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Cost-related analysis of implementing energy-efficient retrofit measures in the residential building sector of a middle-income country – A case study of Bosnia and Herzegovina

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ABSTRACT

This study presents an in-depth analysis of the cost structure when planning EE retrofit measures in the residential sector in Bosnia and Herzegovina. The analysis showed that implementing EE retrofit measures would result in substantial energy savings in single-family houses, however, the specific cost of implementing EE retrofit measures per resident for single-family houses is on average 2.8 times higher than for the other three categories; multi-family houses, apartment buildings, and high-rise buildings. When considering the ratio between the investment costs and GDP per capita showed that the citizens in Bosnia and Herzegovina have four times lower ability to finance EE retrofit measures compared to three other representatives EU members and therefore government subsidy schemes may be inevitable for successfully implementing EE retrofit strategies. The general conclusion based on the cost-effective analysis is that EE retrofit investments, may not be financially viable in single-family houses, multi-family houses, and apartment buildings even if supported by government subsidies due to the very low prices of energy sources (coal and wood) used in these specific building prototypes. On contrary, high-rise buildings, that are mainly driven by natural gas and light distillate fuel oil, show a great EE retrofit-driven profitability in. Looking at the financial assessment outcomes, the most significant benefits are mainly related to retrofit scenario that accounts for improvement in the external wall insulation, window glazing, and improving the heating station efficiency. Looking at the carbon emission outcomes, the most significant benefits in reducing the relative and averaged CO2 emission are strongly related to replacing the existing partly coal-burned furnaces (80% firewood + 20 % coal) in single-family houses with exclusive firewood fueled heating systems. This measure may have an enormous impact on reducing the CO2 emission from single-family houses (minimum 83.1 %), which cover 93.1 % of the total residential building stock in Bosnia and Herzegovina. This study may benefit low and middle-income governments in their aim to translate potential EE retrofit measures in the residential sector to a nationwide economic energy-saving policy.

1. Introduction

1.1. Current energy-efficient retrofitt strategy of the building stock in Bosnia and Herzegovina: challenges and opportunities

The Energy Community (EnC) is an international organization encouraging non-EU members in southeast Europe to be more competitive in their energy transition process by implementing EU energy market rules and principles [1]. As a member of the Energy Community (EnC), Bosnia and Hercegovina (B&H) are required to reach the CO_2 emission reduction targets by 2050 defined by the relevant Energy Community acquis which aims to bring non-EU members in line with actions implemented by other EU members [2]. This process, among others, requires each EnC member to set up long-term strategy frameworks for implementing energy-efficient (EE) retrofit measures in the building stock by defining respective integrated national energy and climate plans, also known as National Energy and Climate Plan(s) (NECP (s)). In the last decade, EE-related activities in Bosnia and Herzegovina were implemented with relative success within the National Energy Efficiency Action Plans (NEEAP) [3] previously defined by the Energy Efficiency Directive (EED) in 2012. As a part of the acquis, EnC countries should gradually transpose and

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implement Energy Efficiency Directive (EED) [4] into their legislation. One of the main goals of EED is establishing a long-term strategy for mobilizing investment in the retrofit of the national stock of both public and private residential and commercial buildings.

However as the vast majority of these EE improvement measures were implemented in the public building sector, the current goal should is focused on analyzing realistic possibilities of achieving similar energy-saving potentials by retrofitting the private residential stock in Bosnia and Herzegovina. The residential sector currently accounts for approximately 41 % of the total final energy consumption in Bosnia and Herzegovina, of which 72 % is used for space heating [2]. For comparison, contemporary data shows that significantly lower values are achieved in the EU: 27 % of the final energy consumption is shared by the residential sector, of which 67 % accounts for space heating [5,6]. In this context, future energy-saving policies and EE retrofit measures in the residential sector in Bosnia and Herzegovina should mainly be focused on reducing the domestic- or space heating energy consumption. Such EE retrofit measures may not only reduce the country's final energy consumption but also provide numerous economic, environmental, and social benefits [7]. According to preliminary data, the suggested yearly planned retrofit rate for Bosnia and Herzegovina is 1–2.8 % of the gross floor surface of the current residential stock [2]. This implies that thousands of buildings, ranging from single-family houses to multi-apartment blocks and high-rise buildings need to be renovated according to predefined EE measures every year.

Taking into account that the vast majority of residential stock in Bosnia ad Herzegovina is private, the homeowners will need to cover a significant part of the EE retrofit costs. Therefore, evaluating the cost structure related to the implementation of EE retrofit measures, especially in low-income countries such as Bosnia and Herzegovina, becomes increasingly important. In 2016, a comprehensive overview of the national building stock in Bosna and Herzegovina was published as part of the "Typology of residential buildings in Bosnia and Herzegovina" [8], providing a systematic and comparative analysis of architectural and energy-related characteristics of the complete national residential stock. The analysis was based on the TABULA methodology [9] with pre-defined criteria for classifying residential buildings according to the period of construction by the type of building, resulting in a total of 29 building categories statistically relevant for Bosnia and Herzegovina. Each category is defined by a specific building type that is selected based on its specific architectural and energy-related characteristics. This recommended classification methodology by EED [4] and which is widely applied by EU members [9,10], facilitates cost-analysis calculations related to EE retrofit measures and all other energy-saving strategies implemented in the whole building stock. In addition to the building classification, another important step of the national building renovation strategy framework according to the EED [9] should include i) identifying cost-effective approaches to EE retrofits and ii) creating policies and measures to stimulate cost-effective deep retrofits of buildings. While these two steps are still part of an ongoing process in Bosnia and Herzegovina, preliminary analysis indicates that certain economic and social elements and aspects should be considered in more detail. This specifically relates to the fact that the drafting of the national building renovation policy in Bosnia and Herzegovina was initiated more than two years ago (2018), thus many of the EE-related retrofit costs may be outdated. In addition, the steps for calculating the EE retrofit included in the current draft of the Building renovation strategy do not take into consideration the absolute and specific values of different building categories. This is probably one of the main reasons that no large-scale government financing initiatives for retrofitting the residential sector have been launched in recent years. Despite several small-scale initiatives that have been offered for funding energy audit costs and partial funding of EE retrofit costs, including the reconstruction of the building envelope and the heating system of residential sector buildings, these initiatives do not offer any diversification of the funding within the context of specific building categories and their energy-saving potential.

1.2. Experience in implementing energy-efficient retrofit measures in the EU member states residential sector of potential relevance to Bosnia and Herzegovina

The experience of both the benefits and challenges arising from implementing EE renovation policies in the residential sector of different EU members may be of crucial importance when planning and analyzing the cost-effectiveness of similar measures in Bosnia and Herzegovina, especially with a focus on the specific building characteristics and financial supports for homeowners.

Baek and Park [11] have presented a detailed review analysis of retrofit policies for several European countries based on four major objectives when introducing retrofitting policies. These objectives include improvement of building physical performance, adjustment of houses for elderly people, improvement of energy efficiency and social cohesion, and revitalization. The review paper [9] also evaluates the impact of introducing state retrofit policy goals on the improvement of financial support programs provided to homeowners. In some EU countries, such as France and Germany, homeowners are offered grants, tax deductions, and low-interest loans by the governments when EE renovating their homes.

The evolution of EE policies in England [12], that although EE retrofit does not only reduces the total energy consumption but also has a positive impact on the occupant's health and thermal comfort there is a significant decline in the trend of implementing EE retrofit measures recently, which could imply that a deeper analysis of policy goals and a financial mechanism is needed. The study by Trotta [12] also implies that socio-demographic characteristics should be taken into account when analyzing the impact of housing characteristics on retrofit measures. The author also discusses that specific groups of households such as older dwellings, outright owners, households living in detached or semi-attached homes, etc. are more likely to invest in EE retrofit, and therefore future EE policies should be targeted towards particular subsets of households.

The importance of re-evaluation of existent financing models for EE retrofit in Germany is presented in a study by Weber and Wolf [13]. Based on the analysis of the energy and rental expenses of households in 10 apartment buildings, and the comparison of pre and post-implementation of EE retrofit measures, the study showed that in some cases expenses may increase after implementing EE retrofit measures. In a total sample of 109 households, the pattern of increasing costs post EE retrofit implementation was observed in 56 households, which represents more than 50% of the total number of households. The authors conclude that the current financial models for EE retrofit need to be adjusted. One of the funding models which are considered promising is based on the "pay as you save" method, i.e. occupants pay back the cost from the saved amount of the energy/heating bills. In addition, analyzing the energy consumption of pre and post- EE retrofit measures revealed that building/apartment energy rating is not accurate enough for the prediction of energy savings in particular apartments/households. Rather, actual consumption should be encountered, where the apartment position in the building and occupant's behavior plays an important role.

The effectiveness of Slovenian subsidy programs for EE retrofit called Eco Fund is analyzed in a study by Dolšak et al. [14]. Based on an analysis of data from 6882 households from 2006 to 2014, the effectiveness of the Eco Fund public subsidy scheme and predominant influencing factors for homeowners to undergo the EE retrofit were investigated. First National Energy Efficiency Action Plan (NEEAP) in Slovenia covers a period from 2008 to 2014, where a total of 380 million Euros (€) are placed to support planned measures, with the largest share in the residential sector, and subsidies ranged between 15 and 40 % of the total investments costs. Once implemented, the Eco Funding subsidy scheme triggered an abrupt increase of public expenditures related to EE retrofit measures, from 0.9 million € in 2008, 41 million € in total for 2011 and 2012 to 18 million € in 2014. As a result, the increase in energy savings shared the same trend, and the predicted energy savings targets were met. It was therefore concluded that strong financial programs, offering high rates of subsidies, result in high retrofit rates in the residential building sector. Other influencing factors that were shown to have a positive effect on the implementation of EE retrofit measures include better financial status of the residents, higher regional GDP, high electricity expenditures, no prior EE retrofit, older building age, as well as advantage multifamily buildings compared to a single-family building. These findings correlate with another study on EE retrofits in Slovenia [15], where it is shown that a combination of financial incentives, education, and informing the public may enhance the EE retrofit implementation in the residential sector.

