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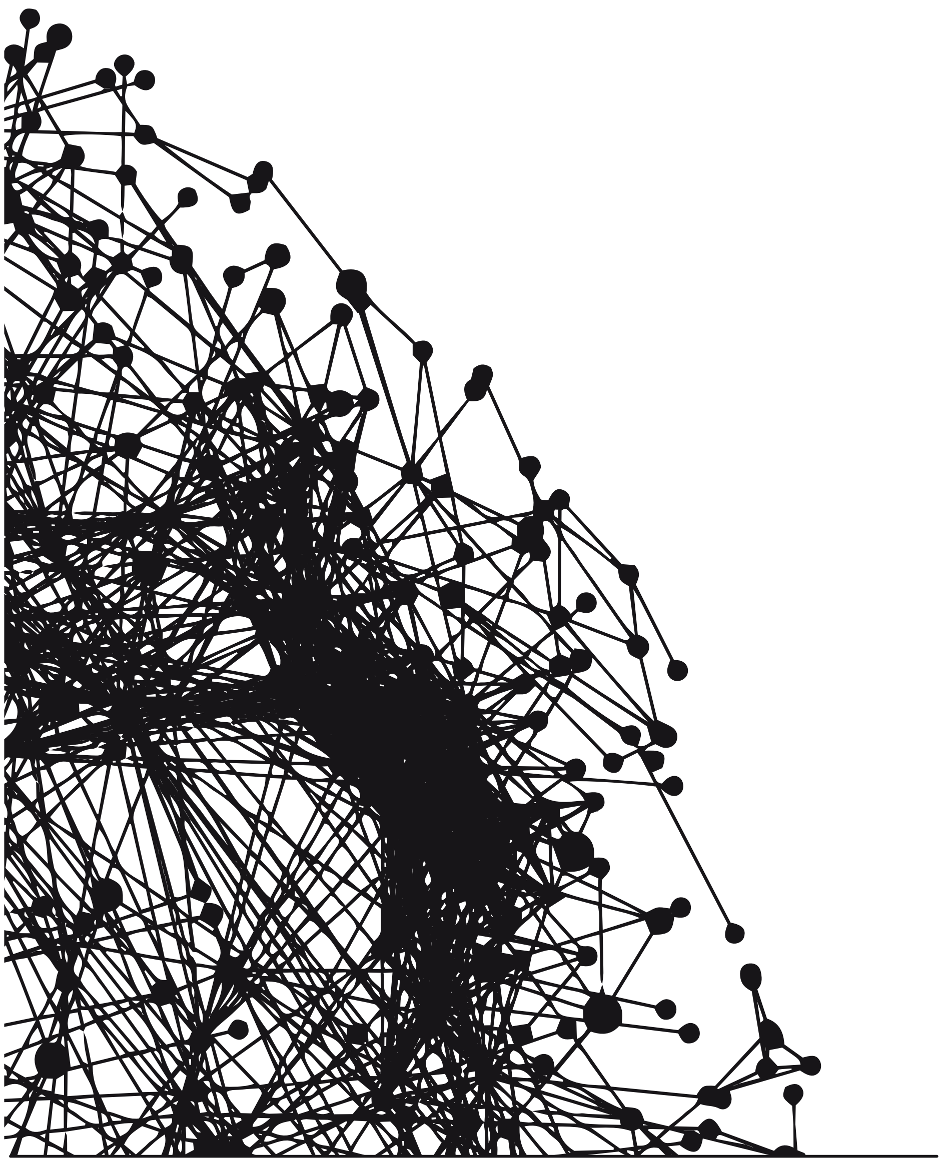

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POTENTIALS AND LIMITATIONS FOR ENERGY REFURBISHMENT OF MULTI-FAMILY RESIDENTIAL BUILDINGS BUILT IN BELGRADE BEFORE THE WORLD WAR ONE

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ABSTRACT

After the adoption of new Regulations on Energy Efficiency of Buildings, energy efficiency became the primary issue of the present building practice in Serbia, referring both to new buildings and to existing ones, among which refurbishment of buildings built before the World War One requires a special attention. Devastation of the building stock during the great wars of the 20th century and the late start of the European model of urban development in the second half of the 19th century in the most parts of Serbia are the main reasons that pre-1919 multi-family houses today represent about 1% of the total building stock. The rarity of the buildings of this age and their structures resulted with large number of them that are listed as cultural heritage, so any intervention on them, including those which are result of the adjustment to modern needs and building rules, becomes especially sensitive and complex. In particular, this refers to energy improvement measures which, according to new regulations, are an inevitable part of any building intervention. Having in mind all the mentioned aspects, and focused on the relevant examples of multi-family houses from Belgrade, this paper deals with investigation of potentials and limitations for energy refurbishment of buildings and building structures dating from the time before the World War One.

