life span – adaptation to contemporary functional and environmental standards, and restoration of its original aesthetic qualities – the renovation contributes meaningfully to the cultural and material sustainability of the built environment.

In a broader context, such interventions align with the principles of sustainable development. They reduce the demand for new construction, conserve material and cultural resources, and promote circular economy strategies within the building sector. As heritage buildings represent a significant share of the existing building stock, their energy-efficient adaptation is essential not only for climate goals but also for maintaining the continuity of place, identity, and memory in architectural heritage.

Acknowledgements
We would like to thank the Faculty of Civil and Environmental Engineering at the Warsaw University of Technology for their support in the execution of this work.

Authors' contributions
Conceptualisation: Ł.C. and A.N.; methodology: A.N.; validation: A.N.; formal analysis: Ł.C.; investigation: Ł.C.; resources: Ł.C.; data curation: Ł.C.; writing – original draft preparation: Ł.C.; writing – review and editing: A.N.; visualisation: Ł.C.; supervision: A.N.

All authors have read and agreed to the published version of the manuscript.

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OCENA WPŁYWU KOMPLEKSOWEJ TERMOMODERNIZACJI NA EFEKTYWNOŚĆ ENERGETYCZNĄ BUDYNKU ZABYTKOWEGO: STUDIUM PRZYPADKU DOMU NA DOLNYM ŚLĄSKU, POLSKA

STRESZCZENIE

Celem niniejszej pracy była ocena wpływu kompleksowej modernizacji termicznej na efektywność energetyczną zabytkowego budynku mieszkalnego z XIX wieku. Główna hipoteza zakładała, że możliwe jest osiągnięcie znacznego zmniejszenia zapotrzebowania na energię pierwotną bez naruszania integralności architektonicznej i historycznej budynku. Badania przeprowadzono w formie studium przypadku istniejącej konstrukcji zabytkowej położonej w województwie dolnośląskim w Polsce. Proponowana strategia modernizacji obejmowała wdrożenie gruntowej pompy ciepła, wentylacji mechanicznej z odzyskiem ciepła, niskotemperaturowego ogrzewania podłogowego, i paneli fotowoltaicznych oraz zastosowanie naturalnych, paroprzepuszczalnych materiałów izolacyjnych zgodnych z zasadami otwartości dyfuzyjnej. Analiza porównawcza certyfikatów charakterystyki energetycznej budynku wykazała znaczne zmniejszenie zapotrzebowania na energię pierwotną (z 878,9 $kWh \cdot m^{-2} \cdot rok^{-1}$ do 54,6 $kWh \cdot m^{-2} \cdot rok^{-1}$), co tym samym potwierdziło hipotezę badawczą. Wyniki te podkreślają możliwość pogodzenia współczesnych wymagań dotyczących efektywności energetycznej z ochroną architektury zabytkowej, pod warunkiem zastosowania rozwiązań dostosowanych do swoistych cech obiektu i odpowiednich pod względem technologicznym.

Słowa kluczowe: modernizacja termiczna, charakterystyka energetyczna budynku, renowacja budynku, budynek historyczny