1.3. Aims and objectives

Implementation of EE retrofit policies and strategies presents a cyclic process, where improvement and adjustment will be needed constantly, as a result of numerous influencing factors. Based on experience from other EU members, it is expected that once officially adopted, the national building renovation strategy in Bosnia and Herzegovina will be subject to periodical revisions, that should include a) the diversity of building categories when analyzing and addressing input data and b) strong financial support as a solid warranty that the planned energy savings will be reached. Therefore, the purpose of this paper is to present a valuable data set and in-depth analysis of the cost structure when planning EE retrofit measures in the residential sector in a middle-income country such as Bosnia and Herzegovina. The specific objective is to provide a detailed cost analysis of EE retrofit measures in four representative types of residential sector housings: single-family houses, multi-family houses, multi-apartment blocks, and high-rise buildings. Furthermore, based on the results this study aims to analyze the potential of translating the EE retrofit measures in the residential sector to a nationwide economic energy-saving policy to facilitate future subsidies and financial schemes for EE retrofit in Bosnia and Herzegovina.

2. Data and methods

2.1. The bottom-up analysis

This study uses the bottom up approach to assess the energy saving potentials of the residential building stock that is loosely based on the experience of a previous TABULA project [17].(Fig. 1).

2.2. Selection of typical building categories

Based on the National Typology Bosnia and Herzegovina [8], which is based on the TABULA method, the representative buildings selected for consideration are shown in Fig. 2. The buildings in Bosnia and Herzegovina are classified based on six different periods and six different building types.

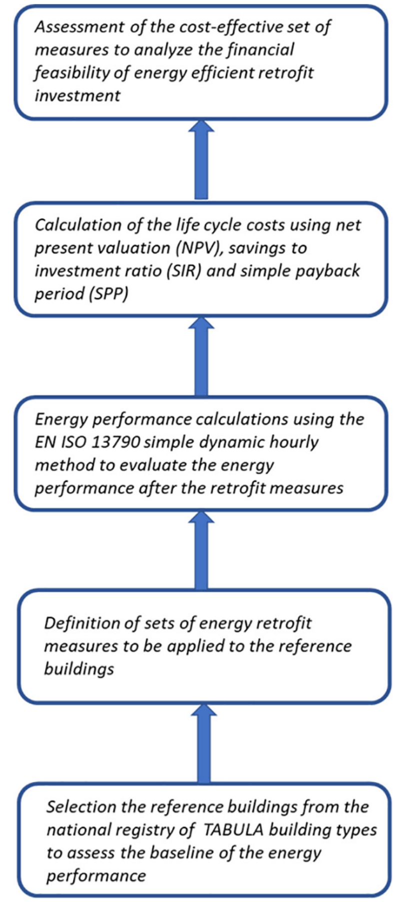

Fig. 1. Bottom up approach to assess the energy saving potentials of the residential building stock.

For this study, we have selected four representative buildings from four different building types: Single-family houses (SFH), multi-family houses (MFH), apartments block (AB), and High-Rise buildings (HRB). Terraced houses are not considered since they are grouped into the SFH category, where some aspects of this category are similar to SFH. Categories AB1 and AB2 in Tabula matrix are grouped into one category, so it is concluded that one representative building from these two categories is sufficient for analysis.

As may be seen from Fig. 3, SFH constitutes 93.91 % of all buildings of the total building stock, MFH 1.39 %, AB 0.46 %, and HBR 0.02 % of the total residential building stock in Bosnia and Herzegovina. We have furthermore for this study selected the representative building type from the period of constructions that we consider most representative in terms of both largest percentage of buildings from the specific building type and largest energy need (Fig. 4).

The percentage of the number of buildings for specific periods of construction and building type as expressed in terms of the total number of buildings in building stock is calculated and this data is presented in Fig. 3. The selected categories are shaded in blue.

From Fig. 3 the selected representative building types are not the ones with the largest share from each category since we also included for the selection of buildings the percentage of the building energy need of total energy need as selection criteria. In Fig. 3, the percentage of energy need of a particular category in total energy need of building stock is shown, where theoretical energy need and building type total gross surface area are considered. SFH (1971–1980) is the dominant category in SFH and total building stock.

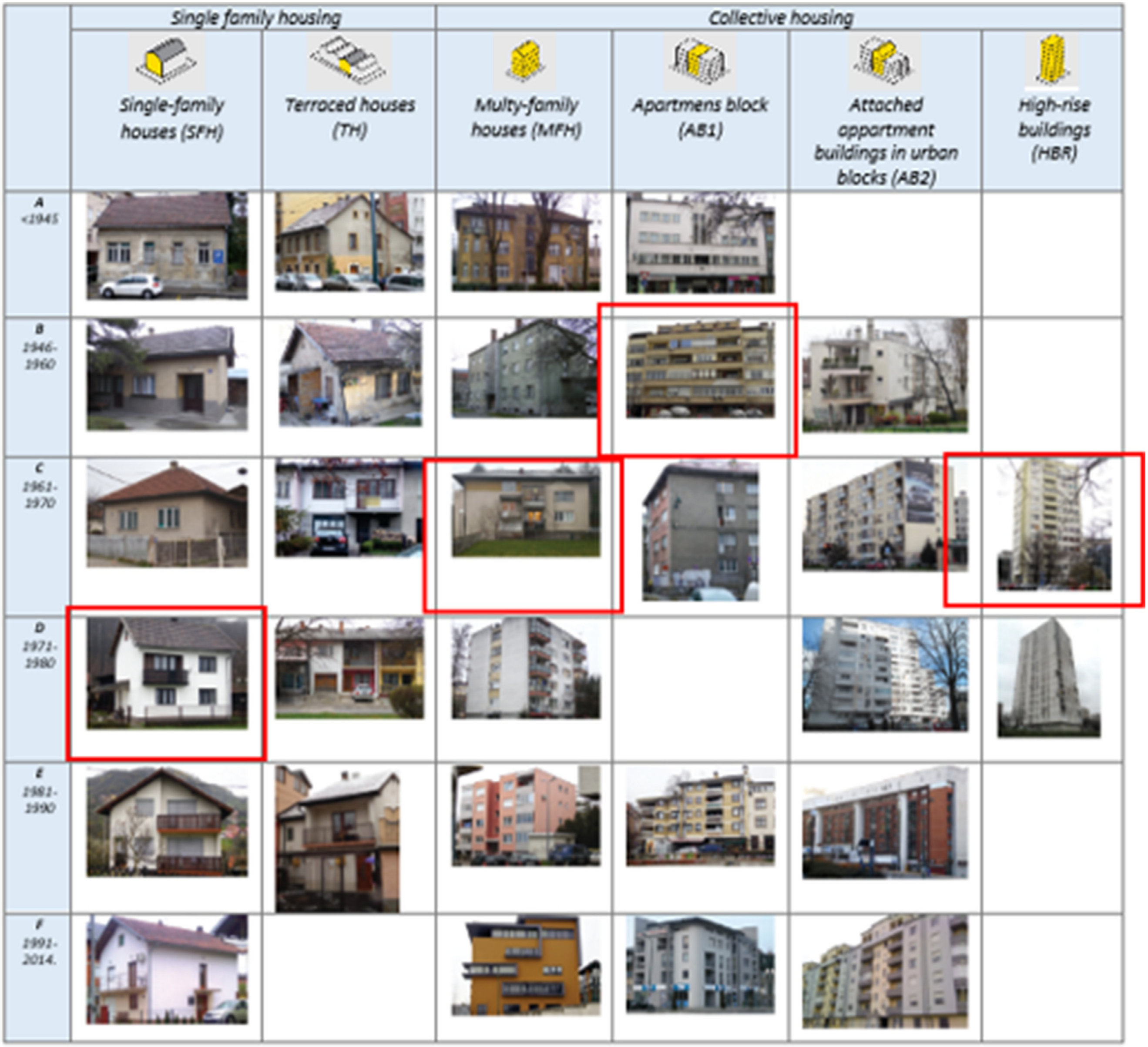

Fig. 2. Residential buildings typology matrix in Bosnia and Herzegovina [8].

	Single-family houses (SFH)	Terraced houses (TH)	Multy-family houses (MFH)	Apartmens block (AB1)	Attached appartment buildings in urban blocks (AB2)	High-rise buildings (HBR)	Total
A <1945	1.25	0.13	0.05	0.03	0.00	0.00	1.5
B 1946-1960	3.03	0.19	0.29	**0.10**	0.04	0.00	3.6
C 1961-1970	10.16	0.87	**0.35**	0.17	0.08	**0.01**	11.6
D 1971-1980	**22.52**	1.07	0.26	0.08	0.16	0.01	24.1
E 1981-1990	27.39	0.69	0.13	0.01	0.10	0.00	28.3
F 1991-2014.	29.56	0.77	0.32	0.08	0.12	0.00	30.9
Total	93.91	3.72	1.39	0.46	0.50	0.02	100

Fig. 3. Number of buildings as a percentage of the total number of buildings in building-stock (%).

	Single-family houses (SFH)	Terraced houses (TH)	Multy-family houses (MFH)	Apartmens block (AB1)	Attached appartment buildings in urban blocks (AB2)	High-rise buildings (HBR)	Total
A <1945	1.25	0.04	0.09	0.10	0.00	0.00	1.48
B 1946-1960	3.67	0.14	1.00	**0.30**	0.13	0.00	5.24
C 1961-1970	14.05	0.45	**1.67**	0.41	1.45	**0.30**	18.33
D 1971-1980	**32.41**	0.80	0.97	0.00	3.38	0.18	37.74
E 1981-1990	15.83	0.46	0.59	0.02	1.01	0.00	17.91
F 1991-2014	18.01	0.00	0.59	0.18	0.54	0.00	19.32
Total	85.22	1.89	4.90	1.01	6.50	0.47	100.00

Fig. 4. The energy need of buildings is expressed in terms of total energy need of building-stock (%).

Based on the largest share from each building category defined by the "Typology of residential buildings in Bosnia and Herzegovina (Typology)" [8], the following four representative building category types are selected for a detailed analysis of EE retrofit costs:

1. Single-family house (SFH), period of construction 1971–1980 (22.52 % of the total residential building stock)
2. Multi-family house (MFH), period of construction 1961–1970 (0.35 % of the total residential building stock)
3. Apartment buildings (AB), period of construction 1946–1960 (0.1 % of the total residential building stock
4. High-rise buildings (HRB), period of construction 1961–1970 (<0.1 % of the total residential building stock)

An overview of data on chosen building categories is given in Table 1.

