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Potential Energy Savings in the Process of Rehabilitation of Residential Buildings built before the Second World War

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Abstract

Improving the Serbian housing stock built before the beginning of World War II has the potential to achieve multiple benefits in terms of both saving energy and enhancing the quality of life in them. Considering the importance of preserving these buildings as testimonies of our architectural past, investing in their rehabilitation will also contribute to the preservation of a significant element of our national identity. Recent data from the 2011 Census show that 322,244 dwellings in Serbia were built prior to 1945, accounting for 10% of total dwellings. Nearly half of these (45%) are located in Vojvodina, and a fifth (20%) belongs to Belgrade area. The methodology for rehabilitation was based on the typology of buildings from this period, as the starting point for calculating the potential energy savings and was developed for the purpose of the National Typology of Residential Buildings in Serbia. The Serbian housing stock built before World War II is characterized by high diversity as to the territorial distribution of construction types, while the remarkable differences between the old urban and rural architecture further add to the complexity of the typology. The present paper defines possible improvements to the selected building types as model representatives of real structures. The calculations of the energy performance and building type distributions were used to determine the potential energy savings in the process of rehabilitation.

Keywords:	Building stock, Energy rehabilitation, Energy savings

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1. Introduction

The results presented in this paper arise from the extensive research conducted by a group of authors from Faculty of Architecture, University of Belgrade, within the IEE Project TABULA [1]. The starting point of the project was the typology of residential buildings, which encompassed family and multifamily housing and aimed to define the structure of the total housing stock in Serbia [2-4]. The characteristic types selected by the year of construction and the defined structure of the thermal envelope were used to analyze the energy performance of the buildings and to propose potential energy savings at the national level [5].

2. Characteristics of the Serbian pre–WWII housing stock

2.1. Specific features of the housing stock pertaining to territorial divisions

The specific characteristics of the Serbian pre-World War II (WWII) housing stock seem pertinent to territorial divisions, the socio-historical context and natural conditions. This paper highlights three territorial entities that reflect the particularities of housing construction in the period before World War II: Vojvodina, South Serbia and the City of Belgrade (Figure 1).

Vojvodina differs from other parts of Serbia by its geographical position and specific historical conditions, which gave rise to the distinctive features of the local architecture. By the end of World War I, Vojvodina had belonged to the Austro-Hungarian Empire so that building construction and architectural styles were influenced by those of Central Europe. Geographically, Vojvodina is a lowland area with a rich river network and sparse forests, its soil composed of loess deposits, and its temperate continental climate characterized by a wide range of temperature extremes. Its natural features influenced the choice of building materials, usually found in the immediate vicinity of the

