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Transition Towards Energy Efficient Housing: Detection of The "Weakest Links" In Energy Performance of the Residential Building Stock of Bosnia and Herzegovina

Nermina Zagora[1], Erdin Salihovic[1], Mladen Burazor[1], Sabrija Bilalic[1]

[1] Faculty of Architecture, University of Sarajevo, Patriotske lige 30, 71 000 Sarajevo, Bosnia and Herzegovina

nerminaz@af.unsa.ba

Abstract. The objective of this paper is to evaluate and distinguish the most critical segments of the residential building stock in Bosnia and Herzegovina in terms of its energy performance, in order to define the guidelines and priorities in the development of the energy efficiency strategies and building refurbishment plans. The research methodology will be explained systematic in the case of the most dominant typology in Bosnia and Herzegovina: the single-family houses built from 1981 to 1991. The analysis will include an overview of the average features for the selected category, which were obtained from the statistical survey and embraces several aspects: urbanism, architecture building physics and heating system. Subsequent methodological steps included the selection of the "representative" or the "typical" buildings, which are characterized by average or the most typical properties of each category within the entire database. This paper will present the analysis, which intend to demonstrate that, according to their potential in terms of possible energy savings, based on the presented improvement measures, the highlighted building typology – the single-family houses of 27 to 37 years of age – can be considered as the most relevant building typology in developing the strategies and plans of the residential building stock refurbishment. This paper is a part of the research on the typology of existing residential buildings in Bosnia and Herzegovina, which was initiated in 2014. Being the first-of-a-kind systematic approach on the subject matter, this research intends to catalyse the shift to the energy efficient housing models in a post-transition and post-conflict country such as Bosnia and Herzegovina.

1. Introduction: The research methodology

This paper examines the correlation between the structure and the energy status quo of the residential building stock in Bosnia and Herzegovina, based on the data obtained from the project "Typology of residential buildings in Bosnia and Herzegovina" (1) , which was conducted from 2014 to 2016 and included a statistical survey of 13 044 existing buildings. The approach to the systematization of the residential buildings was elaborated according to the methodological framework of the European research project TABULA, (2) a unique typological model of classification of residential buildings according to their construction period and typical architectural properties.

Within the overall outline of the methodology of research on the typology of residential buildings, the following key steps represented the milestones in the entire process (Figure 1):

1. Statistical survey of the residential building stock based on the sample 13 044 existing buildings,
2. Selection and technical recording of the 29 representative buildings for each category,

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3. Calculation of the energy need for the 29 representative buildings,
4. Projection of the annual energy need for heating of the entire residential building stock followed by the two proposals of the measures of improvement of EE.

Statistical survey has generated a significant extent of input data, which was collected in the two stages of on-site research. The first stage comprised of the collection of general data on buildings by observation method (using the simple "Questionnaire A") and the second phase consisted of individual interviews with the representatives of households (using a more elaborate survey form – the "Questionnaire B") in order to obtain more precise information on the building physics, envelope and heating system etc.

