GREEN BUILDING CONFERENCE
INNOVATIVE SOLUTIONS FOR A GREENER BUILT ENVIRONMENT

DOI: **10.5937/greenb26025R**
Research paper

SUSTAINABLE BUILDING ENVELOPE RENOVATION: INTEGRATION OF APV FACADE AND TIMBER ENERGY SYSTEMS (TES)

Srđan Radanović[1], Darija Gajić[2], Milovan Kotur[3]

Abstract

Improving the energy performance of buildings effectively reduces consumption and heating costs while elevating indoor comfort. This paper is a part of comprehensive research which examines energy poverty among residential building users—a prevalent issue in Bosnia and Herzegovina and neighboring countries. Furthermore, it analyzes various alternative solutions for upgrading the building envelope to demonstrate their feasibility. This paper investigates the role of energy efficiency in residential buildings and evaluates the potential of adaptive photovoltaic (APV) façade systems in deep energy renovation. Focusing on a multi-family residential building in Banja Luka, this study combines theoretical findings on energy performance with an advanced renovation scenario based on the Timber Energy System (TES) envelope and Solskin adaptive photovoltaic technology. A detailed analysis of this prefabricated alternative solution demonstrates that upgrading the building envelope substantially reduces heating demand, while the integrated active photovoltaic elements enable on-site electricity generation. Energy calculation results indicate that this systemic approach maintains specific energy need for heating at a low level of 21.93 kWh/m²a, elevating the building to energy class B in the study area. Furthermore, CO_2 emissions are drastically reduced from 216.75 tCO_2 to 74.85 tCO_2. Ultimately, the research confirms that comprehensive energy renovation not only enhances building performance but directly drives decarbonization, improves the residents' quality of life, and demonstrates how building envelopes can evolve from passive protective elements into active, energy-producing systems that mitigate energy poverty and support climate goals.

Key words: *energy efficiency, energy renovation, adaptive photovoltaic façade, TES envelope*

[1] Student, Faculty of Architecture, Civil Engineering and Geodesy – University of Banja Luka, Banja Luka, Bosnia and Herzegovina, srdjan.radanovic@student.aggf.unibl.org, ORCid 0009-0002-4212-7432
[2] PhD, Full Professor, Faculty of Architecture, Civil Engineering and Geodesy – University of Banja Luka, Banja Luka, Bosnia and Herzegovina, darija.gajic@aggf.unibl.org, ORCid 0000-0003-1679-5111
[3] PhD, Associate Professor, Faculty of Mechanical Engineering – University of Banja Luka, Banja Luka, Bosnia and Herzegovina, milovan.kotur@mf.unibl.org, ORCid 0000-0003-4292-3236

1. INTRODUCTION

Buildings are among the largest energy consumers in Europe. A considerable share of the housing stock in Bosnia and Herzegovina was constructed before modern energy-efficiency standards. Consequently, renovation of existing buildings is one of the most effective measures for reducing energy consumption, emissions and energy poverty.

Energy efficiency in buildings implies the rational use of energy while maintaining or improving the quality of indoor spaces and living conditions. In the context of residential buildings, it refers to reducing the energy required for heating, cooling, domestic hot water preparation, and other needs, without compromising the thermal comfort of the occupants.

According to European Union definitions, buildings represent one of the largest energy consumers, accounting for approximately 40% of total final energy consumption and roughly 36% of CO_2 emissions. Consequently, improving the energy efficiency of buildings is recognized as a key measure for achieving climate and energy targets, a priority further underscored by current legislative frameworks such as the updated Energy Performance of Buildings Directive [1].

The energy performance of a residential building depends heavily on the characteristics of its envelope—specifically, the thermal properties of both opaque and transparent structural elements. Insufficient thermal insulation, the presence of thermal bridges, and inadequate fenestration lead to increased transmission losses and a higher energy demand for heating [2]. Multi-family residential buildings constructed prior to the introduction of current regulations are particularly vulnerable, as energy efficiency was not a primary design criterion at the time of their construction [3].

Beyond the technical aspect, energy efficiency carries significant social and economic dimensions. By improving the energy characteristics of buildings, it is possible to reduce energy consumption and heating costs, while simultaneously enhancing indoor comfort conditions. On the other hand, the inability to secure adequate domestic energy services is a defining feature of energy poverty. In this regard, energy efficiency serves as a crucial tool for elevating the quality of housing, especially among socially vulnerable groups [4].