The buildings structure properties in the current state are presented in Table 1. As can be noticed from Table 1, the majority of national building stock comprises buildings built during the socialist era, i.e. before the 1980 s. Building structures of that time were made of brick or concrete walls with no thermal insulation. In addition, the wood metal fenestrations installed in the buildings at the time have deteriorated and may be considered as a significant source of heat losses and air infiltration. The heating systems are most commonly found to be in poor conditions, boiler components have deteriorated, distribution pipelines are poorly insulated and control equipment is often not operational. As a result, the efficiency of heating systems for SFH and MFH is low ($\eta_{HS} = 0.5$) . The situation is somewhat better in apartment (AB) and high-rise buildings (HBR) which are predominantly based on heating substations and remote heating systems that have a total heating system efficiency of 0.85.

2.3. Defining energy retrofit levels

The selected EE retrofit measures in this study are based on currently extended practices following the national TABULA project [8] which defines refurbishment methodology principles through a two-stage retrofit, applying standard and "advanced" EE retrofits. The "standard" scenario included upgrading the building envelope thermal insulation thickness together with window glazing replacement, which our study defined as the basis retrofit step or

Table 1
Overview of typical building categories selected for analysis.

Building Category (period of construction)				
SFH		MFH	AB	HRB
				
1971-1980		1961-1970	1946-1960	1961-1970
Net heated floor area, $A_{h\text{-}net}$ (m^2)				
Before retrofit: 35.9 After retrofit: 65.4		561.9	1556.3	3260.7
Building compactness ratio, A/V (m^{-1})				
1.04		0.71	0.52	0.41
Thermal transmittance of buildings structure elements, U-value (W/m^2K)				
EW	1.17	1.21 – 1.22	1.28–1.32	1.17–3.84
R	2.01–2.59	3.32–0.67	2.65–0.40	1.53–2.67
F	2.68	2.37–1.30	2.24–1.81	2.05–1.81
W	2.20	3.60	3.50	3.09
Heating system efficiency, η_{HS} (-)				
	0.5	0.5	0.85	0.85

*OW – exterior wall, R-C – roof/attic ceiling, F – floor/ceiling to basement, W – windows.

EE retrofit measures Level 1 for the four types of building prototypes. The second "advanced" retrofit scenario introduces retrofit measures that upgrade the whole thermal envelope and also the heating system performance significantly by improving the overall thermal performance of the building. These measures are defined by Level II-V in our study and build upon Level I measures with external roof insulation, exterior basement insulation, introducing high-efficiency heating systems and renewable heating technology.

A total of four levels of EE retrofits are defined, as shown in Table 2, and each of the EE retrofit measures is described in detail in Table 3. The defined EE retrofit levels are not defined by a specific energy consumption target (kWh/m^{2}ann), but are rather by a combination of EE retrofit measures, as shown in Table 2. The following EE retrofit measures are considered for installation: windows replacement (WR), external wall insulation (EWI), external roof insulation (ERI), exterior basement insulation (EBI), high-efficiency heating system (HEHS), improved high-efficiency heating system (IHEHS), renewable heating technology (RHT) as described in Table 3. Energy audits (EA) are also included as part of the EE retrofit costs as the data from the energy audit report serves as a guideline during the implementation of EE retrofit measures.

2.4. Building energy performance assessment

The building annual energy need for heating for pre-and post-implementation of EE retrofit levels is calculated according to the EN ISO 13790 standard [16] and the calculation procedure is based on an hour basis. The simple hourly method has with satisfactory accuracy been compared to dynamic simulation tools in previous studies focusing on the heating needs [18–22].

The simple hourly method of EN ISO 13,790 is based on the thermal-electrical analogy between the analyzed thermal zone and the equivalent 5R1C (5 resistances and 1 capacity) electrical network (Fig. 5).

The 5 resistances represent the following heat transfer coefficients,

H_{ve} – ventilation

$H_{tr,is}$ – heat transmission

$H_{tr,w}$ – transmission through windows

$H_{tr,op}$– transmission through opaque components, that consists of $H_{tr,em}$ and $H_{tr,ms}$.

The building fabric effective heat capacity C_m is considered concentrated in the only capacity of the equivalent electrical network.

The nodes of the network are represented by

θ_{air} – the indoor air temperature

θ_{sup}- the supply air temperature

θ_e – the outdoor air temperature

θ_s – the outdoor air temperature

θ_m the mass temperature

The heating/cooling load $\Phi_{H/C,nd}$ is directly applied on the θ_{air} node, while the heat flows due to solar radiation and internal sources are considered split into shares Φ_{ia}, Φ_m and Φ_{st} and they are applied on θ_{air}, θ_s and θ_m, respectively.

The electrical network is solved using a finite difference method (Crank–Nicolson scheme) that analyses the 5R1C network with a time discretization of one hour. At each time step θ_{air} is calculated as follows:

$$\theta_{air} = \frac{H_{tr,is} \cdot \theta_s + H_{ve} \cdot \theta_{sup} + \Phi_{H/C,nd}}{H_{tr,is} + H_{ve}} \quad (1)$$

The θ_{air} the calculation is repeated twice at each time step, the first time considering free-floating conditions ($\Phi_{H/C,nd} = 0$) and obtaining $\theta_{air,0}$ and the second time considering and heating/cooling load to 10 $\frac{W}{m^2}$ ($\Phi_{H/C,nd,10}$) and obtaining $\theta_{air,10}$. The actual $\Phi_{H/C,nd}$ needed to reach the air setpoint temperature $\Phi_{air,H/C,set}$ is calculated as follows:

$$\Phi_{H/C,nd} = \Phi_{10,nd,10} \cdot \frac{\Phi_{air,H/C,nd} - \Phi_{air,0}}{\Phi_{air,10} - \Phi_{air,0}} \quad (2)$$

2.5. Calculation of investment costs

The total costs for different retrofit levels are calculated based on a bottom-up approach, i.e. the costs of implementing different EE retrofit measures are calculated first, followed by the joint costs for implementing EE retrofit levels, as shown in Fig. 6.

The total costs of implementing an EE retrofit measure is calculated according to the following equation:

$$C_{MEAS.} = (C_{MAT.} + C_{LAB.} + C_{GEN.})\hat{A} \cdot (1 + VAT) \quad (3)$$

where, $C_{MAT.}$ is the material and equipment cost in Euros (€), $C_{LAB.}$ is labor cost (€), $C_{GEN.}$ are general expenses (€) and VAT is Value Added Tax (%).

The cost of each particular EE retrofit measure consists of the sum of all of the individual components required to be implemented for the specific EE retrofit measure. Therefore, the material and equipment cost for a particular measure consisting of n number of individual components is calculated as:

$$C_{MAT.} = \sum_{i=1}^{n} q_i \cdot u_i \quad (4)$$

q_i is the quantity of the ith component

u_i is the corresponding unit cost of ith component (€/component)

The labor costs are calculated using the same measuring units as for material costs while taking into account the working time for implementing each particular work task, the worker's qualifica-

Table 2
Overview of considered retrofit measures and retrofit levels.

Building type	SFH					MFH					AB				HRB			
EE Retrofit measures	Level I	Level II	Level III	Level IV	Level V	Level I	Level II	Level III	Level IV	Level V	Level I	Level II	Level III	Level IV	Level I	Level II	Level III	Level IV
WR	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
EWI	✓		✓	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓		✓	✓
ERI	✓		✓	✓	✓				✓	✓				✓				✓
EBI					✓				✓	✓				✓				✓
HEHS		✓	✓				✓	✓				✓	✓			✓	✓	
IHEHS				✓	✓				✓					✓				✓
RHT										✓								
EA	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 3
Description of EE retrofit levels.

EE Retrofit measure	Description of retrofit measure	EE retrofit levels installed in building type			
		SFH	MFH	AB	HRB
WR	New PVC windows installed with an overall heat transfer coefficient U = 1.0 W/m^{2}K	I-V	I-V	I-IV	I-IV
EWI	10 cm of expanded polystyrene (EPS) (λ = 0.0357 W/mK) added to exterior wall insulation	I, III	I,III-V	I, III-IV	I,III-IV
	15 cm of expanded polystyrene (EPS), λ = 0.0357 W/mK added to exterior wall insulation	IV-V	–	–	–
ERI	15 cm of mineral wool (λ = 0.034 W/mK) added to the insulation between the ceiling and the unheated attic	I,III	–	–	–
	20 cm of mineral wool (λ = 0.034 W/mK) added to the insulation between the ceiling and the unheated attic	IV-V	–	–	–
	15 cm of added mineral wool (λ = 0.034 W/mK) to the pitched roof insulation	–	IV-V	IV	–
	10 cm of extruded polystyrene (XPS) added to the flat roof insulation, λ = 0.035 W/mK	–	–	IV	IV
EBI	8 cm of XPS (λ = 0.033 W/mK) added to the floor insulation	V	–	–	–
	10 cm of XPS (λ = 0.033 W/mK) added to the ceiling insulation of unheated basements	–	IV-V	IV	IV
HEHS	Replacing the individual solid fuel-burning appliances with a central heating system	II-III	II-IV	–	–
	Replacing the heating substation			IV	II-III
IHEHS	Replacing the individual solid fuel-burning appliances with a central heating system, thermostatic valves	IV, V	IV		
	Replacing the heating substation, hydraulic balancing, thermostatic valves			IV	IV
RHT	Installing an air-to-water heat pump and heat source (HP)	–	V	–	–

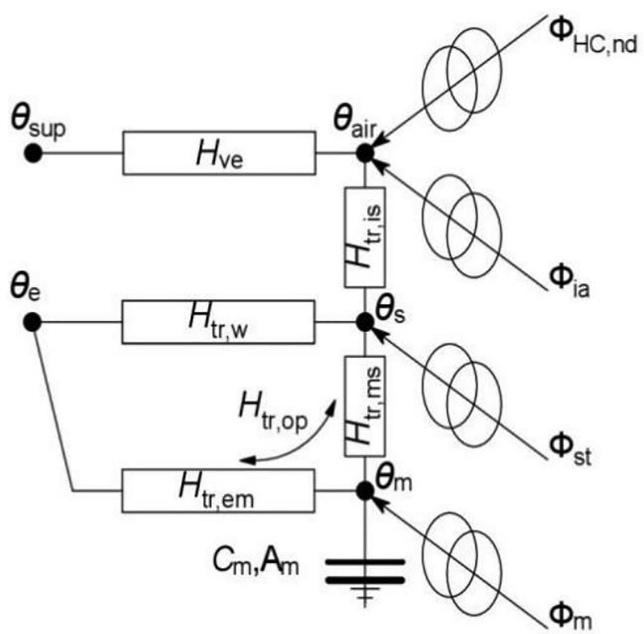

Fig. 5. The equivalent 5R1C electrical network behind the simple hourly method of EN ISO 13790.

tion required, and the average wages for the considered qualification. If the implementation of the measure is decomposed into n tasks then the total cost of labor can be represented as:

$$C_{LABOR} = 1.7\hat{A} \cdot C_{LABOR.NETT} = 1.7\hat{A} \cdot \sum_{i=1}^{n} T_i \cdot L_i \cdot W_i \tag{5}$$

where, $C_{LABOR.NETT}$ is the labor cost after-tax (€), T_i is the quantity of work for the specific task i, L_i is the working norm required per unit of T_i (hours/task)and W_i is the average wage data (€/hour) according to the specific qualification level of the workforce. The working time norms for each task are prescribed by relevant standards [23]. The average wage data is extracted from the Agency for Statistics Bosnia and Herzegovina for the construction sector [24], where the average workforce net monthly salary ranges from 345 € for semi-skilled workers to 751 € for workers with a university degree. For each measure, expenses for expert supervision provided by university degree workers, are included as well.