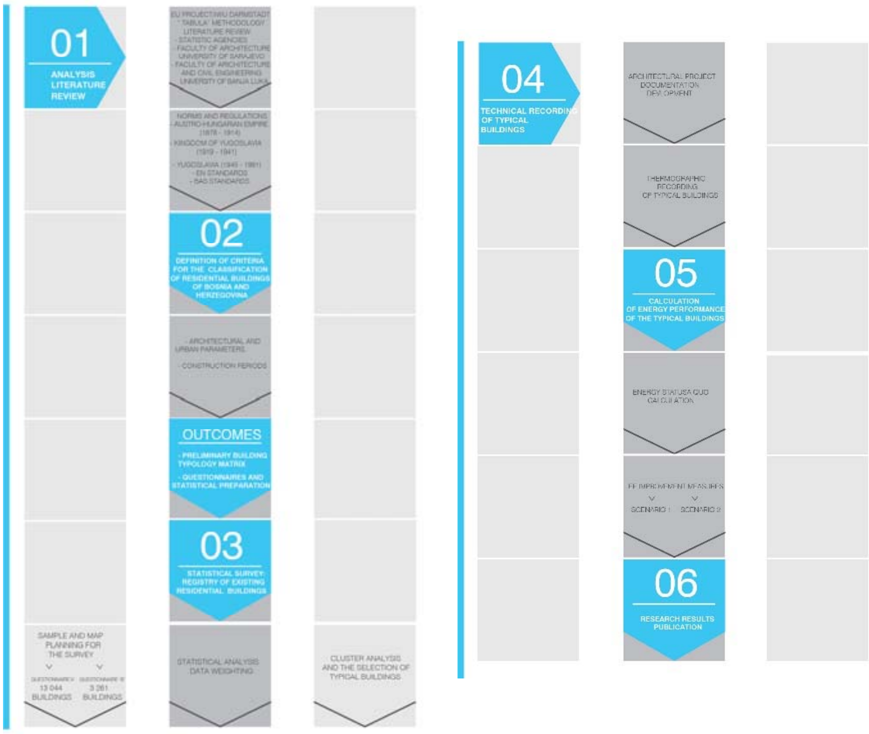


Figure 1. Methodology scheme

From the very first stages of research, it was apparent that the two typologies of individual (single family) housing, originating from both urban and rural areas of Bosnia and Herzegovina were highly expressed in comparison to the four typologies of multifamily housing (**Chyba! Nenašiel sa žiaden zdroj odkazov.**):

After gaining insights into the quantitative aspects and the structure of residential building stock, the building typologies in Bosnia and Herzegovina were categorized in the form of the "building typology matrix" (

Figure **2**). The matrix displays the 29 building typologies, arranged in columns, by their architectural characteristics and in rows, by their construction period. Each typology is exemplified by the real building with the most typical features of the category, or the so-called "typical building", which were subsequently studied, technically recorded and served as a basis for calculation of their energy performance. The methodological process of research will be explained further in the case of the most dominant residential building typology in Bosnia and Herzegovina.

Figure 2. Building typology matrix; [1]

2. Typology in focus: single-family houses from 1981 to 1991

Subsequent stages of analysis of all categories of buildings in relation to their construction periods have shown that, in quantitative terms, the typology of single-family houses built from 1981 to 1991 stand out as the prevailing category within the entire residential stock, as it can be read from the following quantitative data1 (3):

a) The share of the SFH 1981-1991 typology in total number of buildings accounts for 27.39%;
b) The share of the SFH 1981-1991 typology in total number of dwelling units accounts for 18.95%;
c) The share of the SFH 1981-1991 typology in the total gross area of all residential buildings in Bosnia and Herzegovina accounts for 24.49%.

The estimated number of buildings in the indicated category accounts for 236 075; comprising of 306 898 dwelling units and covering 38 282 654 square meters of gross building floor area in Bosnia and Herzegovina. All buildings from the specified category share several common properties in terms of their architectural form and volume: each building from the indicated category comprises of maximum three floors and maximum three dwelling units; in terms of its urban disposition and form, it is a freestanding building dating from the period from 1981 to 1991.

First stage of statistical survey has exposed typical features for each category. The dominant architectural features of the SFH 1981-1991 typology include the compact geometrical shape of the floor plan, two floors, 1-2 dwelling units, average ground floor area accounts for 77.59 m2 and the prevailing pitched roof shape.

[1] According to the research on the Typology of residential buildings in Bosnia and Herzegovina (1), the listed residential buildings were organised in six building periods: (1) up to 1945, (2) 1946-1960, (3) 1961-1970, (4) 1971-1980, (5) 1981-1991 and (6) 1992-2014. Since the length of building periods varies, the 1980s decade in was accounted as the period with the most intense residential building construction.

In almost 50% of cases of the entire category, the facades are original and haven’t been refurbished, which might be a noteworthy fact, having in mind the after-effects of the war destruction 1992-1995 in Bosnia and Herzegovina which occurred only a decade after their date of construction, indicating the need for their reconstruction.

Facades of the greater part of houses from this category have rather small number of window openings (less than 50% of the glazed surface), and the windows in more than half of the total number of cases are old, and have not been replaced since their construction.

