University of Banja Luka
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DEMI 2025

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PROCEEDINGS

Banja Luka, 29–30 May 2025

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CONTENT

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Techo-economic analysis and enhancing energy efficiency in a residential building

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Abstract *Enhancing energy efficiency in residential buildings is essential for reducing energy consumption, minimizing environmental impact and improving overall sustainability. A comprehensive techno-economic analysis is critical for evaluating the effectiveness of energy efficiency measures in residential buildings. It helps to balance technical feasibility with economic considerations. This paper analyzes the energy performance of a residential building and explores different strategies to enhance its efficiency. The current energy classification of the building is analyzed, and the study identifies strategies for reducing electricity consumption and operational costs. It evaluates these measures' technical feasibility and potential energy savings, highlighting their effect on long-term energy demand and operational costs. It also outlines specific interventions needed to improve the building's energy rating by one level, concentrating on optimizing overall energy performance and sustainability. This paper presents enhancing energy efficiency using Knauf software. The analysis also considers the techno-economic aspects of the proposed measures, assessing their feasibility and cost-effectiveness to ensure a balanced approach to improving energy efficiency.*

Keywords *energy efficiency, techno-economic aspects, residential buildings*

1. INTRODUCTION

The primary energy challenges today are supply insecurity and the environmental consequences of excessive consumption. Growing energy demand and the depletion of fossil fuels necessitate increased reliance on renewable sources, while reducing CO2 emissions remains crucial for environmental protection. The increasing global demand for energy, particularly electricity, is driven by population growth, evolving lifestyles, and rapid technological progress. As energy consumption rises, more efficient and sustainable solutions become increasingly critical. Consequently, developing energy-efficient and environmentally responsible buildings has gained significant attention recently.

In 2022, households in the EU accounted for 25.8% of final energy consumption and 18.1% of gross inland energy consumption, highlighting their significant role in overall energy demand. Natural gas was the primary energy source for households, making up 30.9% of final energy consumption, followed by electricity at 25.1% and renewables and waste at 22.6%. Oil and petroleum products contributed 10.9%, while derived heat accounted for 8.2%. Despite a shift towards cleaner energy, 2.3% of households still relied on coal products (solid fossil fuels). The largest share of household energy use, 63.5%, was dedicated to space heating, emphasizing the sector's dependence on energy for thermal comfort. Notably, renewable energy sources played an increasingly important role in

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household heating, covering 31.4% of total space heating consumption, reflecting a gradual transition towards more sustainable energy solutions [1].
Serbia's final energy consumption in 2023 amounted to 9,302,605 Ktoe, ranking it 21st among 42 countries [2]. Figure 1 presents the annual energy consumption of households. As shown, in 2023, it amounted to 3,388 Ktoe [2].

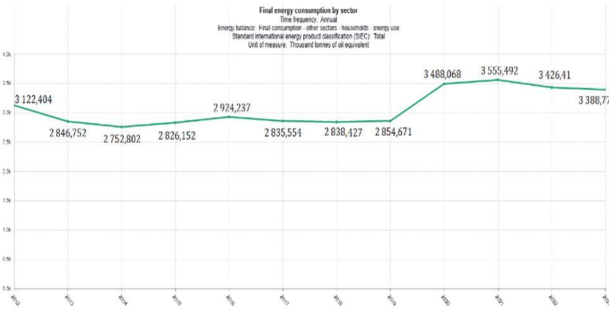

Fig. 1. Annual energy consumption of households in Serbia [2]

The share of end users is shown in the Figure 2.

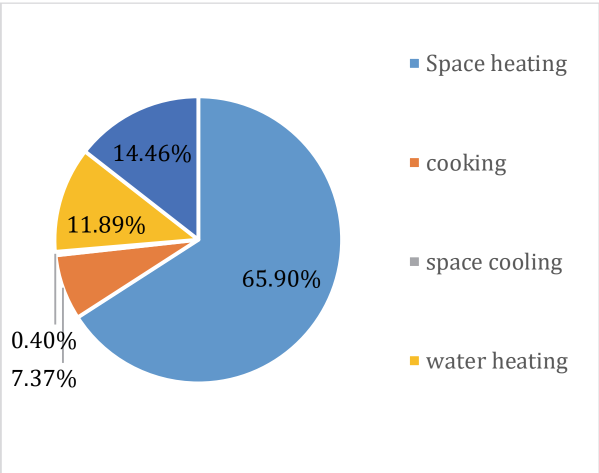

Fig. 2. Final energy consumption in the residential sector by the type of end-use [1]

This study examines a two-story family house, for which annual energy consumption data was collected and its energy efficiency analyzed. Various strategies for improving energy performance were proposed, along with a cost analysis detailing the necessary replacements and investments required to enhance the building's energy efficiency rating by one level. The findings provide a comprehensive assessment of the current state of the house's energy performance and offer practical recommendations for optimizing efficiency while evaluating the financial implications of such upgrades.