The qualification of workers who are required to perform these tasks varies from semi-skilled workers to skilled workers. For each work task and professional qualification, the total working hours are calculated as a product of the amount of work done and the working time. Finally, the total labor cost is calculated as a product of total working hours and labor. All individual task costs are summed to calculate the labor cost for a particular measure after the task, which is then multiplied by 1.7 to calculate the total labor costs. The coefficient of 1.7 presents the ratio between gross and net costs (salary).

The general expenses present unavoidable costs that include among other depreciation of fixed assets, investment and current maintenance of fixed assets, salaries of overhead staff, field allowance, and the company profit. Finally, the value-added tax (VAT) is calculated for 17% [24] and the total costs for implementing EE retrofit measures are calculated by Equation (4).

The total costs for implementing EE retrofit levels are calculated by summing up individual costs of all the EE retrofit measures included in that particular EE retrofit level as:

$$C_{R.LEV.} = \sum_{i=1}^{n} C_{MEAS.i} \tag{6}$$

where n represents the number of EE retrofit measures included in retrofit level (Fig. 5) and $C_{MEAS.}$ represents the cost of individual measures included in the corresponding EE retrofit level.

2.6. Specific investment costs for different building categories and retrofit levels

For a relative comparison of the implementation costs of different EE retrofit measures, the specific investment costs per refurbished envelope area $C_{M.ENV.}$ (€/m^2) are calculated using the following equation:

$$C_{M.ENV.} = \frac{C_{MEAS.}}{A_{ENV.}} \tag{7}$$

where $C_{MEAS.}$ (€) is the total cost of the individual measure included in retrofit level and $A_{ENV.}$ (m^2) is the area of the refurbished envelope. The specific investment costs of four EE retrofit measures (windows replacement (WR), external wall insulation (EWI), external roof/attic insulation (ERI), exterior basement insulation (EBI)) are calculated for two building categories (SFH and MH) and compared to the corresponding specific investment costs of implementing the same retrofit levels in other three EU countries (Slovenia, Czech Republic and Italy). The specific costs of

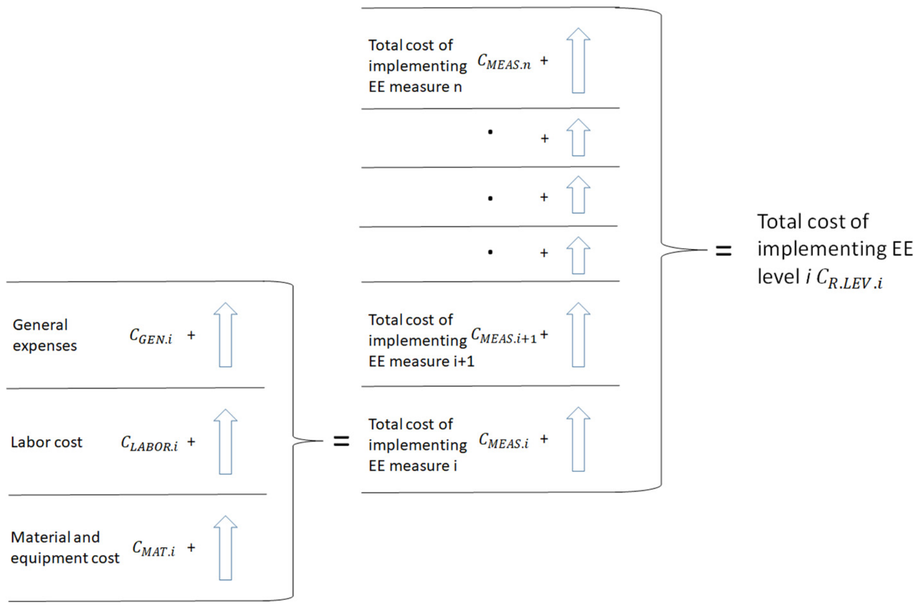

Fig. 6. Schematic representation of the bottom-up approach when estimating the investment costs of implementing an EE retrofit level consisting of EE retrofit measures *i...n*.

implementing EE retrofit levels $C_{M.ENV.}$ (€/m^2) for the EU members were derived from a comprehensive study of building energy renovation activities published by the European Commission in 2019 [25].

For three EE retrofit measures (windows replacement (WR), external wall insulation (EWI), and external roof insulation (ERI)) the ratio of GDP per capita and the investment costs per the building envelope area is calculated for Bosnia and Herzegovina and compared against the same index for Slovenia, Czech Republic, and Italy. According to the annual report from Agency for Statistics Bosnia and Herzegovina [24], while the GDP input data for the Czech Republic, Slovenia, and Italy are derived from the Statistical Office of the European Communities [26].

The specific index representing the ratio of GDP per capita and specific investment costs for individual measure per refurbished envelope area, $C_{GDP.M.}(m^2/year)$ is calculated using the following equation:

$$C_{GDP\_M.} = \frac{GDP}{C_{M.ENV.}} \tag{8}$$

For further comparative analysis, the total costs for implementing different EE retrofit levels are expressed relative to the total net heated floor area of the relevant building category, by using the following equation:

$$C_{RL.NH.} = \frac{C_{R.LEV.}}{A_{NH}} \tag{9}$$

where, $C_{R.LEV.}$ (€) is the total cost of retrofit level and A_{NH} (m^2) is the net heated floor area of the building presented in Table 1 for all building categories.

Investment costs per building resident $C_{M.RES.}$ (€/person) are calculated as the ratio between total costs and the number of residents for a particular building category and EE retrofit level, using the following equation:

$$C_{RL.RES.} = \frac{C_{R.LEV.}}{n_{RES.}} \tag{10}$$

where, $C_{R.LEV.}$ is the total cost of retrofit level (€) and $n_{RES.}$ is the number of residents for a particular building category (-).

According to data from Agency for Statistics Bosnia and Herzegovina [24], the average number of household members is valued at 3.06. Based on this data and the average number of households in different building categories, the total number of residents was calculated for all building categories and presented in Table 4.

2.. Cost-effectivness analysis

The financial viability of each of the presented EE retrofit levels is assessed by carrying out a cost analysis that takes into account the costs of initial investment and energy consumption. The financial viability is analyzed through the following four indicators:

i) The net present value (NPV) as the sum of present values cash flow:

$$NPV = -C_{R.LEV.} + \sum_{n=1}^{N} \frac{E_{SAV,n}}{(1+i)^n} \tag{11}$$

Where $C_{R.LEV.}$ are the total costs for implementing a certain EE retrofit level as calculated by equation (7)

$E_{SAV,n}$ the cash inflow represented by the yearly savings as the sum of the energy savings costs calculated as:

$$E_{SAV,n} = (Q_{H,fin,pre} - Q_{H,fin,post}) \cdot C_E \cdot I_E^n \tag{12}$$

C_E is the price of energy by energy type, given in Table 5 for various energy sources. The annual energy inflation rate of $I_E = 1.014$ is estimated from the inflation trends over the past 15 years in Bosnia and Herzegovina [27]. The discount rate i is the rate of return that could be earned by investing capital in other ventures. The discount rate is i = 5.5 % and the observed time is N = 20 years, which is the average period proposed by EU regulations. Maintenance costs before and after investments are assumed to be equal and therefore excluded from the calculation of NPV and all cash flows including energy costs are expressed in 2021 prices.

ii) The savings to investment ratio (SIR)

The SIR value measures the cost-effectiveness of an EE retrofit level. Higher SIR values indicate shorter paybacks periods and larger savings at the end of the observed period. The SIR is the ratio of the value of saved energy to the initial investment calculated as:

$$SIR = \frac{\sum_{n=1}^{N} \frac{E_{SAV,n}}{(1+i)^n}}{C_{R.LEV.}} \tag{13}$$

Table 4
The average number of residents in different building categories.

Building category	SFH	MH	AB	HRB
Number of residents	3.06	33.66	70.38	159.12

Table 5
Energy consumption and CO_2 emission by energy . Source [28,29]

Energy Type	Primary Energy factor PEF	CO_2 emission factor (kg CO_2/GJ)	Price (€/kWh)
Coal	1.08	105.13	0.015
Wood	1.11	8.08	0.0125
Light destilate fuel oil	1.10	71.08	0.080
Natural gas	1.13	53.06	0.080

An EE retrofit level achieves its payback period when NPV = 0 and SIR = 1, which is when the present value of energy savings reaches the initial investment.

iii) The simple payback period (SPP)

The SPP is defined as the ratio between the initial investment costs $C_{R.LEV.}$ and the projected annual energy saving costs E_{SAV} :

$$SPP = \frac{C_{R.LEV.}}{E_{SAV}} \quad (14)$$

iv) Carbon dioxide emission of heating system

The carbon dioxide emission of the heating system during its operation is calculated by using the following equation:

$$S_{CO2} = PEF_{wood} \cdot g_{wood} \cdot E_{wood} + PEF_{coal} \cdot g_{coal} \cdot E_{coal} \quad (15)$$

E_{wood} is the energy consumption from wood per heating season and E_{coal} is the energy consumption from coal per heating season. g_{wood} stands for the specific CO_2 emission factor for wood (kg CO_2/GJ) and g_{coal} stands for the specific CO_2 emission factor for electricity (kg CO_2/GJ). These values together with the primary emission factors PEF are given in Table 5.