In architectural practice, energy efficiency is achieved through an integrated approach that encompasses envelope design and renovation, the optimization of structural details, the control of thermal bridges, and the application of appropriate materials. Indeed, well-executed envelope details exert a decisive influence on the actual energy performance of a building, often more so than the nominal values of the thermal insulation itself.

Considering the aforementioned, it can be concluded that energy efficiency in residential buildings is not merely a technical parameter, but a complex issue unifying the architectural, energy, and social aspects of housing. This conceptualization of energy efficiency serves as the baseline for analyzing and defining energy renovation measures within this research. The paper was prepared from the master's thesis within the program "Energy Efficiency in Buildings" at the University of Banja Luka, using research tools developed within the European project ENPOWER.

2. THEORETICAL BACKGROUND

The housing stock in Bosnia and Herzegovina (B&H) is characterized by a large number of multi-family residential buildings constructed between the post-World War II period and the late 1980s. This stock is defined by a lack of or insufficient envelope thermal insulation, substandard fenestration, unaddressed thermal bridges, and the low energy efficiency of indoor building systems [5].

According to European Commission data [6] and relevant studies on building energy renovation, retrofitting can lead to substantial energy consumption reductions. Depending on the type and scope of the intervention, these savings frequently range from 30% to 50%. Such measures directly impact the mitigation of energy poverty and enhance residential comfort.

Energy renovation encompasses a series of interventions that can be categorized into:

- Technical interventions on the building envelope – improving the thermal insulation of walls, roofs, and floors, replacing fenestration, and renovating facades and windows.
- Building services solutions – optimizing heating and cooling systems, installing energy-efficient boilers or heat pumps, and implementing controlled ventilation.
- Application of renewable energy sources (RES) – solar panels, passive heating systems, and integrated photovoltaic facades.

Energy renovation in the Western Balkans often faces strict socio-economic constraints due to residents' limited financial capacity, underscoring the critical need for external subsidies, credit lines, or collective management initiatives [7]. Best practice examples in Bosnia and Herzegovina, such as projects led by the United Nations Development Programme (UNDP) and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), demonstrate that successful retrofits must pair technical upgrades with user education and active community involvement [7]. In alignment with the European Energy Efficiency Directive [8], such integrated frameworks are essential to guarantee sustainable outcomes, improve housing quality, and address regional socioeconomic challenges [9]. Ultimately, mitigating the high energy losses characteristic of uninsulated, legacy structures [4] not only minimizes the broader environmental footprint and atmospheric emissions but also directly enhances the occupants' quality of life by reducing household financial burdens [9].

The most prevalent issues resulting from low energy efficiency include transmission heat losses through the surface components of the envelope (facade walls, roofs, windows, doors, and floors), as well as linear heat losses caused by thermal bridges across the building envelope. The consequences of these deficiencies directly impair residential comfort, leading to uncomfortable indoor temperatures, moisture condensation, and mold growth. Vulnerable groups, such as low-income households, are particularly affected; the high financial burden of heating or cooling energy triggers energy poverty, restricts access to basic housing conditions, and consequently undermines occupant health and well-being [10].

From an environmental perspective, energy-inefficient buildings increase the consumption of fossil fuels, thereby amplifying greenhouse gas emissions and degrading air quality in urban areas [11].

The impact of energy efficiency on the quality of life is not merely a technical issue, but a profound social phenomenon. Properly insulated and energy-optimized spaces guarantee stable and predictable energy consumption for occupants, which alleviates economic pressure and fosters conditions for better health and psycho-social comfort.

3. METHODOLOGY

The methodology of this study is based on a comprehensive case study analysis of a multi-family residential building located in Banja Luka.

In the primary phase of the research, a detailed energy audit was conducted alongside a thorough, on-site physical and technical assessment of the building's existing condition. This diagnostic stage involved collecting geometric and structural data, evaluating the thermal properties and U-values of both opaque and transparent structural components of the envelope, identifying critical construction deficiencies (such as extensive thermal bridging and air leakage), and calculating baseline energy performance indicators under current operational states. The thermal and heating energy demand calculations were performed in strict compliance with the valid methodology prescribed by the official national Rulebook on the Methodology for Calculating the Energy Performance of Buildings [12]. For data processing, complex algebraic numerical simulations, and monthly energy balance analysis, a custom-developed, rigorously verified calculation model implemented within the Excel software package was utilized.

The existing building is characterized by an envelope compliant with the regulations that were in force until 2016, representing a typical construction style for the 1996–2016 period. The specific energy need for heating is maintained at a high level of $Q_{H,nd}$ = 116.82 kWh/m²a, positioning the building into energy class E [12]. The estimated specific primary energy is E_{prim}= 429.96 kWh/m²a.