2. ANALYZED OBJECT

A family residence in Kragujevac was selected for the energy consumption analysis, as shown in Figure 3. The house comprises a ground floor and an upper floor with a pitched roof, encompassing a total area of 225 m^2. Each floor includes a living room, a kitchen with a dining area, a bathroom, and two bedrooms, ensuring a functional and well-organized layout. Furthermore, the property features a basement and a semi-basement, contributing to its overall spatial capacity and utility.

Fig. 3. 3D analyzed object

The structural exterior and load-bearing partition walls are constructed from 25 cm thick brick blocks with mortar. The building's foundation is reinforced concrete designed to mitigate soil temperature fluctuations. Reinforced concrete columns measuring 25x25 cm have been incorporated at the corners and junctions of structural walls. Thermal insulation was installed in 2008 using 5 cm polystyrene boards. The parapet walls are made from the same material as the exterior walls but with a reduced thickness of 20 cm. The interior surfaces are finished with two layers of lime plaster. The residential building features a pitched, double-pitched roof.
The exterior doors and windows, as well as all interior joinery, are standard models manufactured by Jelovica. The windows feature wooden frames, double glazing, thermal insulation, and shutters, and they come in various dimensions. The living areas are finished with oak parquet flooring, while the bathrooms and the kitchens are fitted with ceramic tiles. It is important to note that the building lacks floor thermal insulation.

Fig. 4. The ground floor layout

3. ENERGY CONSUMPTION

Table 1 presents the collected electrical energy consumption data for the entire year of 2024, while Figure 5 presents data for electrical energy consumption spent in lower and higher tariffs. As illustrated in the table, electrical energy consumption peaks in July and reaches its lowest point in February.

Table 1. Electrical energy consumption data for 2024

Month	Sum (kWh)	Amount Due (RSD)
January	148	835.77
February	124	726.46
March	339	1885.6
April	399	2145.22
May	416	2358.15
June	546	2943.42
July	583	3133.58
August	432	2245.41
September	426	2358.14
October	435	2323.98
November	441	2306.9
December	495	2873.96
SUM	**4784**	**26136,59**

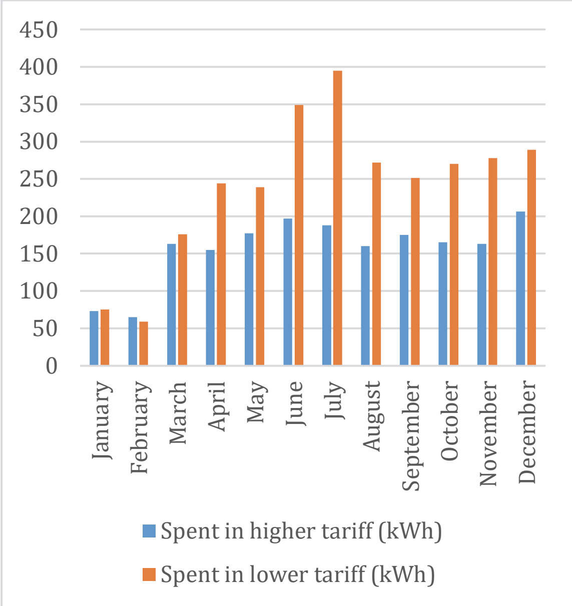

Fig. 5. Electrical energy consumption spent in lower and higher tariffs

Table 2 presents calculations that provide a detailed insight into the electricity consumption and costs per household member, as well as the average price paid per kilowatt-hour.