3. Results

3.1. Impact of different retrofit levels on building energy performance

The impact of different retrofit levels on the building's energy needs and consumption are shown in Table 6. The specific space heating energy need per heated floor area is highest for the single-family house (SFH) building category. The data from "Typology of residential buildings in Bosnia and Herzegovina (Typology)" [8] showed that only a portion of the net floor area is heated in the SFH buildings, therefore for the SFH category the net heating floor area in current state and after retrofit, differs. For the baseline state, the net heated area of SFH is 35.9 m^2, while after retrofitting and installation of a new central heating system, the total useful floor area becomes equal to the net heated area: 65.4 m^2. The annual energy consumption for heating after implementing EE retrofit measure Level I for SFH decreases by 8% compared to the baseline scenario. However, the annual specific energy need for heating per net heated area (kWh/m^2ann) decreases substantially, since the total net heated area increases. The implementation of Level I retrofit measures results in a reduction of the transmission and ventilation losses, and therefore a substantial reduction of the total energy consumption, energy need for heating, and final energy consumption.

The implementation of EE retrofit Level I significantly reduces both the specific energy need for heating and the specific final energy consumption for heating. Further implementing the EE retrofit Levels II-IV improves the thermal performance of the building envelope and the heating system efficiency further by additionally decreasing the specific energy need for heating and the specific, final energy consumption for heating. Improving the heating system efficiency will result in a smaller gap between the energy need for heating and final energy consumption, as shown in Table 6.

Implementing EE retrofit levels I-V for all building categories will reduce the relative energy demand, as shown in Fig. 7. The relative reduction of the energy demand is calculated as the ratio between the energy reduction between post EE retrofit measures and baseline state (pre-retrofit) and the total energy consumption for the baseline state (pre-retrofit):

$$\Delta Q_{H,fin} = \frac{Q_{H,fin,pre} - Q_{H,fin,post}}{Q_{H,fin,pre}} \quad (11)$$

For multi-family (MFH) and single-family (SFH) houses, implementing EE retrofit Level I- II (III for SFH) resulted in the largest energy savings. The predicted results are in agreement according to available literature data [30], indicating that the majority of energy savings can be obtained by implementing EE retrofit measures related to windows replacement and external wall insulation and that implementation of further improvement measures results in energy savings but with a declining trend. Implementing EE retrofit levels III and IV for multi-family houses (MFH) shows that, along with substantial energy savings achieved by improving the building envelope thermal properties, additional savings can be achieved by installing a heat pump. The data presented for AB and HRB category shows that windows replacement has a significant influence on energy savings while installing thermal insulation on external walls results in additional energy savings.

When comparing the data after EE retrofit level to the baseline state shows that windows replacement reduces the total heat loss coefficient by 28 % and installing external wall insulation reduces it by 38.7 %. Taking into account that the efficiency of the heating

Table 6
Building energy performance for all categories and EE retrofit levels.

Building type	SFH					MFH					AB				HRB			
EE Retrofit measures	Level I	Level II	Level III	Level IV	Level V	Level I	Level II	Level III	Level IV	Level V	Level I	Level II	Level III	Level IV	Level I	Level II	Level III	Level IV
Specific energy need for heating (kWh/m²ann)																		
Baseline			233.5					143.8				128.7				135.9		
EE ren	176	221	97	87	65	79	117	79	39	39	43	80	43	31	36	102	36	26
Specific energy need for heating (kWh/m²ann)																		
Baseline			467.0					287.6				151.5				159.9		
EE ren	353	260	114	97	72	158	138	93	43	13	50	91	48	35	42	116	41	29

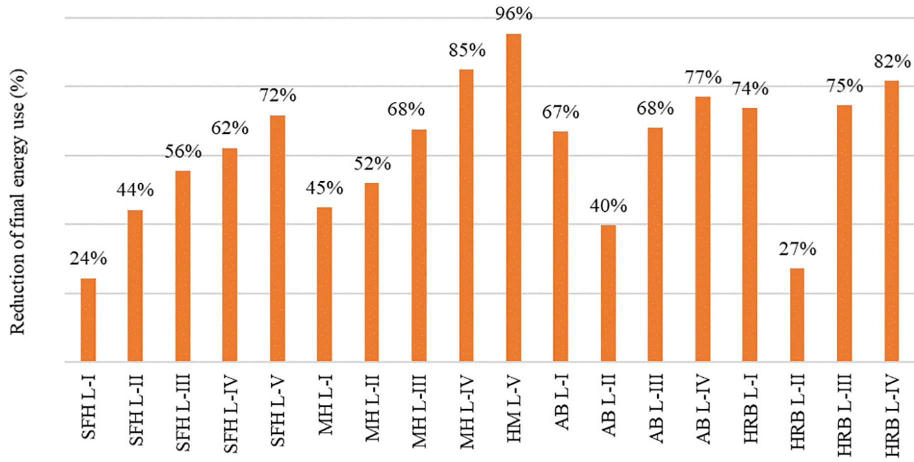

Fig. 7. Relative, final energy savings when implementing retrofit levels for all building categories considered.

system is equal for Level II and III, the energy savings when implementing Level II are significantly higher compared to Level II.

The overall data for all four building categories shows that implementing the EE retrofit level I results in a reduction of final energy consumption by 53 %, and by 41 % when implementing the level II EE retrofit level, while a reduction by 66 % is achieved when implementing EE retrofit level III, and by 76 % when implementing EE retrofit level IV.

Fig. 8 shows the specific energy need for heating as a function of the building compactness ratio (f_0). The building compactness ratio has a significant impact on the specific energy need for heating for the baseline state, but it substantially drops after implementing EE retrofit measures. Level I consists of same set of architectural measures as Level III, therefore it is omitted for clarity of diagram. Fig. 9a.Fig. 9b.Fig. 10.

The overall data for all four building categories shows that implementing the EE retrofit level I results in a reduction of specific final energy consumption by 53 %, and by 22 % when implementing the level II EE retrofit level, while a reduction by 61 % is achieved when implementing EE retrofit level III, and by 73 % when implementing EE retrofit level IV. The specific heating need and final energy consumption are highest for single-family houses for all EE retrofit levels due to the most unfavourable building compactness ratio.

3.2. Structure of costs for different building categories and EE retrofit levels

The total costs of implementing the EE retrofit levels are calculated by summing up the costs of the individual EE retrofit measures included in a particular EE retrofit level considered by using Equation (6). For this purpose, the cost of implementing individual EE retrofit measures for each specific building category is calculated using Equation (4) and these results are presented in Table 7. The costs of implementing individual EE retrofit measures vary significantly for different types of building categories, which is expected considering the differences in the building's size and the scope of works performed.

Table 8 and Fig. 4 a) and b), provide an overview of the cost structure of implementing different EE retrofit levels for different types of building categories. The costs increase from SFH to HRB, due to the increase in the average size of considered building types. In addition, implementing EE retrofit levels III and IV include further improvement of the building envelope insulation and the heating system which consequently results in higher investment costs.

Given the detailed analysis of the investment costs, it is possible to conclude that material and equipment costs have the largest share in total investment costs for all building categories and EE retrofit levels. The share of material and equipment costs of the total costs is on average 64 % for all building categories. The material cost share of the total costs increases with the size of the building categories: ranging from 60 % for single-family houses and up to 68 % for high-rise buildings. The share of labor costs of the total costs is lower than that for material and equipment costs, equalling 17 % on average. The labor costs share of the total cost has a declining trend with the increase in the building size, ranging from 20 % for single-family houses type to 14 % for high-rise buildings. The company's running utility costs have an average of 5 % of the share of the total cost. A visual representation of the different costs for all building categories and EE retrofit levels is given in Figs. 9 a and b.

The presented data shows that the largest share in total costs for implementation of EE measures is for material and equipment. This implies that the largest benefit from implementing EE retrofit levels will be gained by the manufacturing and construction sectors. Therefore, a potential risk for implementing EE retrofit levels in Bosnia and Herzegovina exists as the labor force has up to 4 times a lower share of the total costs compared to the material and equipment costs for implementing EE retrofit measures. This may be explained by the fact the average monthly net salary for workers in the construction sector in Bosnia and Herzegovina is relatively low, ranging from 345 € for semi-skilled workers to 751 € for workers with a university degree. Considering that the building retrofit strategies are under implementation in many EU countries, the demand for skilled workers will only increase over the near future which may tempt the domestic workforce to leave

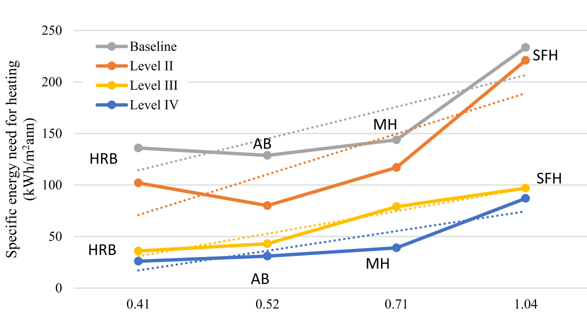

Fig. 8. Specific energy heating need vs building compactness ratio (f_0) of the selected buildings categories.

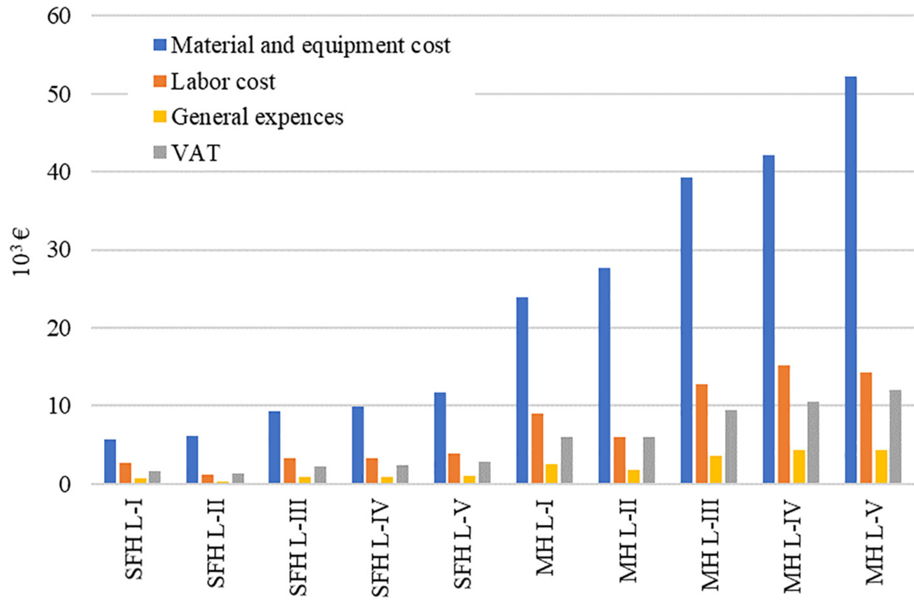

Fig. 9a. The cost structure for SFH and MH for all EE retrofit levels (I-V).