Following the quantitative establishment of the baseline operational profile, three distinct and progressive renovation scenarios were systematically developed and simulated to determine the most effective and feasible retrofitting pathway:

- **Scenario 1 (Standard Upgrade):** Focused primarily on conventional passive insulation techniques, including the application of contact thermal insulation (ETICS) on facade walls and standard building service upgrades such as upgrading the central heating substations.
- **Scenario 2 (TES Upgrade):** Investigated the application of a prefabricated, industrialized Timber Energy System (TES) envelope, optimizing the construction process through off-site manufacturing and rapid dry-assembly installation.
- **Scenario 3 (Alternative Solution – TES with APV Facade):** Represented the most advanced scenario, investigating the comprehensive integration of the industrialized TES timber framework with an innovative, dynamic, and adaptive photovoltaic (APV) facade technology (Solskin system).

While the first two scenarios primarily targeted the reduction of transmission losses via static thermal resistance, this paper specifically focuses on the third, Alternative Solution. This advanced scenario introduces a paradigm shift by utilizing real-time solar tracking and automated panel angle optimization to achieve simultaneous heating demand reduction and on-site electricity generation.

By employing comparative and sequential approach, the study evaluates how the building envelope can transition from a passive protective barrier into an active, energy-producing multi-functional system.

The selected and presented alternative holds the greatest significance from the perspectives of sustainable development, energy independence, and long-term system stability.

4. SUSTAINABLE BUILDING ENVELOPE

Alternative Solution represents an advanced concept for the energy renovation of the existing building, based on an industrialized approach to facade envelope renovation and the integration of active energy systems. The solution combines the prefabricated Timber Energy System (TES) facade with Solskin active photovoltaic facade elements, thereby enabling the transformation of the building envelope from a passive protective element into a multifunctional energy system (Figure 1).

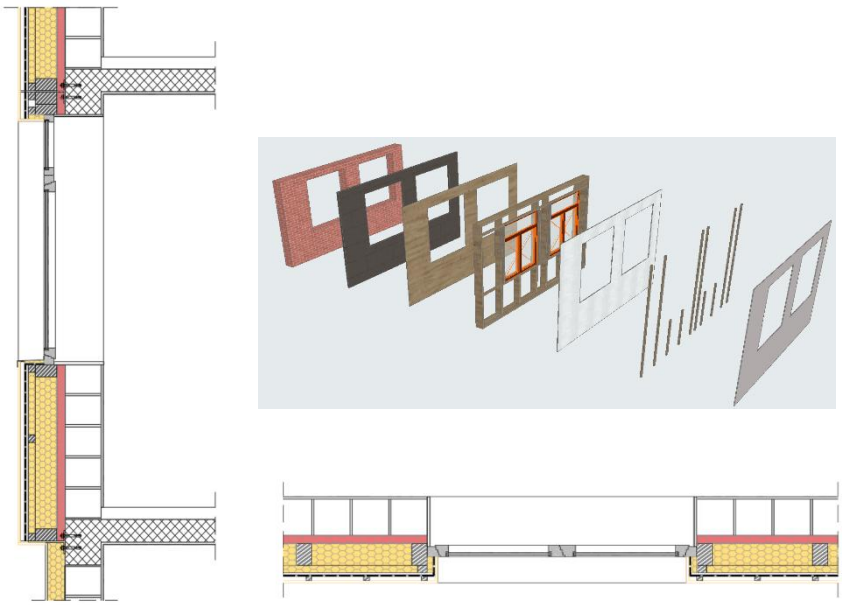


Figure 1. Prefabricate modul and renovation existing envelope with TES facade system

The primary objective of this alternative solution is the simultaneous improvement of the envelope's thermal characteristics, the reduction of heating energy demand, and on-site electricity generation, complemented by the integration of a dynamic shading function. Due to the highest intensity of solar radiation, the south facade stands out as the most favorable orientation for the integration of photovoltaic systems.

The "Solskin adaptive solar façade system" is an adaptive facade system that combines electricity generation, shading control, and daylight management in real time. Unlike conventional shading systems (such as fixed louvers, blinds, and passive photovoltaic panels), this system dynamically tracks the path of the sun and optimizes the panel angle. Consequently, it simultaneously maximizes electricity generation, minimizes overheating risks, and enhances natural daylighting conditions (Figure 2).