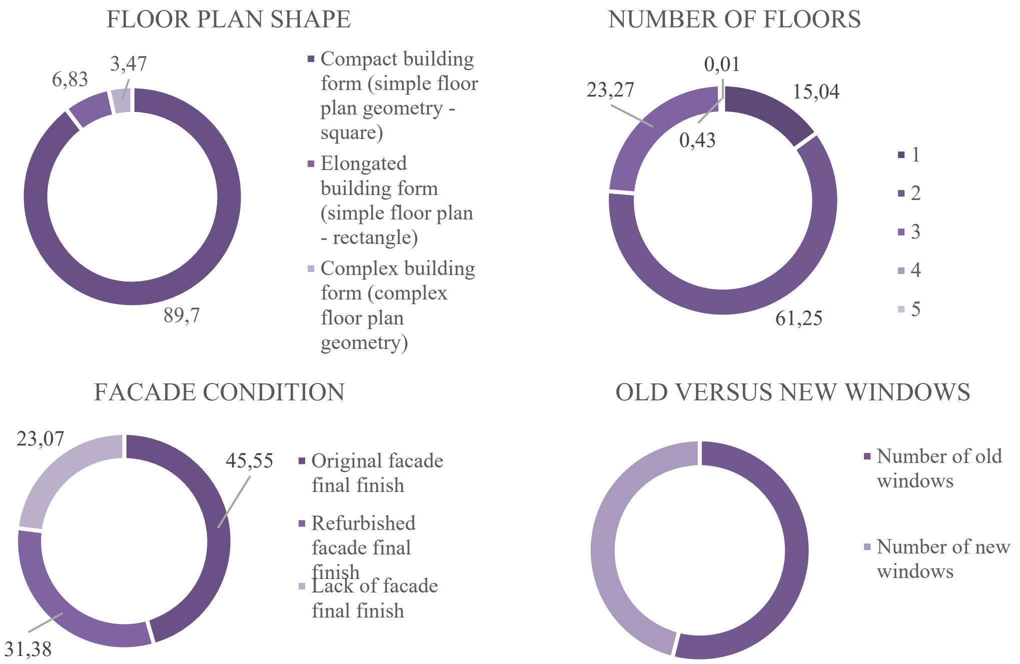


Figure 3. Typical features of the SFH 1981-1991 typology

The main objective of the second phase of statistical survey was to collect the data on the conditions of the building envelope and characteristics of the heating system of existing buildings, and it was performed by observation and interview methodology.

The survey results for the analysed building typology show that, in regards of the level of refurbishment of building and/or building envelope, less than 40% of SFH 1981-1991 houses have been reconstructed, and most them were submitted to partial reconstructions, e.g. ranging from window or roof cover replacement, façade renovation or building horizontal/vertical extensions.