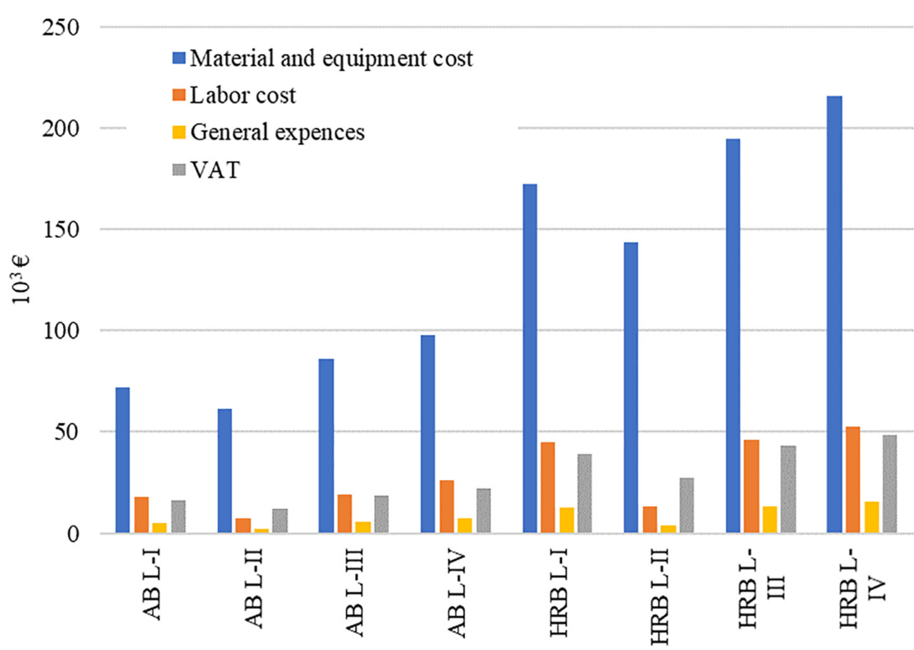

Fig. 9b. The cost structure for AB and HRB for all retrofit levels (I-IV).

Bosnia and Herzegovina due to higher salaries. This may present a long-term issue for low-income countries such as Bosnia and Herzegovina.

3.3. Financial indicators of the energy retrofit measures compared to other EU countries

To compare the EE retrofit costs in the residential sector in Bosnia and Herzegovina and three EU member states, the specific investment costs per refurbished envelope area are calculated, using Equation (7) and the calculated values are shown in Fig. 5. The data from building categories SFH and MH are combined, and the averaged costs in Bosnia and Herzegovina are calculated accordingly. The values of specific investment costs per refurbished envelope area, for the other EU countries: Slovenia, Czech Republic, and Italy are used from an EU final report study by Esser et al. [25]. The specific, investment costs for windows replacement are similar in Bosnia and Herzegovina, and Slovenia, while the highest costs are reported in Italy for the same type of EE retrofit measure. The specific, costs for installing additional roof insulation towards the unheated attic and exterior basement insulation are similar for Bosnia and Herzegovina and Italy, while for the Czech Republic and Slovenia these costs are lower. The lowest specific investment costs are reported for external roof insulation in Bosnia and Herzegovina, while the highest costs for the same type of EE retrofit measure are reported for Italy.

To predict the citizen's financial ability to invest in EE retrofit measures, the ratio between GDP per capita and specific investment cost for individual retrofit measures is calculated for Bosnia Herzegovina and three EU countries, using Equation (8).

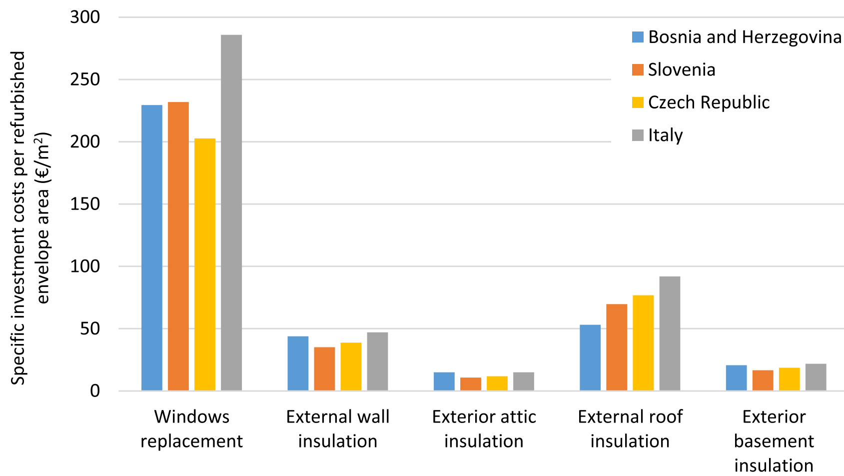

Fig. 10. The specific investment costs per refurbished envelope area in Bosnia and Herzegovina compared to three EU countries: Slovenia, Czech Republic, and Italy (VAT included).

Table 7
Overview of costs for different building categories as calculated in Euros (€). EE RL (Energy-efficiency retrofit level). BC – Building Category.

	BC			
EE RL	SFH	HM	AB	HRB
WR	3636	17,023	62,964	157,124
EWI	6303–6771	23,598	46,250	109,811
ERI	632–723	5473	21,782	18,119
EBI	2982	1257	3863	5703
HEHS	5104	21165–23463	15572–17653	23749–27007
IHEHS	5171	23,833	17,130	37,782
HP	–	34,587	–	–
EA	161	931	2034	2547

Table 8
Overview of costs for different building categories and EE retrofit levels in €.

EE retrofit levels	Costs for material [€]	Costs for labor force [€]	General expenses [€]	Total excl. VAT [€]	VAT [€]	Total [€]
SFH						
Level I	5736	2654	783	9173	1559	10,732
Level II	6140	1118	350	7608	1293	8901
Level III	9329	3254	952	13,535	2301	15,836
Level IV	9858	3258	953	14,069	2392	16,461
Level V	11,652	3880	1072	16,618	2825	19,443
MFH						
Level I	23,932	9035	2548	35,515	6038	41,552
Level II	27,639	6052	1707	35,399	6018	41,417
Level III	39,252	12,727	3590	55,568	9447	65,015
Level IV	42,172	15,183	4282	61,637	10,478	72,115
Level V	52,151	14,344	4334	70,828	12,041	82,869
AB						
Level I	72,176	18,059	4850	95,084	16,164	111,248
Level II	61,546	7680	2166	71,391	12,137	83,528
Level III	86,319	19,190	5413	110,922	18,857	129,778
Level IV	97,761	26,429	7454	131,644	22,380	154,024
HRB						
Level I	172,552	45,064	12,710	230,327	39,156	269,483
Level II	143,801	13,024	3673	160,498	27,285	187,783
Level III	194,902	46,373	13,080	254,354	43,240	297,594
Level IV	215,683	52,492	15,531	283,706	48,230	331,936

Fig. 11 shows the values of the calculated indicator for the three envelope-related EE retrofit measures (WR, EWI, and ERI) which are the most commonly implemented EE retrofit measures that result in substantial energy savings. The presented indicator predicts the amount of a particular surface area that can be renovated within a year by considering GD value per capita. The financial ability of a citizen to invest in EE retrofit measures in the residential sector is several times lower in Bosnia and Herzegovina compared to the other three EU countries considered: the citizens' ability to financially support the three envelope-related EE retrofit measures (WR, EWI, and ERI), it is averagely 3.8 times lower compared to Slovenia, Czech Republic, and Italy. If the exterior basement insulation (EBI) is also considered in addition to the three other envelope-related EE retrofit measures (WR, EWI, and ERI), then this indicator is on average 4.2 times lower. This implies that if the national authority does not provide subsidies for EE retrofit measures, then the Building renovation strategy may take four times as long to implement in Bosnia and Herzegovina compared to the other three EU countries. Hence, this delay would not provide the expected results in achieving energy-saving targets as defined by the National Energy and Climate Plan [1].

3.3.1. Investment costs per net heated floor area

The total costs of implementing EE levels as normalized per square meter of the net heated floor area of a certain building category are described by Equation (9) and the outcomes for the four countries considered are shown in Fig. 6. The highest specific investment cost per square meter for implementing EE retrofit level is found for the single-family house category, reaching values even three times higher compared to other building categories. For the purpose of this analysis, it is assumed that total heated area of SFH for all retrofit levels is 65.4 m^2. Specific investment cost for Level I and II for SFH would be substantially higher when expressed via heated area of 35.9 m^2, leading to greater discrepancy between the specific investment costs between SFH and other categories (Fig. 12).

The specific investment costs increase with increasing EE retrofit levels, and this is expected considering that more measures are implemented for the same building which results in higher material, equipment, and labor costs, as well as general expenses. The specific investment costs are generally declining with the increase in the average net heated floor area. A deviation from this trend is noted in the AB category since it represents attached apartment buildings in urban blocks with two adiabatic exterior walls that are not subject to EE retrofit measures. This eventually reduces external wall insulation costs as well as costs related to the window replacement measure for the same particular building category.

It is important to note that the SFH category is the most widespread building type in Bosnia and Herzegovina and it has also been shown to account for the highest specific EE retrofit investment costs. It is therefore important to differentiate between the types of building categories during the development of the national building renovation strategy and potential investment models since lumping all building categories into one may miscalculate the actual costs.

3.3.2. Investment costs per resident

Considering total costs for particular levels of retrofit (Table 5) per average number of residents (Table 6), investment costs per building resident are calculated using Equation (10), and these values are shown in Fig. 13. The trend of costs per building resident is similar to the one shown in Fig. 7 for costs per net heated surface area. It can be concluded that the highest costs per resident for implementing EE retrofit are for SFH, which is on average 2.7 times larger than the average cost for other building categories.

Fig. 13 also shows that single-family houses homeowners will have a substantially higher financial burden when implementing EE retrofit levels compared to the residents of multi-apartment buildings.

3.3.3. Cost-effectiveness analysis

Table 9 reports the financial aspects reflecting the individual performance of studied EE retrofit levels I-V. The shaded cells represent the energy efficiency measures with the favorable indicators.