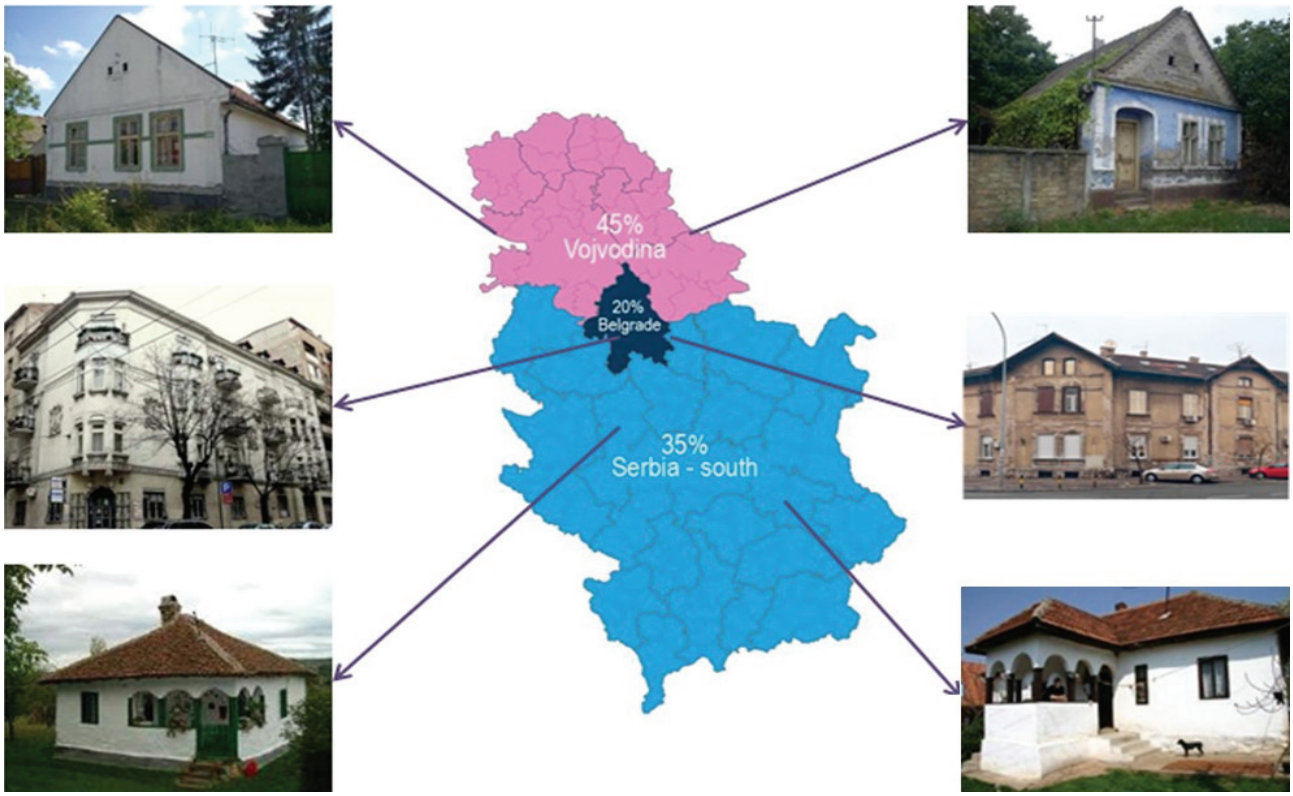


Figure 1. Characteristics of the Serbian housing stock built before the World War II by territorial criteria

Table 1. Distribution of dwelling units by territorial criteria

	A before 1919			B 1919-1945		
territorial distribution	total no. of units	share in total no. of units	share in total no. of units of the period	total no. of units	share in total no. of units	share in total no. of units of the period
Serbia	115 879	3.59%	100%	206 365	6.39%	100%
• no. of units in max-2 unit houses	96 923			154 442		
• solid construction materials	52 940			128 369		
Vojvodina	76 519	9.02%	66%	69 255	8.17%	33.56%
• no. of units in max-2 unit houses	66 830			62 716		
• solid construction materials	30 244			30 816		
South Serbia	29 167	1.77%	25.2%	84 386	5.12%	40.9%
• no. of units in max-2 unit houses	26 428			78 692		
• solid construction materials	13 760			46 770		
Belgrade	10 193	1.39%	8.8%	52 724	7.17%	25.5%
• no. of units in max-2 unit houses	3 665			13 034		
• solid construction materials	8 936			50 783		

construction site. The key features of Vojvodina's building construction were determined by the abundance of land suitable for building and, on the other hand, the paucity of stone and timber, which caused the houses in the area to be built of rammed earth or brick, firstly unbaked and later baked.

Statistics show that 45% of the preserved housing stock built in Serbia before World War II is located in Vojvodina, while most of the dwellings (90%) are family houses comprising no more than two living units (Table 1). Houses built of rammed earth and unbaked brick account for 60% of the total number of buildings in this area; the preference to these materials persisted even after World War II. The 1957 Ordinance *On technical and other requirements of design and* construction of buildings in the city area introduced a ban on the use of rammed earth and unbaked brick, which marked the beginning of planned elimination of adobe architecture.

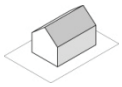
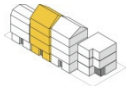
For a time, the building method endured in the rural areas of Vojvodina only to gradually give way to baked brickwork.

In contrast, the territory south of the rivers Sava and Danube is characterized by different geographical features: the terrain is hilly to mountainous, and rivers and forests abound. Besides physical differences, the historical development of this Serbian region was also dissimilar to that of the northern province, resulting in the distinctive techniques of architectural design and construction. The centuries of Ottoman dominance over the territory contributed to the evolution of the oriental architecture and construction techniques widespread in the Balkans and Asia Minor. The availability of timber influenced the ubiquity of this building material in traditional houses: log houses were built in the mountainous regions (Užice, Stari Vlah), and post and petrail prevailed in the highlands of East and South Serbia. Statistics show that 35% of the preserved pre-WWII housing stock can be located to the south of the Sava and the Danube; most of the dwellings are family houses with a maximum of two living units (as much as 92%), found predominantly in rural areas (70%). Half of the buildings from that period (53%) were built of solid material, while the other half (47%) were done in post and petrail technique (Table 1).