Table 2. Electrical energy consumption calculations

The specific electricity consumption per user	956.8 [kWh/user]
The specific electricity cost per user	5227.318 [RSD/user]
The average electricity price	5.46 [RSD/kWh]

In the dual-generation residential building, certain daily-use appliances are duplicated; most are well-maintained, with some recently replaced and others relatively old. The building contains a single air conditioning unit located in the upstairs dining room, which achieves the desired temperature during summer after a certain period. Other rooms are ventilated through natural methods, facilitated by opening windows and doors, with the nearby lake contributing to a cooler environment compared to urban areas. During summer, ventilation is performed daily, whereas in winter, it occurs once or twice a week. The lighting system comprises 44 bulbs of various types tailored to room sizes; in some areas, incandescent bulbs have been replaced with compact fluorescent lamps to conserve energy. Lighting is manually controlled via switches without the integration of sensors or automated systems. Figure 6 presents Energy consumption by the type of end users in this household.

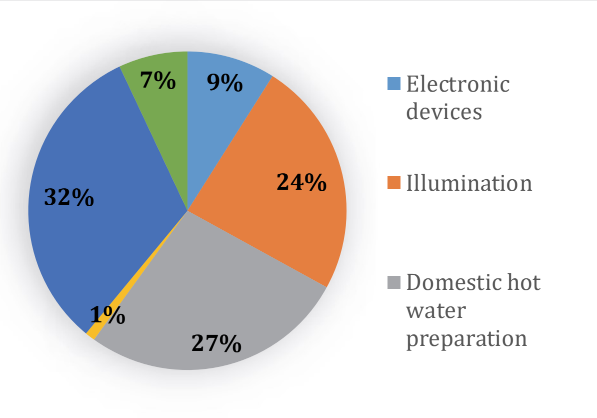

Fig. 6. Energy consumption by the type of end-user

For the preparation of domestic hot water, an instantaneous combination boiler is used for the bathrooms. In the ground floor kitchen, an 8-liter instantaneous water heater is utilized, while a 5-liter instantaneous water heater is employed in the upstairs kitchen. Table 3 presents data on water consumption and the amount due.

Table 3. Water consumption data for 2024

Month	Sum (m^3)	Amount Due (RSD)
January	34	3879.06
February	12	1642.92
March	29	3970,39
April	46	6297,86
May	30	4107.30
June	22	3012.02
July	34	4654.94
August	31	4244.21
September	32	4381.12
October	15	2053.65
November	39	5339.49
December	33	4518.03
SUM	**357**	**37832.74**

Calculations for average water price and specific water consumption are presented in Table 4.

Table 4. Water consumption calculations

Average water price	105.97 RSD/m^3
Specific water consumption	71.4 m^3/user

In the residential building, a natural gas connection was established in 2008. The primary heating source is a Vaillant ecoTEC plus VU 306/5-5 boiler, offering a heating output of 30 kW at an 80/60°C system temperature. This condensing boiler achieves an efficiency of approximately 89.4%, ensuring effective heating. Detailed data on total consumption and costs associated with natural gas supply are presented in table 5.

Table 5. Natural gas consumption for 2024

Month	Sum (kWh)	Amount Due (RSD)
January	*5440*	27616.24
February	*3616*	18419.2
March	*3192*	16280.76
April	*1427*	7378.99
May	*753*	3979.67
June	*522*	2814.61
July	*487*	2638.1
August	*427*	2335.49
September	*474*	2576.06
October	*1724*	8876.9
November	*4465*	22701.14
December	*4574*	23250.88
SUM	**27101**	**138868.04**

Considering that natural gas is also used for heating domestic hot water, consumption during summer months can be indicative of winter usage for the same purpose. This is particularly evident from the data in July, August, and September when natural gas was exclusively used for heating domestic hot water. Based on this data, it can be concluded that approximately 5,552 kWh is consumed annually for heating domestic hot water, with the remaining energy used for space heating. Considering the average price of natural gas at 4.57 RSD/kWh, the total annual cost for heating water is approximately 25372.64 RSD. This amount may vary depending on appliance efficiency and current gas prices.

4. BUILDING ENERGY RATING (BER)

For determining the energy efficiency class of the building, the KnaufTerm2S software was used [3]. By inputting actual parameters corresponding to the building's dimensions, location, and construction materials, all necessary data for establishing the building's energy class were defined. The building's envelope comprises external walls, a roof, a floor-ceiling structure above the unheated space, windows and balcony doors, entrance doors, and the ground floor. The envelope structure diagram is shown in Figure 7.