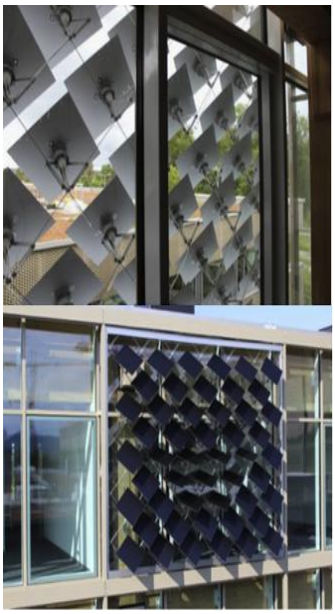


Figure 2. APV façade system prototype according to [13]

5. RESULTS AND DISCUSSION

Research indicates that adaptive systems can achieve up to 56% in energy savings compared to buildings without shading, and approximately 25% compared to buildings equipped with conventional fixed shading systems [13]. Vertical surfaces achieve better utilization of solar radiation during the winter season when energy consumption peaks. According to research conducted for a case study in Zurich, the average annual energy generation via photovoltaic systems amounts to 83.2 kWh/m² [13]. Given that the solar radiation intensity in the territory of Banja Luka is approximately 10–15% higher, the specific annual yield of photovoltaic systems in this area is roughly 1100–1300 kWh/kWp, which translates to an expected area-specific energy generation of about 90–130 kWh/m² per year Figure 3.



Figure 3. Integration of Adaptive PT Systems and Timber Energy Systems (TES) according to authors

By integrating the photovoltaic facade system across a total active surface area of 430 m², the total energy generation presented in Table 1 is achieved.

Table 1. Electricity generation of the photovoltaic systems, source: authors

Parameter	Value
PV surface area	430 m²
Specific generation	90–130 kWh/m²a
Total annual generation	38,700–55,900 kWh/a
Estimated self-consumption	60%
Energy consumed within the building	≈ 23,000–33,000 kWh/a
Surplus energy	≈ 15,000–22,000 kWh/a

Based on 2026 prices, the average cost of the Solskin system, including installation, is approximately 1,125 CHF/m² (≈ 1,179 €/m²). For the analyzed facade surface area of 430 m², the total investment in the photovoltaic systems amounts to approximately 506,994 €. The annual energy benefits encompass savings and revenues totaling approximately 3,100–4,100 €. Although economic analysis is challenging due to market turbulence, the analysis also demonstrates the share of specific works required to execute the aforementioned building envelope improvement, Table 2 presents a summary overview of the characteristic works for Alternative Solution.

Table 2. Summary overview of characteristic works – Alternative Solution, source: authors

Work Category	Value EUR (€)	Share (%)
Preparatory works	15,364.55	1.13%
Dismantling and cleaning	39,300.12	2.89%
Insulation works	51,717.09	1.06%
Sheet metal works	1,825.34	0.13%
Facade works	153,136.26	11.25%
TES elements	273,188.56	20.06%
Locksmith works and fenestration	326,156.20	23.95%
Electrical heating appliances (Norwegian radiators)	23,315.26	1.71%
Photovoltaic systems "SOLSKIN"	506,994.58	37.23%

Work Category	Value EUR (€)	Share (%)
Miscellaneous works	7,657.75	0.56%
Total (excluding VAT)	1,398,667.49	100%
VAT 17%	237,773.47	-
Total (including VAT)	1,636,440.96	-

Based on current energy prices in Bosnia and Herzegovina estimated payback period for Scenario 3 (Alternative solution) is 41 years, while for Scenario 1 it is 25 years, and for Scenario 2 is 34 years. Rising energy prices would reduce the payback period of the investment.

Based on the thermal calculations performed, the energy balances of the building were obtained and are summarized in Table 3.

Table 3. Energy calculation results for Alternative Solution, source: authors

Parameter	Value
Transmission heat losses	2,835.80 W/K
Ventilation heat losses	2,804.49 W/K
Total heat losses	437,844.27 kWh/a
Solar heat gains	241,007.06 kWh/season
Internal heat gains from occupants	27,094.58 kWh/a
Internal heat gains from electrical appliances	103,099.61 kWh/a
Total heat gains	371,201.24 kWh/a
Specific energy need for heating - $Q_{H,nd}$	21.93 kWh/m²a
Specific primary energy – E_{prim}	123.35 kWh/m²a
CO_2 emissions – PV systems included	74.85 tCO_2

Alternative Solution represents the highest level of integration between energy and architectural systems. The specific energy need for heating is maintained at a low level of $Q_{H,nd}$ = 21.93 kWh/m²a, positioning the building into energy class B [12]. The estimated specific primary energy is E_{prim}= 123.35 kWh/m²a.