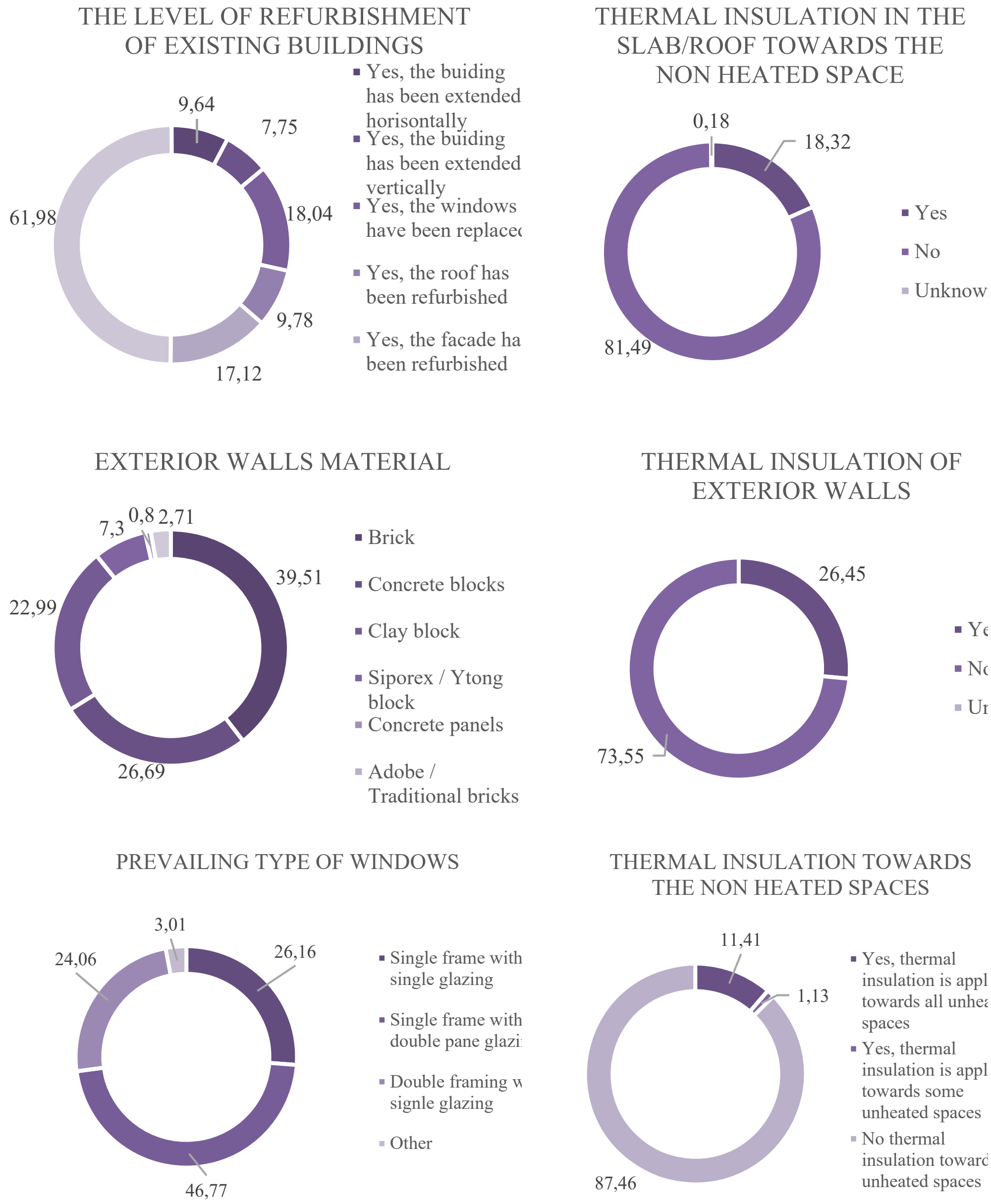


Figure 4. Current conditions of the architectural envelope of the SFH 1981-1991 building typology

Exterior envelope most commonly consists of masonry walls made of brick (39.51%), concrete blocks (22.99 %) or brick blocks (26.9%), of an average width of 25.73 cm. Only 26.54 % of SFH 1981-1991 buildings have thermally insulated exterior walls, with median insulation thickness of 6.99 cm amid all SFH 1981-1991 houses. Similarly, more than 80 % of the buildings do not contain thermal insulation towards the non-heated spaces (neither at the level of the roof/attic slab nor at the level of the floor slab towards the ground or non-heated basement). The most typical windows are single frame windows (the new windows frames are most commonly PVC, while the old ones are wooden frame) with double pane or single pane glazing.

The starting point for analysis of the modes of heating of all housing typologies was the ratio between the total gross internal area and the area of the heated space. In the case of single-family houses built from 1981-1991, the average gross internal area accounts for 116.1 m2, while in 2/3 of the households, the heated area is less than 80 m2. Average area of the heated space in SFH 1981-1991 is 66.66 m2. According to the assessments of the results of the interviews with the household owners and/or representatives, in circa 70% of the houses from the SFH 1981-1991 category, each room is heated individually, and in the 94% of cases, the heating system has not been refurbished in the last five years. Research has confirmed the empirical hypothesis that the solid wood is the most widely used fuel for household heating (80% of the SFH 1981-1991), both in primary and in secondary heating systems.