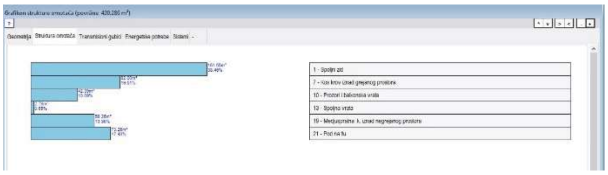

Fig. 7. The envelope structure diagram

The external walls have an area of 161.646 m^2. They consist of a layer of lime mortar with a thickness of 2 cm, hollow brick blocks laid with a longitudinal mortar of 1 cm thickness, another layer of lime mortar of 2 cm, 5 cm thick polystyrene insulation, and a facade. The block bricks have dimensions of 25 × 19 cm. The heat transfer coefficient is 0.534 W/m^{2}K.
The roof structure consists of concrete and wooden beams, a membrane, and roof tiles. Its surface area is 82 m^2, and the heat transfer coefficient is 0.675 W/m^{2}K. The total thickness of the roof is 47.5 cm.
The floor-ceiling structure above the unheated space is made of hollow concrete blocks, 20 cm thick, laid in cement mortar 1 cm thick, a 4 cm thick concrete layer, and either parquet or tiles, depending on the area (kitchen or living room). A 2 cm thick concrete screed is used to level the floor in rooms where parquet is present. The surface area of rooms with parquet is 47.14 m^2. The heat transfer coefficient is 1.166 W/m^{2}K. In rooms like the kitchen and pantry, where tiles are installed, the structure consists of concrete blocks, concrete, and ceramic tiles. The surface area of this space is 10.85 m^2. The heat transfer coefficient is 1.321 W/m^{2}K.
The windows and balcony doors have a total surface area of 42.39 m^2. These are wooden windows of medium insulation quality. The heat transfer coefficient for the windows is 1.5 W/m^{2}K. The external doors are also made of wood, with a surface area of 2.73 m^2 and facing west. The heat transfer coefficient for the external doors is 1.6 W/m^{2}K.
Transmission heat losses through the building's envelope are a critical factor in assessing the building's energy efficiency, as they directly influence the overall energy requirements for heating and cooling. A detailed analysis of these losses facilitates the identification of weak points in the building's thermal insulation and provides a foundation for enhancing energy efficiency through targeted interventions. Figure 8 illustrates these losses, offering a visual representation of how thermal energy dissipates across various parts of the building.

Fig. 8. Transmission heat losses

Based on all the entered parameters, the energy performance certificate of the building has been determined, classifying it in energy class D, as shown in Figure 9.

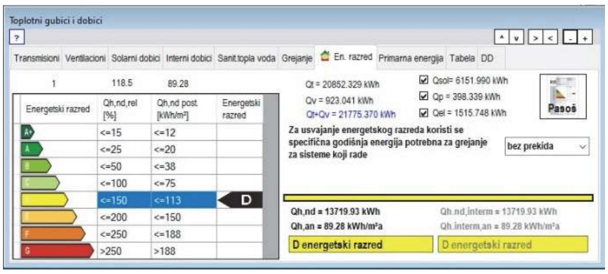

Fig. 9. Energy classification, grade D

5. ENERGY EFFICIENCY IMPROVEMENTS

Considering that the residential building currently features wooden windows and doors, one potential improvement measure is their replacement with PVC counterparts. This substitution offers numerous advantages, including enhanced durability, superior thermal and acoustic insulation, and minimal maintenance requirements. Additionally, PVC windows and doors are often more cost-effective compared to traditional wooden ones, making them a practical choice for homeowners seeking both quality and affordability.
The proposed improvements include replacing existing wooden windows and doors with PVC alternatives. Specifically, it is recommended to install Eco+ windows from the manufacturer Sunce Marinković. These windows feature a 5-chamber design, a thermal conductivity coefficient of 1.3 W/m^{2}K, low-emission glass

filled with argon, and an installation depth of 70 mm [4]. For the entrance door, the Termo+ model from the same manufacturer is advised, offering excellent thermal and acoustic insulation and a modern design and durability. Implementing these measures will contribute to reducing energy losses and enhancing indoor comfort [5]. Tables 6 and 7 present the specifications of the required windows and door along with their prices, which include manufacturing, transportation, and installation costs [6].