The general conclusion from Table 9 is that none of the EE retrofit levels pays back the investments shorter than the 20 years equipment lifetime for single-family houses, multi-family houses, and apartment buildings, and in none of the cases do the energy savings reach the initial investment. Therefore, an additional analysis was included when a hypothetical government incentive or subsidy of 40 % was considered. Possible government incentives would significantly improve the situation, but still not enough to motivate the owners to invest in EE retrofit as the minimum simple payback period is slightly shorter than 20 years for multi-family houses and apartment buildings but this was not the case for single-family houses that generally showed the worst financial aspect predictors of all four building types considered. On contrary, implementing Levels I-IV shows a great potential of EE retrofit-driven profitability in high-rise buildings: the maximum simple payback period is 8.3 years even without government incentives. The main reason behind the significant differences between potential profitability in EE retrofit in SFHs, MFHs and ABs and HRBs on the other side is mainly due to two reasons: i) higher occupancy rates per square meter in HRBs, the initial investment per both square meter and resident is on average 2.7 times times lower for HRBs compared to the rest of building prototypes ii) due to

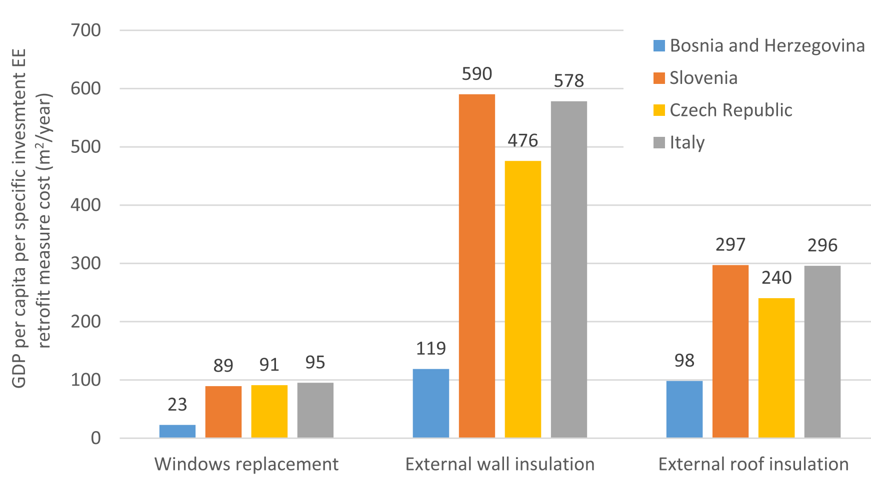

Fig. 11. GDP per capita ratio to specific investment EE retrofit measure cost for Bosnia and Herzegovina compared to Slovenia, Czech Republic, and Italy.

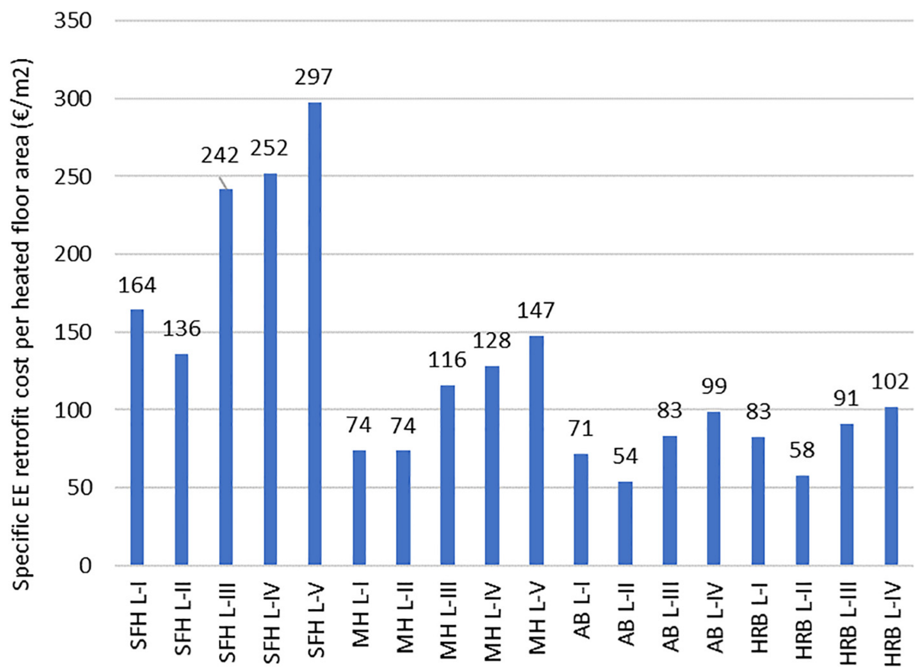

Fig. 12. Specific EE retrofit level costs per net heated floor area.

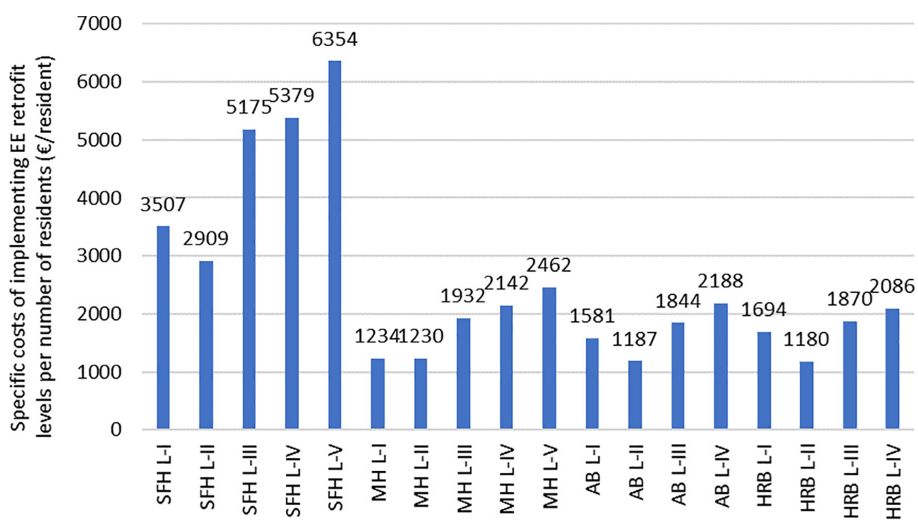

Fig. 13. Specific costs of implementing EE retrofit levels per number of residents.

the very low prices of solid fuel and wood (current prices 0.012–0.015 €/kWh) the replacement of solid fuel-burning furnaces (80% firewood + 20% coal) with central heating systems (100% firewood) will not have as a strong impact on the financial profitability of the potential investment on the financial savings, even though the energy savings ((kWh/m^2 a) for all levels considered are up to 3–5 times higher for SFHs than HRBs. The heating systems in HRBs are mainly fueled by light distillate fuel oil and natural gas that are up to 6 times more expensive compared to coal and wood per kWh, resulting in significant overall higher savings over an equipment lifespan of 20 years. Therefore, it can be expected that the interest of owners will be sufficient for the success of EE retrofit in high-rise buildings. A general conclusion from Table 9 regarding reducing the CO_2 emission is that improving the technical heating systems by excluding coal (Level I) is key to reducing at least 83.3–95.4 % – of the annual CO_2 emission [kg CO_2 /m^2] for SFH and MFH. Implementing only the most basic measure of improving external wall insulation and window glazing will have less of an impact on the carbon reduction (24.1% for single-family houses and 45.1 % for multifamily houses). These differences are somewhat lower for ABs due to generally lower energy savings for all considered EE retrofit levels I–IV. Scenario analyses (Table 9) were also subject to sensitivity analysis of financial viability to the changes of critical parameters used in NPV calculation. The historic plunge in global energy consumption in the early months of the Covid-19 crisis last year drove the prices of many fuels to their lowest levels in decades. But since then, they have rebounded strongly, mainly as a result of an exceptionally rapid global economic recovery [31]. At the moment, it is not clear to what extent the government in Bosnia and Herzegovina is ready to liberalize the energy market and this process will determine the current energy prices. If energy prices are projected to grow

Table 9
Financial indicators of the energy efficiency measures.

Building type	SFH					MFH					AB				HRB			
Retrofit level	Level I	Level II	Level III	Level IV	Level V	Level I	Level II	Level III	Level IV	Level V	Level I	Level II	Level III	Level IV	Level I	Level II	Level III	Level IV
Initial Investment [€/m²]	- 154.4	- 136.1	- 242.1	- 251.7	- 297.4	- 73.9	- 69.6	- 115.7	- 128.3	- 147.4	- 71.5	- 51.7	- 82.8	- 98.9	- 34.1	- 24.8	- 39.5	- 47.2
Initial Investment [€/resident]	- 3300.6	- 2908.8	- 5175.2	- 5379.4	- 6353.9	- 1234.5	- 1162.2	- 1932.5	- 2142.4	- 2462.0	- 1580.7	- 1144.8	- 1831.5	- 2188.5	- 699.1	- 506.3	- 810.1	- 968.0
Averaged value of energy savings annualy [€/m² a]	+ 2.0 (+ 2.2*)	+ 3.6 (+ 4.0*)	+ 6.1 (+ 6.8*)	+ 6.1 (+ 6.8*)	+ 6.8 (+ 7.6*)	+ 2.3 (+ 2.5*)	+ 2.6 (+ 2.9*)	+3.4 (+ 3.7*)	+ 4.3 (+ 4.7*)	+ 4.8 (+ 5.3*)	+ 1.8 (+ 1.9*)	+ 1.0 (+ 1.1*)	+ 1.8 (+ 2.0*)	+ 2.0 (+ 2.2*)	+ 8.4 (+ 10.7*)	+ 3.1 (+ 4.0*)	+ 8.5 (+ 10.7*)	+ 9.3 (+ 11.8*)
Averaged value of energy savings annualy [kWh/m² a]	+ 273.0	+ 207.0	+ 370.0	+ 352.0	+ 395.0	+ 129.6	+ 149.6	+ 194.6	+ 244.6	+ 274.6	+ 101.5	+ 60.5	+ 103.5	+ 116.5	+ 109.5	+ 35.5	+ 110.5	+ 122.0
NPV as a % of investment	- 85.1 (- 83.7*)	- 69.1 (- 66.4*)	- 69.1 (- 67.8*)	- 71.6 (- 69.1*)	- 73.0 (- 70.7*)	- 64.3 (- 61.3*)	- 56.4 (- 52.6*)	- 65.8 (- 62.3*)	- 61.3 (- 57.9*)	- 62.2 (- 58.9*)	- 71.2 (- 68.6*)	- 76.3 (- 74.2*)	- 74.6 (- 72.4*)	- 76.1 (- 74.0*)	+ 228.9 (+ 257.5*)	+ 69.1 (+ 83.8*)	+186.3 (+ 211.1*)	+163.8 (+ 186.8*)
NPV as a % of investment - subsidy 40 %	- 45.1 (- 43.7*)	- 29.1 (- 24.4*)	- 29.1 (- 27.8*)	- 31.6 (- 29.1*)	- 33.0 (- 30.7*)	- 24.3 (- 21.3*)	- 24.4 (- 21.6*)	- 25.8 (- 22.3*)	- 21.3 (- 17.9*)	- 22.2 (- 18.9*)	- 31.2 (- 28.6*)	- 36.3 (- 34.2*)	- 34.6 (- 32.4*)	- 36.1 (- 34.0*)	+268.9 (+ 297.5*)	+109.1 (+ 123.8*)	+226.3 (+ 266.3*)	+ 203.8 (+ 226.8*)
SIR	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.3	0.4	0.4	0.3	0.2	0.2	0.2	3.3	1.7	2.9	2.6
SIR (with subsidy 40 %)	0.3	0.5	0.5	0.5	0.5	0.6	0.7	0.6	0.6	0.6	0.5	0.4	0.4	0.4	5.5	2.8	4.8	4.4
SPP	93.9	45.6	47.6	49.6	52.2	39.5	32.3	41.2	36.4	37.2	30.9	61.6	60.6	56.5	4.3	8.3	4.9	5.3
SPP (with subsidy 40 %)	56.4	27.4	28.5	29.7	31.2	23.7	19.4	24.7	21.8	22.3	18.6	37.0	36.4	33.6	2.6	5.0	2.9	3.2
Averaged CO_2 reduction annually [kg CO_2 /m² a]	29.9	102.0	113.5	114.8	116.8	34.0	64.6	68.1	72.0	74.3	26.6	32.6	36.0	37.0	76.7	28.6	77.4	85.1
Relative CO_2 reduction annually [%]	24.4	83.3	92.7	93.8	95.4	45.1	85.6	90.3	95.5	98.6	67.0	82.0	90.5	93.1	73.9	27.5	74.5	82.1