Belgrade, the capital city, accounts for 20% of the total housing stock constructed before World War II, with the largest number of houses built in the interwar period (1919–1945). The capital became a distinct entity not only due to the high concentration of housing but also because the urban development gave rise to specific housing types pertaining to urban areas. Although Belgrade is an ancient European settlement considering its historical development, its architecture does not reveal this heritage, primarily due to the lack of material evidence of its rich history. The time boundary for the establishment of the Belgrade housing stock is set to the beginning of the 19th century; however, few surviving buildings (mostly public by purpose) testify about this period, and the largest number of the existing housing units date back to the second half of the 19th century and later [6-7]. Belgrade is distinguished from other parts of Serbia by a large number of dwelling units in multifamily buildings (with three or more units), with 63% of the total housing stock built before World War I and 75% from the interwar period (Table 1). The first multifamily houses in Belgrade were constructed in the 1850s, but it was not before the early 20th century and the period of intensive settlement after World War I that the building construction activities fully flourished.

Despite the predominance of one-floor family houses at the time, the present data reveal the results of using construction materials not solid enough to resist the ravages of time and surges of urbanization. Two specific types of family houses could be distinguished: gentry town homes modeled on the European architecture, and small, modest dwellings for the poor, who translated the models from their original rural areas into the city [8]. The latter have not been preserved as they were mostly built in post and petrail technique with the infill of wattle and daub or unbaked brick.

Table 2. The national typology of residential buildings in Serbia

	family housing		multifamily housing		
	1	2	3	4	5
type					
A before 1919					
B 1919-1945					

2.2. Selecting the model representatives of the typology structure for the national housing stock

In compliance with the recommendations of the Project TABULA on the formation of the national typology of residential buildings, and with consideration of the specific characteristics of the national housing stock, the adopted typology structure comprised particular building types (Table 2). The following types were defined: for family housing, 1. Freestanding family house; 2. Row family house; *for multifamily housing*, 3. Freestanding residential building; 4. Lamella residential building (with repeated lamellar cores and multiple entrances); 5. Row residential building; and, 6. High-rise residential building (tower). The last category was excluded from the tables analyzed in this paper as such buildings date from a considerably later period. The national typology adopted the periodization according to the key socio-political events, the changes introduced in the building technologies, and the regulations relevant to the construction industry. Thus, the pre-WWII residential stock was divided into two periods: A—before the end of World War I (before 1919), and B—the interwar period and World War II (1919–1945). This division is consistent with the changes in the building technologies, choice of materials and equipment, and relevant legislation.

The representatives of the characteristic building types were selected upon the survey developed for this research, which included 6,000 family houses and 13,000 multifamily buildings. The research was based on architectural and urban parameters, quantitative indicators (dwelling unit area, gross floor area, number of floors), and characteristics that determine the thermal performance of the building (floor plan complexity, façades, roof, windows and doors). The defined criteria were included in the survey and then used to establish the characteristics of typical buildings that were representative of specific periods of construction; finally, the national typology was formed.

The A1 type model (a freestanding family house built before 1919) is a ground floor house with a compact floor plan, without a basement, and with an unoccupied loft. Depending on the territorial criterion, it can be a post and petrail construction in South Serbia or a rammed earth/unbaked brick structure in Vojvodina. A large number of such houses still exist, mostly in rural areas.

The A2 type model (a family house in a row built before 1919) is a ground floor house with a complex floor plan, mostly built of unbaked brick, with a basement, and an unoccupied loft. Such houses can be found only in Vojvodina, as Austro-Hungarian authorities imposed planned housing development according to the orthogonal parceling pattern. The houses are positioned along the border to the adjacent lot so that they have adjoining walls and thus form a row. The type is characteristic of both urban and rural areas. However, the settlements in other Serbian regions are of a dispersed type so that such a layout cannot be found.

The selected A3 type model (a freestanding multifamily building built before 1919) has the GF+1 floor scheme, with a basement and a loft. It is one of the first multifamily houses built by the Belgrade municipality to provide housing for the socially disadvantaged. Its construction features make it a typical representative of its time, with baked-brick walls, wooden floor constructions and Prussian vaults above the basement. It is characteristic of the urban environment.

The selected A4 type model (a lamella built before 1919) has the GF+1 floor scheme, with a basement and a loft. Similarly to the type above, it represents a social housing complex, and has the same characteristics as the previous example. However, a novelty was achieved by an innovative architectural and urban layout, whose common core of dwelling units is multiplied to form a lamellar row with several entrances, comprising a building as a whole. It is one of the first examples of this type of house and is characteristic only of urban areas.

The A5 type model (a row house built before 1919) has the GF+2 floor scheme, with a basement and a loft, which has been converted into a living area. Integrated into the city matrix, the building takes the full length of the lot to the street front. The same as the types above, its construction consists of load-bearing brick walls, wooden floor constructions, and Prussian vaults above the basement. It is characteristic only of urban environments.