Table 6. The specifications of the required windows

Window dimension (cm)	Quantity	Price (RSD)	Sum (RSD)
180x140	6	40662.3	243973.8
120x140	3	31889.92	95669.76
140x140	4	34522.72	138090.88
60x60	1	9626.93	9626.93
100x90	1	16452.56	16452.56
90x200	2	26936.03	53872.06
		SUM	***37832.74***

Table 7. The specifications of the required door

Door dimension (cm)	Quantity	Price (RSD)	Sum (RSD)
90×210	1	130408.73	130408.73
		SUM	***130408.73***

Intermediate floor structures are insulated primarily to mitigate sound transmission while also contributing to the reduction of thermal losses, representing an additional measure aimed at improving the building's energy performance rating. The project includes the installation of thermal insulation for two types of floor structures: a ground-level floor covering an area of 30 m², and an intermediate floor structure covering 137 m².

For the ground-level floor, thermal insulation is provided in the form of stone wool boards, type Knauf Insulation DF, manufactured in accordance with EN 13162. These boards feature a minimum declared thermal conductivity of λ = 0.037 W/mK, tolerance class T5, declared compressive strength of 30 kPa at 10% deformation, and a non-combustibility rating of A1. The required thickness of the insulation layer is determined based on the building physics calculations.

For the intermediate floor structure, rigid stone wool boards are to be installed, such as Knauf Insulation POD PLUS, also manufactured in compliance with EN 13162. The boards must have a minimum thickness of 3 cm, a thermal conductivity of λ = 0.039 W/mK, tolerance class T6, compressibility class CP3, load resistance up to 5 kPa, and a minimum air flow resistance rating of AF5 (MW - EN 13162 - T6 - CP3 - WS - WL(P) - AF5). The specific type of board is selected according to the expected loads and the functional use of the space.

For both floor types, edge strips made of stone wool (e.g., Knauf Insulation), 13 mm thick, are to be installed along the perimeter walls to prevent the transfer of heat and sound to adjacent structural elements. Over the thermal insulation layer, a PE vapor control layer is to be laid, such as Knauf Insulation Homeseal LDS 35, with a vapor diffusion resistance Sd = 35 m, thickness of 0.24 mm, and surface mass of 100 g/m², with overlaps at joints of at least 10 cm. If the floor area exceeds 30 m², depending on the type of screed used, the execution of expansion joints is required. This item includes the supply, delivery, and installation of all specified materials, as well as the use of light scaffolding where necessary. Measurement and billing shall be based on the finished floor area in square meters, as presented in tables 8 and 9 [7].

Table 8. The specifications of intermediate floor structures

Material	**Price per m² (RSD)**	**Total price for 30 m² (RSD)**
Mineral wool Pod Plus 3cm	660	90420
Vapor barrier Homeseal LDS 35	65	8905
Edge strips	40	5480
Cement screed	850	116450
Adhesive/underlay for parquet	150	20550
Standard parquet flooring	1200	164400
Installation of wool + vapor barrier	350	47950
Cement screed application	600	82200
Parquet installation	900	123300
SUM	***4815***	***659655***

Table 9. The specifications of ground-level floor

Material	Price per m^2 (RSD)	Total price for 30 m^2 (RSD)
Mineral wool DF 10cm	1700	51000
Vapor barrier Homeseal LDS 35	65	1950
Edge strips	40	1200
Cement screed	850	25500
Adhesive/underlay for parquet	150	4500
Standard parquet flooring	1200	36000
Installation of wool + vapor barrier	350	10500
Cement screed application	600	18000
Parquet installation	900	27000
SUM	***5855***	***175650***

Implementing the recommended energy efficiency measures would elevate the residential building's energy classification from grade D to grade C, as shown in Figure 10. This enhancement signifies a substantial improvement in the building's energy performance, leading to reduced energy consumption and associated costs. Consequently, occupants would benefit from increased thermal comfort and a diminished environmental footprint. Achieving this upgraded energy status aligns with Serbia's broader objectives to enhance energy efficiency in its building sector, addressing the significant potential for energy savings identified in residential structures.