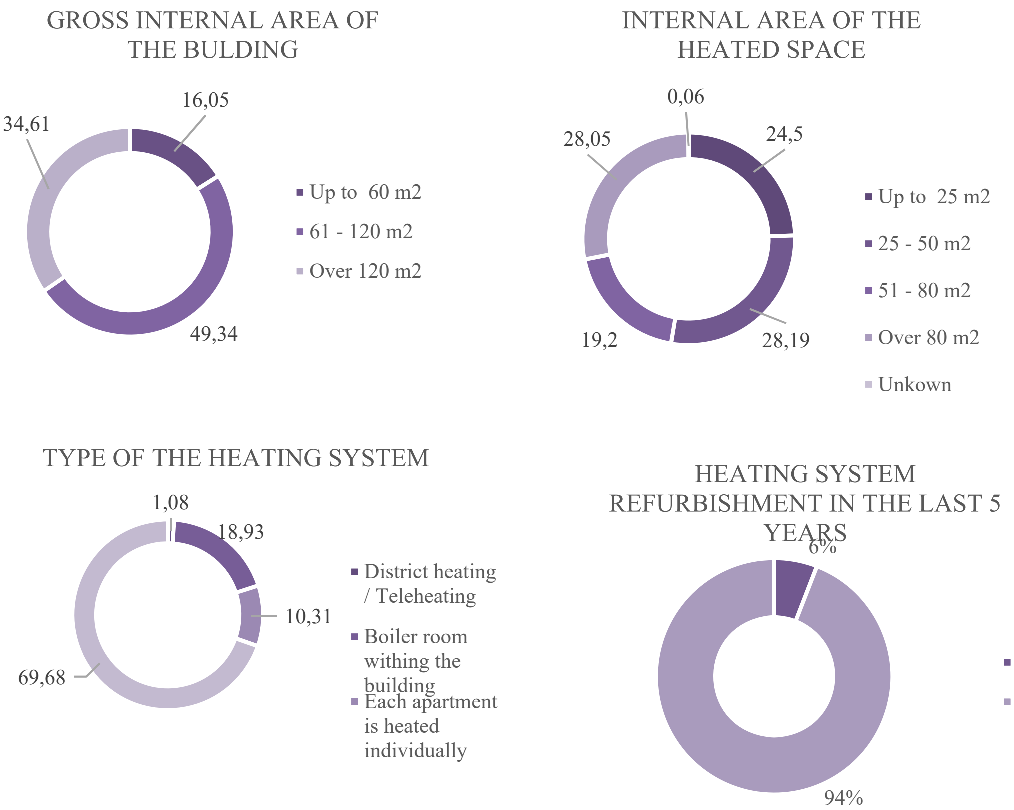
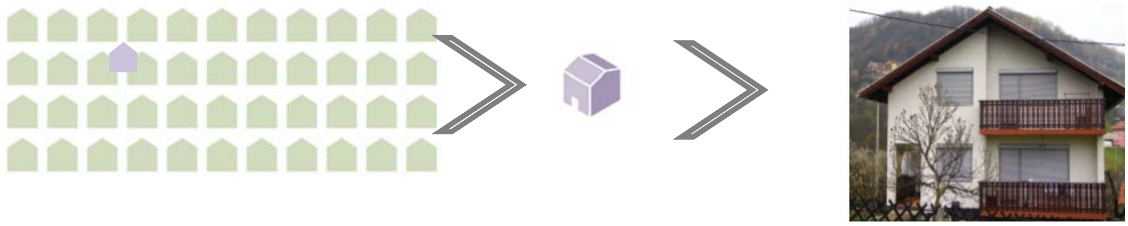


Figure 5. Modes of heating of the SFH 1981-1991 building typology (Source: Authors)

3. Cluster analysis: "model" building and the "typical" building

Outlining the principles of classification of building typologies and the development of the database enabled the extraction of the typological features of the buildings, their architectural envelope and heating systems. The succeeding objective was to search for an existing building within the entire database, which would reflect the shared properties for each category, and hence may be proclaimed as the "representative" or the "typical" building. Therefore, the selection of typical buildings signifies finding the closest match to the "ideal" or the "model" buildings characterized by average or the most typical properties of each category (Figure 6).



Building typology „Model“ building „Typical“ building

Figure 6. The selection of the “typical” building (Source: Authors)

The data-mining tool, which was used in process of assessment and selection of the 29 representative buildings, was the cluster analysis (Table 1). Numerical studies were performed in the database that was created during the statistical survey of existing buildings, containing quantitative data collected throughout the two stages of survey.

Owing to the available data obtained in the course of statistical survey, the search for the existing, most representative building that would match the average properties of the category was refined by the subsequent architectural/physical criteria, which included the following characteristics:

the ground floor area, floor plan shape, number of floors, number of dwelling units, the form of the roof, assessment of the condition of the building façade, the residential/public use of the ground floor, the quantity of window openings, assessment of the condition of the windows.

Table 1. Cluster analysis (Source: Authors)

Cluster	1	2	3	4	5
Ground floor area	179.81	53.20	120.75	83.2	382.2
Floor plan shape	0.52	0.93	0.83	0.89	0.90
Number of floors	2.25	1.91	2.23	2.18	2.00
Number of dwelling units	2.10	1.22	1.62	1.27	2.98
Roof form	0.98	0.99	0.99	1.00	1.00
Condition of the building façade	0.86	0.74	0.85	0.77	1.00
Ground floor use (residential use)	0.79	0.91	0.83	0.89	1.00
Ground floor use (public use)	0.17	0.03	0.10	0.05	0.08
Ground floor use (garage)	0.59	0.11	0.23	0.16	0.79
Quantity of window openings	0.52	0.12	0.34	0.21	0.79
Condition of the existing windows	0.33	0.61	0.51	0.55	0.33

Number of Cases in each Cluster		Un-weighted	Weighted
Cluster	1	41	1806
	2	1058	83117
	3	372	24803
	4	1658	126170
	5	4	179
Valid		3133	236075

The enumerated criteria. obtained from the data collected in the second stage of statistical survey using the “Questionnaire B”. enabled the congregation of five relatively homogenous clusters. In the case of the category SFH 1981-1991. the cluster analysis underscored the Cluster no. 4 as the prevailing group of buildings within same typology. which share the same average properties. For this reason, the representative or the typical building was selected from the most numerous cluster no 4 in the entire category of the SFH 1981-1991. and its characteristics are compared to the average properties “model” building from the two most dominant clusters: cluster no. 4 and cluster no. 2 (Table 2).