The key advantage of this solution lies in the introduction of an active energy component through the Solskin system, which enables the facade to actively generate electricity and dynamically control solar heat gains. Compared to passive alternatives, this concept introduces the highest technological complexity but offers long-term energy self-sufficiency. Additionally, a significant reduction in CO_2 emissions is observed. In the previous passive models, emissions amounted to 216.75 tCO_2, whereas in this solution, they are reduced to 74.85 tCO_2. This decline is a direct result of the localized decarbonization of electricity consumption, achieved via the photovoltaic system integrated into the building envelope.

6. CONCLUSION

The deep energy renovation of a residential building in Banja Luka demonstrates that upgrading an envelope typical of the 1996–2016 construction period by implementing a sustainable envelope solution based on the Timber Energy System (TES) can reduce the specific energy need for heating from 116.82 kWh/m²a (Class E) to 21.93 kWh/m²a (Class B). By implementing this industrialized framework integrated with the active 'Solskin' APV facade, the building envelope transitions from a passive barrier into an active, energy-producing system. This highly integrated architectural and energy concept generates between 38,700 and 55,900 kWh of electricity annually, enabling a significant reduction in specific primary energy from 429.96 kWh/m²a to 123.35 kWh/m²a through this advanced solar integration. Consequently, this on-site decarbonization reduces overall CO_2 emissions from 216.75 tCO_2 to 74.85 tCO_2. Although this Alternative Solution introduces substantial investment costs and higher technological complexity compared to standard passive insulation techniques, it establishes a new paradigm for long-term energy self-sufficiency, sustainable urban development, and grid stability. Future energy market volatility and scaling up production could impact the long-term cost-effectiveness of the Solskin facade.

ACKNOWLEDGMENT

The authors acknowledge the support of the European Research Executive Agency (REA) for funding this research under the project “ENPOWER – Enhancing Scientific Capacity for Energy Poverty (101160253 — ENPOWER — HORIZON-WIDERA-2023-ACCESS-02)”.

DISCLAIMER

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union, European Research Executive Agency (REA). The European Union, the granting authority, can be held responsible for them.

LITERATURE

[1] European Parliament and Council of the European Union. (2024). Directive on the energy performance of buildings. Brussels, Belgium.

[2] Tushar, A. M., Bhuiyan, M. Z., & Riffat, S. (2024). Thermally comfortable energy efficient affordable houses: Exploring building codes and thermal performance of old housing stocks. *Building and Environment*, *257*, Article 111537. doi.org

[3] Gajić, D. (2025). Održiva obnova omotača zgrada [Sustainable renovation of building envelopes]. Univerzitet u Banjoj Luci, Arhitektonsko-građevinsko-geodetski fakultet.

[4] Bouzarovski, S. (2014). Energy poverty in the European Union: Landscapes of vulnerability. Energy Policy, 75, 276–286. doi.org

[5] Arnautović-Aksić, D. (2016). Typology of residential buildings in Bosnia and Herzegovina. Faculty of Architecture, University of Sarajevo.

[6] European Commission. (2020). A renovation wave for Europe – greening our buildings, creating jobs, improving lives (COM/2020/662 final). Brussels, Belgium.

[7] United Nations Development Programme. (2021). Istraživanje i projekti energetske obnove u BiH [Research and projects of energy renovation in BiH]. UNDP Bosnia and Herzegovina.

[8] European Parliament and Council of the European Union. (2018). Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources. Brussels, Belgium.

[9] European Commission. (2023). Renovation Wave strategy and energy efficiency policies. Brussels, Belgium.

[10] Thomson, H., Bouzarovski, S., & Snell, C. (2019). European energy poverty index: Assessing vulnerable households. Regional Studies and Science, 47(1), 112–125.

[11] European Environment Agency. (2021). Air quality in Europe and the role of building emissions. EEA.

[12] *Rulebook on minimum requirements for energy characteristics of buildings, Rulebook on Methodology for Calculating the Energy Performance of Buildings and Rulebook on Conducting Energy Audits of Buildings and Issuing Energy Performance Certificates of the Republic of Srpska*, Official Gazette of the RS no. 30/15

[13] Nagy, Z., Sveinsson, J., & Schlueter, A. (2016). The Adaptive Solar Facade: From prototype to performance. In Proceedings of the International Adaptive Facades Conference (pp. 116–123). Zurich, Switzerland