The B1 type model (a freestanding family house dating from 1919–1945) is a ground floor house with a compact floor plan, built of brick in a massive construction with a wooden ceiling to the loft. Such buildings mark the transition to the new way of building that used solid and more durable materials for walls, such as baked brick, while the use of old materials, rammed earth and unbaked brick, was discontinued. Although most buildings of this type have been preserved in rural areas, some have also survived urban growth in the cities.

The B2 type model (a family row house built in 1919–1945) is a ground floor structure with a compact floor plan, with a basement and an unoccupied loft. The building materials may have been unbaked or baked brick, with a wooden floor construction to the loft and a Prussian vault above the basement. Similarly to the representative row houses of the older period, such structures can be found only in Vojvodina, where planned parceling was the norm. This type is characteristic of both rural and urban areas.

The B3 type model (a freestanding multifamily building dating from 1919–1945) has the GF+2 floor scheme, with a basement and a loft subsequently converted to a living area. After World War I, the cities faced a severe housing crisis and rental multifamily housing developments were a lucrative business. Its construction characteristics are typical of its time, with brick walls, wooden floor constructions, and reinforced concrete ceiling above the basement level. It is characteristic only of urban areas.

The B4 type model (a lamela built in 1919–1945) has the GF+2 floor scheme, with an unoccupied loft. This building concept generally refers to social housing; thus, the chosen development was financed by a wealthy industrialist, the owner of "Bajloni and Sons" company, to provide housing for their workers and clerks [9]. The construction consists of brick walls and ribbed reinforced concrete floors. The use of reinforced concrete grew after World War I, firstly only for ceilings above the basement (which had to be fire resistant). Later, the material replaced the wooden floors completely, becoming the only choice for floor constructions. Considering its layout, the building is typical merely of urban environments.

The type B5 model (a row building built in 1919–1945) has the GF+3 floor scheme, with a basement and a loft subsequently converted into residential space. Integrated into the city matrix, the building is characteristic only of urban areas. The construction comprises load-bearing brick walls, wooden floor constructions and a reinforced concrete ceiling above the basement.

2.3. Quantitative analysis of the typology structure for the national pre-WWII housing stock

The typology structure was the starting point for the quantification of the selected representative buildings nationwide, while the results thus obtained were used to assess the total Serbian housing stock. The survey of the buildings conducted for the purposes of this project, the 2011 National Census, and other data from the Statistical Office of the Republic of Serbia, [10] yielded the following numerical values for each identified type at the national level: the areas, the number of buildings, and the number of dwelling units (Table 3).

In summary, the numerical values expressing the distribution of certain types can indicate that freestanding family houses (type 1) constitute by far the largest percentage of buildings constructed by 1945 (91%), while their area accounts for 78% of the total square meters built during this period. The distribution of the other types is much lower (under 10%), especially for multifamily residential buildings. This numerical distribution can be explained by the facts that multifamily housing had not begun its development until the early 20th century; that it was characteristic only of urban areas, which in Serbia were few; and, that most of such buildings were concentrated in Belgrade. In addition, years of war and the economic crisis in the interwar period held back any large-scale investment and building projects, which primarily affected multifamily housing. Buildings of the lamella type were

Table 3. National typology before World War II—Type distribution

Type distribution by area (m^2)								
		family housing		multifamily housing				
		1	2	3	4	5	Σ m^2	%
A	< 1919	8 812 918	1 641 759	181 255	128 836	319 202	11 083 970	37.90
B	1919-1945	14 060 213	871 044	1 056 060	343 833	1 829 417	18 160 567	62.10
	Σ m^2	22 873 131	2 512 803	1 237 315	472 669	2 148 619	29 244 537	100.00
	%	78.21	8.59	4.23	1.62	7.35	100.00	
Type distribution by number of buildings (items)								
		family housing		multifamily housing				
		1	2	3	4	5	Σ items	%
A	< 1919	117 985	17 394	183	40	345	135 947	39.43
B	1919-1945	194 546	10 937	1 530	170	1 663	208 846	60.57
	Σ items	312 531	28 331	1 713	210	2 008	344 793	100.00
	%	90.64	8.22	0.50	0.06	0.58	100.00	
Type distribution by number of dwelling units (items)								
		family housing		multifamily housing				
		1	2	3	4	5	Σ items	%
A	< 1919	117 985	17 394	1 098	567	2980	140 024	36.86
B	1919-1945	195 812	11 078	12 240	2 457	18 267	239 854	63.14
	Σ items	313 797	28 472	13 338	3 024	21 247	379 878	100.00
	%	82.60	7.50	3.51	0.80	5.59	100.00	