Table 2. Selection criteria

	Cluster analysis criteria:	 **Cluster 4 "Model" building**	 **Cluster 2 "Model" building**	 **"Typical"/ "Representative" building**
1.	Ground floor area (m^2):	**83.29 m²**	53.20 m²	69.66 m²
2.	Floor plan shape (%): simple versus complex geometry	**89 %** **Simple geom.**	93 % Simple geom.	Simple floor plan geometry AV ratio 0.83
3.	Number of floors (average):	**2.18**	1.91	2 (two floors)
4.	Number of dwelling units (average):	**1.27**	1.22	1 (one dwelling unit)
5.	Roof form (%): pitched versus flat roof	**100 %** **Pitched roof**	99 % Pitched roof	Pitched roof
6.	Condition of the building façade (%): Façade final finish presence or lack of façade final finish	**77 %** **Final finish present**	74 % Final finish present	Façade final finish present
7.	Ground floor use (%): residential use	**89 %**	91 %	Residential use
8.	Quantity of window openings (%): less than (<50%) of glazed area in relation to total façade area versus more than (>50%) of the glazed area in relation to total façade	**21 %** **<50% of glazed area**	12 % <50% of glazed area	Less than (<50%) of glazed area in relation to total façade area
9.	Condition of the existing windows (%): Prevalence of old windows versus prevalence of new windows	**55 %** Prevalence of old windows	0.51 Prevalence of old windows	Prevalence of old windows

4. Energy performance of the "typical" SFH 1981-1991 building

Each "typical „or the „representative" building was measured and recorded both technically and thermo-graphically to identify the status quo of its current energy performance. The SFH 1981-1991 typology is represented by a single-family house with two floors. ground floor and attic. combined as one dwelling unit (Figure 7).

The structure of the house consists of 29 cm loadbearing walls (the external walls are made of hollow clay bricks). the semi-prefabricated concrete slab (RC beams and hollow clay elements infill). and the traditional gable solid wood roof construction covered with clay roof tiles. The external walls and the roof planes are protected with 5 cm of insulation. However, the thermo graphic recordings indicate the thermal losses in several regions of the envelope: the window openings. the RC beams and columns as well as well as in the zones of the decay of the facade final finish material.

The results of the technical recordings were used as input data for calculation of the energy required for heating of the typical buildings. According to the calculations. the specific energy needed QH.nd.cont for continuous heating for the representative building of the SFH 1981-1991 typology on annual basis accounts for 176.45 kWh/m2/annum. categorizing it in the G energy class. In response to the research and calculation outcomes. two scenarios of the measures of EE improvement were simulated at the level of the architectural envelope and heating systems [1]. The measures of improvement of the architectural envelope (walls. slabs. floors. roofs) consisted of the application of the thermal insulation layer towards the non-heated spaces with predefined width and heat transfer coefficients (e.g. for the external walls. basic improvement scenario consisted of application of 10 cm of thermal insulation of λ=0.041 W/mK; the advanced improvement scenario 20 cm of thermal insulation of λ=0.041 W/mK). The EE improvement measures included the replacement windows with upgraded U coefficients. and installation of the new heating systems.