* If energy prices are projected to grow 1% above inflation

1% above inflation, it will increase both energy savings in monetary terms and the cost-effectiveness of EE retrofit measures as indicated by the values in brackets shown in Table 9.

3.4. Model limitations

The modeling approach used in this study to test various EE retrofits measures and scenarios of residential building archetypes had its limitations. For this study, we lacked reliable monitored post-retrofit data and had to rely on calculation equations to estimate energy saving percentages. This may have resulted in overestimated energy savings, as rebound effects, installation issues, and other constraints could not be accounted for. A simplified ISO 13790 dynamic hour method calculation was used as more detailed, dynamic models require additional inputs, such as hourly internal gains, heating setpoints, and ventilation rates which were unknown for the analyzed building category types. In addition, using ISO 13790 simple dynamic hour method may lead to calculations that deviate from what the energy performances and savings would be in reality in complex buildings with high thermal inertia [18]. In addition, any interactive effects between the measures were not considered in this study. As this study was solely focused on the energy need and consumption for space heating a neither were energy efficiency improvements of lighting fixtures or household appliances considered. In the next phase of the study, uncertainty analysis needs to be carried out to account for gaps in information and variability. Many of the input parameters considered including energy use, volatility of cost, availability of cost data, energy prices, interest rate, climate conditions, and energy need are subject to uncertainties and variations. Besides a variety of input parameters, the cost analysis could also be influenced by technical or social constraints which are outside of the scope of this study. It should be noted that this study assumes that the complete residential buildings stock in Bosnia and Herzegovina is retrofitted at once (e.g. within one single year). Also, the cost of material transport and distribution is not considered. This is not a realistic scenario and calls for comprehensive scenario development, which is recommended for future research.

4. Discussion

Implementing energy-efficient retrofit measures in the building sector is an activity required by each state member of the Energy Community (EnC) to achieve the defined energy savings and CO_2 emission reduction goals by 2050 [1]. This goal is especially important for Western Balkan countries, where between 30 % and 60 % of the total final energy consumption is used by the residential sector [2]. The situation becomes more demanding for developing and middle-income countries, where the energy efficiency of households and heating systems are low, and the average purchasing power of citizens is lower compared to EU members. This further implies that the national building renovation strategies need to be developed very carefully and take into consideration many socio-economic factors in addition to energy savings and environmental benefits. A member of EnC, Bosnia, and Herzegovina is also a potential candidate country for EU membership. From an economic perspective, it is characterized as a developing and middle-income country. Like the other Western Balkans country, Bosnia and Herzegovina are today lagging behind the EU in its level of economic development, economic and institutional reforms.

To formulate the national building renovation strategy for the energy transition, it is important to know the current energy use cost structure by also considering the consumers' financial potential to participate in implementing EE retrofit measures. As a contribution to this topic, this study presents a detailed analysis of the total and specific costs of implementing EE retrofit measures in four representative residential buildings in Bosnia and Herzegovina: single-family houses, multi-family houses, apartment buildings, and high-rise buildings. The available data on the residential building stock in Bosnia and Herzegovina [8] has shown that the majority of the population lives in single-family houses, which have been identified as the poorest energy performing segment of residential building stock due to the highest specific energy need per m^2 of heated floor area. The single-family-houses category includes 93.91 % of the total number of residential buildings in Bosnia and Herzegovina, implying that this specific building category should be given special attention when creating a national Building renovation strategy.

As the baseline thermal characteristics of the buildings envelope and heating system efficiency of all building categories in Bosnia and Herzegovina currently result in high specific energy consumption use, several EE retrofit levels were considered for implementation in this study. The EE retrofit levels consist of individual measures aimed to improve the thermal characteristics of the buildings envelope and heating system efficiency, including the energy audit of the buildings. Total costs for implementation of EE retrofit levels are calculated as a sum of all costs of individual measures. All EE retrofit levels would result in substantial energy savings, while most of the energy would be saved by replacing windows, external wall insulation and improving the efficiency of the baseline heating systems.

A detailed analysis of the cost structure of the retrofit levels showed that of all costs, the material and equipment costs were highest regardless of EE measures and building categories. This implies that the building materials and heating equipment manufacturing sector would benefit most from implementing EE retrofit levels in the long run.

The analysis presented in this article also showed that the specific costs of implementing EE retrofit measures per heated floor area and per number of residents are highest for single-family houses. The specific cost per heated floor area for single-family houses is on average three times higher than for the other three analyzed categories; multi-family houses, apartment buildings, and high-rise buildings. The specific cost per resident for single-family houses is on average 2.7 times higher than for the other three categories; multi-family houses, apartment buildings, and high-rise buildings. The comparison of the specific costs heated floor area and per number of residents with the GDP per capita in Bosnia and Herzegovina reveals that the specific cost per resident in single-family houses exceeds half of the value of the GDP per capita for Level I (window replacement and external wall insulation) of EE retrofit measures and even the total GDP for the other three EE retrofit levels (III-V) that include installing additional thermal insulation in the external wall, roof or basement. Previous analysis reveals that implementing EE retrofit levels puts a significant financial burden on homeowners and residents, which may be discouraging for the homeowners when considering investing in EE retrofits strategies in the residential sector in Bosnia and Herzegovina.

Another potential risk for implementing EE retrofit measures in Bosnia and Herzegovina is that the labor force and construction companies may have up to 4 times lower share in the total costs compared to the material and equipment costs for EE improvement. The main reason behind this is the very low net salary for workers in the construction sector in Bosnia and Herzegovina. The high demand for skilled workers in developed EU countries may lead to a shortage of skilled workers in larger-scale building EE retrofit activities in Bosnia and Herzegovina.

Finally, the ratio between the investment costs and GDP per capita showed that the citizens in Bosnia and Herzegovina have four times lower ability to finance EE retrofit measures compared to the other three representative EU countries (the Czech Republic, Italy, and Slovenia).

This study offers a valuable data set and in-depth analysis of the cost structure of energy-efficient retrofit in middle-income countries such as Bosnia and Herzegovina. Such data is essential when planning subsidy and financial schemes for EE retrofit implementation in the residential building sector, especially for low-income countries such as Bosnia and Herzegovina. Considering that significant energy savings can be achieved when implementing any of the presented retrofit levels, it is possible to create adequate investment models and subsidy schemes for implementing the national energy policy in Bosnia and Herzegovina where special attention should be given to single-family houses.

Even though this paper focuses on a specific case for Bosnia and Herzegovina, the proposed methodology, as well as the results may be viewed in the wider context. This paper may serve as a starting point for examining the state and perspective across different developing countries that are at the beginning of the energy transition process.

Future work should focus on further analysis of input data and extrapolation of data in the residential building stock. Special attention should be given to the single-family house sector, due to the unfavorable building compactness ratio, which results in high specific final energy consumption when compared with other categories, even for deeper retrofit levels of energy efficiency. The analysis should categorize the heating systems and energy carriers accordingly so that the expected and actual outcomes are approximately equal. Techno-economic analysis of measures and retrofit levels should also be included.

5. Conclusion

- The findings of the study can be summarized in the following key points: The general conclusion based on the cost-effective analysis is that EE retrofit investments, may not be financially viable in single-family houses, multi-family houses, and apartment buildings even if supported by government subsidies due to the very low prices of energy sources (coal and wood) used in these specific building prototypes.
- On contrary, implementing EE retrofit levels show a great potential of EE retrofit-driven profitability in high-rise buildings that are mainly driven by natural gas and light distillate fuel oil: the maximum simple payback period is 8.3 years even without government incentives.
- Looking at the financial assessment outcomes, the most significant benefits (energy savings, net present value, savings to investment ratio, and simple payback period) are mainly related to retrofit scenario that accounts for improvement in the external wall insulation, window glazing, and improving the heating station efficiency.
- Looking at the carbon emission outcomes, the most significant benefits in reducing the relative and averaged CO2 emission are strongly related to replacing the existing partly coal-burned furnaces (80% firewood + 20% coal) in single-family houses with exclusive firewood fueled heating systems. This measure may have an enormous impact on reducing the CO2 emission from single-family houses (minimum 83.1%), which cover 93.1% of the total residential building stock in Bosnia and Herzegovina.
- Considering the i) very low energy prices of existing energy sources in single-family houses in Bosnia and Herzegovina and ii) the high ratio between the investment costs and GDP per capita - creating a much needed large-scale EE retrofit plan on a national level in a middle-income country as Bosnia and Herzegowina that will also motivate the owners to invest in EE retrofit measures appears like a difficult task in current times.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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