Keywords: energy refurbishment, multi-family residential buildings, built heritage

INTRODUCTION

Although by the time of its origin Belgrade represents the old European settlements, these historical facts are not visible through its architecture today. History of the city was marked by wartime destruction, fires, floods and other devastations, resulting with a small number of preserved buildings from the past, among which residential buildings built prior to the World War One represent only one percent of the total housing stock of the city. These circumstances distinguish Belgrade from other European capitals. The European model of urban development of the city started in the first half of the 19th century. However, most of the preserved buildings of the period come from the second half of the 19th century until the beginning of the World War One. Many of them have been protected as a cultural heritage, making the process of harmonization with modern standards in the field of thermal protection sensitive and complex.

Selection of the sample of Belgrade residential architecture prior to the World War One

Recently conducted research of building typology of housing stock in Serbia showed that existing pre-1919 multifamily residential buildings were massive, low-rise structures which rarely kept their authentic construction features. Having this in mind, a working class housing complex from Venizelos' Street in Belgrade was selected as an appropriate model for investigation of energy refurbishment potentials. The erection of the complex which, up to now, underwent just small-scale alterations, was financed by the Belgrade municipality was built in 1911 according to the design by the first woman architect in Serbia, Jelisaveta Načić. Planned for living of the poor civil servants and workers, this was the first settlement of social housing in Belgrade.

Figure 39: Housing complex in Venizelos' Street: free standing building (left) and lamela type building (right)

Functional organization

The complex was composed of three parts: two small free-standing buildings on the corners between which there was a residential *lamela* type building that comprises six entrances and represents multiplied form and organization of free-standing units. Buildings have a Ba+GF+1 scheme, with an unoccupied loft that was converted into a living space during the time. They are modest in volume, elements of form and decoration, expressing the designer's skill to avoid a potential impression of penury such houses might give due to the low investment in their construction. Free-standing buildings are of a square floor plan with a centrally positioned staircase placed between two identical small apartments of simple spatial organization. Apartments consisted of a room and a kitchen while the toilets were placed outside in a separate building in the yard. Elongated *lamela* type building is organized in a similar way, with two residential units per floor, but with toilets located inside the entrance area, symmetrically to the stairway zone, ensuring in this way that the apartments were fully fitted for the time of construction.

Applied structures and building materials

In the mid of 19th century, the brick masonry became the dominant type of massive wall construction. Brick format was prescribed in 1896 by the *Building law for the City of Belgrade* in the tradition of the so-called Austrian format (29x14x6,5 cm). Following the building practice of the time, massive façade and load bearing walls of selected buildings had the thickness of 1½ or 1 brick.

As a compulsory fire protection measure imposed ty the building regulations, floor constructions above the unheated basement had to be massive. Therefore, the Prussian vault floor construction, a combination of steel beams and shallow brick vaults, was used in the buildings of the complex. This type of structure has pushed into the background conventional brick barrel vault. The use of reinforced concrete was limited to public buildings of a complex structure, while in other multi storey buildings its use was sporadic. In the analysed case, the staircase was solely of reinforced concrete, while the floor constructions to the loft were wooden, originally having a wooden decking and rammed earth layer above and straw-plaster ceiling below the wooden beams. The buildings had a typical wooden roof construction that formed the tile-clad pitched roof. Original windows were wooden, having double frame, with single glazed sash. Today, some of them are replaced with PVC windows. The façade was rendered with plaster with a shallow architectural decoration, but today it is in a poor condition. This could be the motive for energy refurbishment, which would inevitably lead to the improvement of the total living comfort.

Energy improvement proposal

During 2012, energy improvement measures that could be applied on the Serbian housing stock were investigated and discussed in the framework of *Tabula* project.[164] Among the total energy saving measures, those that refer to interventions on the building envelope, i.e. construction measures which will be analyzed. The principles that were established refer to the achievement of two levels of potential improvement of energy efficiency of buildings, the so called standard measures and enhanced measures.

[164] The IEE Project TABULA aimed at defining common principles for the creation of national typologies Approach for Building Stock Energy Assessment

The first level of improvement considered construction interventions on the building thermal envelope that were typical of the local market, such as replacement of existing windows with new ones that fullfil the requirements of thermal regulations and addition of thermo insulating layers along the relevant wall and floor structures. The purpose of these measures was improvement of building energy performance for at least one energy efficiency class, which was in accordance with the current thermal regulation. The advanced level of energy improvement refered to the maximal possible measures that were in accordance to the features of a renovated building. They include installation of the most efficient, top quality windows available on the local market, as well as further thickening of additional thermo insulating layers.

The *Regulations on Energy Efficiency of Buildings* adopted in 2011 imposed significantly lower permited thermal transmittance values and introduced mandatory energy certification of buildings. Assessment of achieved energy efficiency of a building is expressed by the energy label, graded from A (most energy efficient) to G (lower efficiency) which corresponds to calculated value of annual energy usage. The required specific heating energy demand per year *QH,nd,max* [kWh/(m^{2}a)] for the new buildings corresponds to the energy class "C", while, as already stated, existing ones should be improved for at least one energy rate.