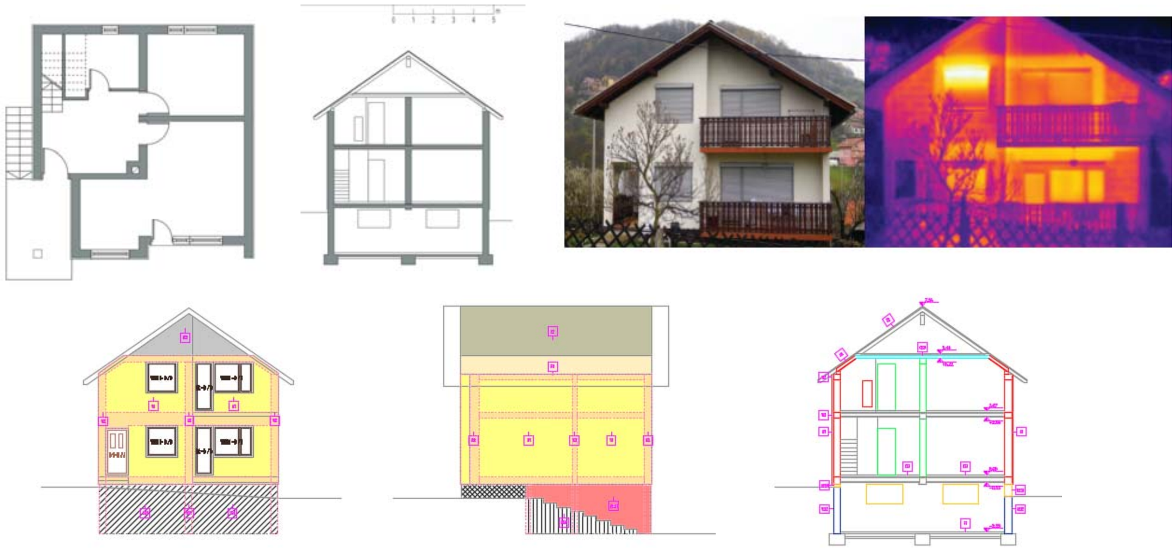


Figure 7. Building survey

The EE improvement 1 and Improvement 2 scenarios would affect the reduction of the heat transfer coefficients of the elements of the architectural envelope. the specific energy need for heating and the CO_2 emission (Figure 8).

Figure 8. Specific energy need for heating and the CO_2 emission [1]

5. Conclusions: Simulation of the energy performance improvement for the SFH 1981-1991 building typology

In the final stages of research on the typology of residential buildings in Bosnia and Herzegovina, [1] the results of the calculations of the energy needed for heating of the individual typical buildings were transposed to the level of the residential building stock. According to the results. the current energy need for heating of the building typology in focus (the SFH 81-91) of 3 101 309 MWh/a. could be reduced to 1 658 914 MWh/a by application of the basic EE improvement measures (Improvement 1). and to 1 257 590 MWh/a by application of the advanced EE improvement measures (Improvement 2) (Table 3).

Table 3. Energy need for heating of residential buildings in BiH [1]

Tabela 12. Potrebna toplotna energija za grijanje stambenih objekata u BiH (MWh/god.) | Table 12. Energy need for heating of residential buildings in BiH (MWh/year)

	INDIVIDUALNO STANOVANJE | SINGLE-FAMILY HOUSING		KOLEKTIVNO STANOVANJE | COLLECTIVE HOUSING					
	Slobodnostojeća kuća Single-family house SF	Kuća u nizu Terraced house TH	Manja stambena zgrada Multi-family house MH	Stambena zgrada u nizu/ gradskom bloku Attached apartment building in urban blocks AB1	Veliki stambeni blok/ stambena lamela Apartment block AB2	Neboderi High-rise building H	UKUPNO TOTAL	UKUPNO TOTAL
do 1945. | up to 1945	244.439	8.433	17.488	20.151			290.512	1,48%
1946-1960	719.865	28.327	195.151	58.365	24.688		1.026.397	5,24%
1961-1970	2.752.871	87.198	327.081	80.437	284.792	58.326	3.590.706	18,32%
1971-1980	6.350.897	156.250	189.255		662.681	34.574	7.393.657	37,74%
1981-1991	3.101.309	89.498	115.571	3.022	197.170		3.506.571	17,90%
1992-2014	3.528.879		116.191	35.918	105.050		3.786.038	19,32%
UKUPNO | TOTAL	16.698.261	369.706	960.738	197.893	1.274.382	92.900	19.593.880	100,00%
UKUPNO | TOTAL	85,22%	1,89%	4,90%	1,01%	6,50%	0,48%	100,00%	

Tabela 15. Energija potrebna za grijanje stambenih objekata na području BiH nakon primjene standardnih mjera (MWh/god.) | Table 15. Energy need for heating of residential buildings on the territory of BiH after implementation of standard measures (MWh/year)