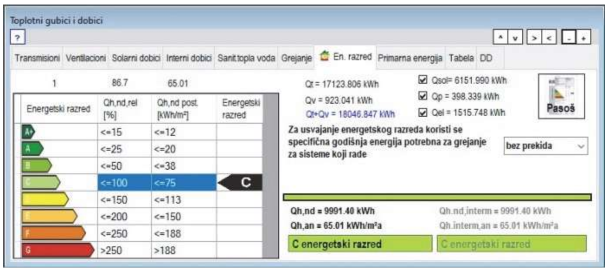

Fig. 10. Energy classification, grade C

According to established energy efficiency benchmarks, window and door replacement may lead to a reduction of approximately 15% in heating costs, whereas floor insulation may contribute an additional 10% savings. Combined, these measures are projected to reduce annual heating expenses by approximately 28,374 RSD, lowering the total annual energy-related expenditures from 165,004.63 RSD to around 136,630.63 RSD. This corresponds to an estimated return on investment period of about 35 years.

Following the implementation of the recommended measures, transmission losses have been reduced, as depicted in Figure 11.

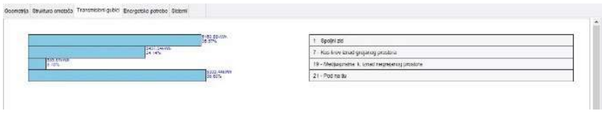

Fig. 11. Transmission heat losses

Despite the implemented interventions, transmission losses persist through the ground floor, which is situated above the basement. Insulating this floor would yield similar results to previous measures; however, such an investment is not cost-effective, as the basement is solely used for storage.

Implementing energy-saving practices, such as turning off electrical devices when not in use and replacing older appliances with more energy-efficient models, can significantly reduce electricity consumption. Specifically, replacing incandescent light bulbs with LED alternatives offers substantial benefits. LED bulbs consume approximately 80% to 90% less energy than traditional incandescent bulbs and have a significantly longer lifespan [8].

In a scenario where 25 incandescent bulbs are replaced with LED bulbs, the annual energy savings would be approximately 1,048.91 kWh, equating to a financial saving of around 7,619.53 RSD per year. Given that the average price of a single LED bulb is about 270 RSD, the total investment for replacing 25 bulbs would be 6,750 RSD. This investment would pay for itself in less than a year, considering the annual savings. Moreover, LED bulbs emit brighter light, allowing for a reduction in the number of bulbs needed to achieve the desired illumination levels [9].

By adopting these measures, households can achieve a reduction of approximately 78.20% in electricity consumption for lighting, leading to both economic and environmental benefits.

6. CONCLUSION

This study analyzes the potential improvement of energy efficiency in a residential building occupied by a five-member family. The focus is placed on electrical energy consumption, both in total and on a per-user basis. According to the collected data, the household records an annual electricity consumption of 4784 kWh, which corresponds to a specific consumption of 956.8 kWh per user. The associated cost of electricity amounts to 26136.59 RSD annually, or 5227.32 RSD per user. A combination boiler system is employed for both domestic hot water (DHW) preparation and space heating, relying on natural gas as the primary energy source. The total annual expenditure on natural gas reaches 138868.04 RSD, of which approximately 25372.64 RSD is attributed to DHW preparation, while the remaining portion covers heating costs. In summary, the family's total annual expenditure on electricity, water, and heating amounts to approximately 165004.63 RSD, highlighting the significance of targeted energy efficiency measures to reduce both consumption and associated costs.

The residential property's current energy efficiency rating is classified as D, primarily due to factors such as wooden windows and uninsulated flooring. In order to improve the building's overall energy performance and reach a higher energy class, several targeted interventions are proposed. These include the replacement of existing windows and doors with PVC models, an investment amounting to 168241.47 RSD and the insulation of the floor, estimated at 836305 RSD. Together, these measures are projected to yield a cumulative reduction in heating costs of approximately 25%, corresponding to an annual saving of around 28,374 RSD. Following the implementation of these measures, the BER improves to Class C, indicating a significant enhancement in thermal performance and energy conservation. Additionally, efforts to reduce electricity consumption are also considered. In a scenario where 25 incandescent light bulbs are replaced with LED bulbs, the household would achieve an estimated annual energy saving of 1048.91 kWh, translating into a financial saving of approximately 7619.53 RSD per year.

Implementing such sustainable refurbishment practices can significantly improve the building's environmental performance, leading to reduced energy consumption and increased occupant comfort. By adopting these measures, the household can achieve substantial energy savings, reduce utility costs, and contribute to environmental sustainability.

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