Table 4. National typology before World War II—Type distribution by heating consumption [MWh/year]

		family housing		multifamily housing				
		1	2	3	4	5	Σ [MWh/year]	%
A	< 1919	2 317 797	512 229	38 064	21 129	52 988	2 942 187	41.01
B	1919-1945	3 402 572	284 831	196 427	75 299	272 583	4 231 712	58.99
	Σ [MWh/year]	5 720 369	797 060	234 491	96 428	325 551	7 173 899	100.00
	%	79.74	11.11	3.27	1.34	4.54	100.00	

Table 5. National typology—Savings after the standard improvement of building energy performance [MWh/year]

		family housing		multifamily housing				
		1	2	3	4	5	Σ [MWh/year]	%
A	< 1919	1 427 693	270 890	19 757	11 209	21 067	1 750 616	43.10
B	1919-1945	1 841 888	166 369	108 774	49 512	144 524	2 311 067	56.90
	Σ [MWh/year]	3 269 581	437 259	128 531	60 721	165 591	4 061 683	100.00
	%	80.50	10.76	3.16	1.50	4.08	100.00	

a novelty in the construction industry; as they demanded large investments, it was not until the 1970s that their development reached its peak.

3. Energy performance and savings potential in pre–WWII residential buildings

The next step in the analysis of the housing stock in Serbia was to determine the energy properties of the representative types of residential buildings. The review of technical documentation and the field research helped to define the structure of the thermal envelope and the heat and domestic hot water supply systems so as to carry out the thermal calculations and establish the energy class of the building. The data on the specific annual heating energy demand for each building type [kWh/m^2/year] and the distribution balance of the types and the total area [m^2] were used to determine the energy required for heating [MWh/year]. The results are shown in Table 4. Considering the predominance of family houses (A1 and B1) compared to other housing types, these buildings show the highest demand for heating energy [11-12].

3.1. Energy performance and savings potential in pre-WWII residential buildings

The suggested measures for improving the energy efficiency of the representative buildings of the typology structure considered two levels of improved performance: standard measures, and advanced measures.

Standard measures encompassed construction interventions that are typical of domestic practice in improving energy efficiency of a building: replacement of the existing windows with new packages, compliant with thermal codes; and, adding thermal insulation to walls and floor constructions to the external or unheated areas. The purpose of the standard improvement measures was to raise the energy efficiency class by one, with respect to the valid regulations on energy efficiency of buildings.

Advanced measures took into account the maximum possible improvement of energy performance considering the characteristics of the building in question. This included the installation of top quality windows available on the domestic market and thick insulation layers in the thermal envelope, with the purpose of raising the energy efficiency class as high as possible.

Energy savings achieved by standard improvement measures are shown in Table 5. The intervention on freestanding family houses, which account for most of the total housing stock built before 1945, would yield the greatest energy savings. If standard measures were applied on the buildings of this construction period, the potential annual savings could amount to 4,061,683 MWh, which would reduce the total heating energy demand by 56% of the present figures.

Energy savings achieved by advanced improvement measures are shown in Table 6. The greatest proportion of freestanding residential buildings contributed to the highest energy savings achieved in this category. The comparison between the total energy savings achieved by advanced improvements (5,039,391 MWh per year)

Table 6. National typology—Savings after the advanced improvement of building energy performance [MWh/year]

		family housing		multifamily housing				
		1	2	3	4	5	Σ [MWh/year]	%
A	< 1919	1 683 267	357 903	26 282	14 172	31 920	2 113 545	41.94
B	1919-1945	2 362 116	189 017	129 895	56 389	188 430	2 925 846	58.06
	Σ [MWh/year]	4 045 383	546 920	156 177	70 561	220 350	5 039 391	100.00
	%	80.28	10.85	3.10	1.40	4.37	100.00	

and the present consumption (7,173,899 MWh per year) highlights the reduction in total heating energy demand by 70%.

4. Conclusion

Improving the energy performance of buildings constructed before World War II could result in significant energy savings and a better standard of living. However, the importance of preserving and refurbishing this segment of the Serbian housing stock lies beyond the scope of potential energy savings. A significant number of these buildings have been included in the national cultural heritage and are under state protection, which can further complicate the process of rehabilitation. On the other hand, the measures that contribute to their better energy efficiency can be viewed as the process of renovation and preservation, which is of special interest in such buildings. Although the proportion of the buildings of this period in the total housing stock is small, they represent a testimony of our architectural past so that the investment in their rehabilitation would contribute to the preservation of a significant facet of our national identity.

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