	INDIVIDUALNO STANOVANJE | SINGLE-FAMILY HOUSING		KOLEKTIVNO STANOVANJE | COLLECTIVE HOUSING					
	Slobodnostojeća kuća Single-family house SF	Kuća u nizu Terraced house TH	Manja stambena zgrada Multi-family house MH	Stambena zgrada u nizu/ gradskom bloku Attached apartment building in urban blocks AB1	Veliki stambeni blok/ stambena lamela Apartment block AB2	Neboderi High-rise building H	UKUPNO TOTAL	UKUPNO TOTAL
do 1945. | up to 1945	80.221	4.142	6.396	6.433			97.191	1,11%
1946-1960	261.376	12.203	60.137	15.687	7.130		356.533	4,06%
1961-1970	1.017.597	35.182	117.788	23.982	88.851	14.632	1.298.032	14,80%
1971-1980	2.232.026	85.606	68.938		263.950	10.927	2.661.448	30,34%
1981-1991	1.658.914	33.184	35.099	1.003	90.838		1.819.038	20,74%
1992-2014	2.379.318		76.753	20.680	62.961		2.539.712	28,95%
UKUPNO | TOTAL	7.629.451	170.318	365.111	67.785	513.730	25.560	8.771.954	100,00%
UKUPNO | TOTAL	86,98%	1,94%	4,16%	0,77%	5,86%	0,29%	100,00%	

Tabela 18. Potrebna toplotna energija za grijanje stambenih objekata na području BiH nakon primjene poboljšanih mjera (MWh/god.) | Table 18. Energy need for heating of residential buildings on the territory of BiH after implementation of improvement measures (MWh/year)

	INDIVIDUALNO STANOVANJE | SINGLE-FAMILY HOUSING		KOLEKTIVNO STANOVANJE | COLLECTIVE HOUSING					
	Slobodnostojeća kuća Single-family house SF	Kuća u nizu Terraced house TH	Manja stambena zgrada Multi-family house MH	Stambena zgrada u nizu/ gradskom bloku Attached apartment building in urban blocks AB1	Veliki stambeni blok/ stambena lamela Apartment block AB2	Neboderi High-rise building H	UKUPNO TOTAL	UKUPNO TOTAL
do 1945. | up to 1945	51.499	2.850	4.489	4.607			63.446	1,05%
1946-1960	159.978	8.481	42.805	10.349	4.484		226.097	3,73%
1961-1970	632.053	23.023	74.939	15.622	54.343	9.444	809.424	13,36%
1971-1980	1.302.168	64.999	45.615		205.413	6.252	1.624.448	26,81%
1981-1991	1.257.590	25.138	24.709	743	49.840		1.358.019	22,41%
1992-2014	1.857.494		55.952	15.706	48.720		1.977.873	32,64%
UKUPNO | TOTAL	5.260.782	124.490	248.509	47.028	362.800	15.696	6.059.306	100,00%
UKUPNO | TOTAL	86,82%	2,05%	4,10%	0,78%	5,99%	0,26%	100,00%	

As a result of the application of the basic EE improvement measures (Improvement 1 scenario). current energy need would be reduced down to 53.49%. or even to 40.55% after application of the advanced measures of EE improvements (Improvement 2 scenario). If we focus on the typology of the single-family houses. these improvements would instigate the 8.63% reduction in total energy needs (with EE Improvement measures 1). up to 11.04% (with EE Improvement measures 2). On a scale of all residential buildings. these improvements account for 7.36% and 9.40%. respectively. which is a considerable amount if we compare it to maximum possible savings of 55.23% (Improvement 1) and 69.08% (Improvement 2) for the entire building stock [4].

It general. the lack of efficiency in energy supply sector and the current trends of energy consumption are related to the economic and social instigators in Bosnia and Herzegovina. a country that is still undergoing a process of transition and recovering from the conflict aftermaths. The analysis presented in this paper indicate that. according to their potential in terms of possible energy savings based on the presented improvement measures. the highlighted building typology – the single family houses of 27 to 37 years of age – can be considered as the most relevant building typology in developing the strategies and plans of the residential building stock refurbishment. Hence. the development of such initiatives for improving the EE in the residential sector ought to be supported by subventions. specialized financial incentives and investment funds. of Bosnia and Herzegovina and encouraging the homeowners to invest in the refurbishments of their dwellings. not only for the long term financial savings but also or the improvements in their housing comfort and ecological benefits. In the long run. the EE improvement programs would positively affect the civil engineering market and generate new workplaces in the industries. which concentrate on the production the thermal insulation. windows and doors. and heating systems.

Being aware of the urgency to change the current approaches towards a more responsible interaction with environmental issues and a more rational energy use. this paper intended to contribute to a better understanding of the negative impacts of the residential building sector on the overall energy consumption in Bosnia and Herzegovina. specifically targeting its key segments that might be recognized as priorities for the development of the local EE strategies.

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