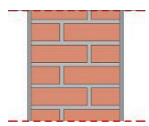
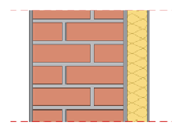
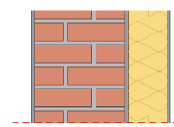
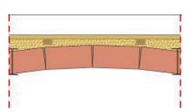
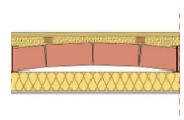
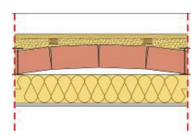
Present condition of the buildings from Venizelos' Street does not fulfil requirements set by the *Regulations*. However, although analyzed residential buildings do not need an energy certifate, being protected as a cultural heritage, compatibility with the current requirements of energy efficiency contributes to the improvement of the living quality. In the present state, energy rating of the free-standing house ranks it in the „G" class, while *lamela* type building from the same complex is categorized as „F" class, so they both significantly deviate from the permitted levels set for the new building.

Improvements

Proposed improvement measures in the first level of improvement were the same on both, free-standing and *lamela* type building. Standard improvement measures include additional 10cm thermo insulating layer on the external side of the wall as well as bellow the floor construction to unheated basement. Double framed wooden windows should be replaced with wooden single framed, with double glazed low-E glass unit, filled with inert gas, while existing roof windows need to be replaced with aluminium framed roof windows with improved thermal break and glazed with the same type of glazing as improved ordinary windows. Applied measures of energy refurbishment contributed to reduction of U-values to prescribed limits for each of the elements that were the subject of improvement.

The second level of improvement strives to achieve the highest possible energy class of the building, involving all the elements that could contribute to energy saving and improving them to the level of prescribed limits (Table 1). This means addition of 20 cm thermo insulating layer on external side of the façade walls and 5cm layer in the case of walls to unheated space (staircase and corridor). Below the adopted roof structure there is an additional 15cm of thermo insulation, while floor construction to unheated basement requires addition of 15cm thermo-insulating layer below the structure. Existing windows need to be replaced with PVC windows of six chamber profiles, glazed with triple low-E glass unit, filled with inert gas. Roof windows need to be of aluminium profiles with improved thermal break, glazed with the same type of glass unit as that of improved ordinary windows. Wooden doors need to be replaced with metal ones with an insulated leaf.

Table 1: Improvement interventions on some of the original elements of the thermal envelope

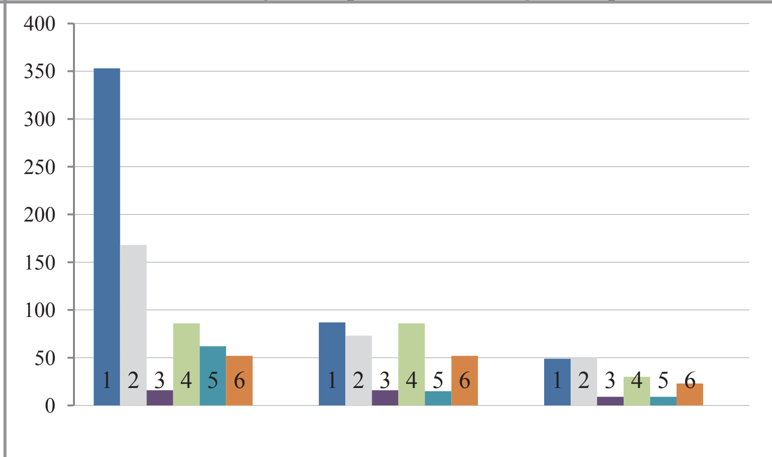
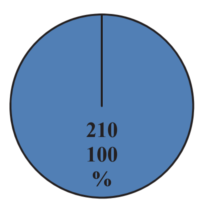
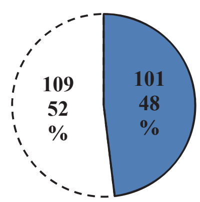
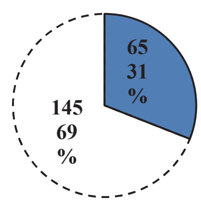
	Present state	Improvement 1	Improvement 2
External Wall U_{max}=0,40			
	plaster 2cm brick 44cm plaster 2cm	plaster 2cm brick 44cm plaster 2cm thermal insulation 10 cm plaster 1 cm	plaster 2cm brick 44cm plaster 2cm thermal insulation 20 cm plaster 1 cm
U (W/m^{2}K)	**1.12**	**0.26**	**0.15**
Floor Construction to Unheated Area (Basement) U_{max}=0,40			
	wood decking 2cm sleepers 8/5 in sand bedding 5-8 cm Prussian vault (14 cm)	wood decking 2cm sleepers 8/5 in sand bedding 5-8 cm Prussian vault (14 cm) thermal insulation 10 cm plaster 1 cm	wood decking 2cm sleepers 8/5 in sand bedding 5-8 cm Prussian vault (14 cm) thermal insulation 15 cm plaster 1 cm
U (W/m^{2}K)	**1.15**	**0.28**	**0.21**

Achieved energy savings

The effects of two levels of energy improvement measures conducted on the case of the free-standing building are presented in Table 2. Diagram of heat loss through the elements of thermal envelope shows that the greatest savings are achieved by proposed façade wall insulation, which contribute the most to the total heat loss in the original building form, but decreasing four times within the first stage of improvement. Replacement of original windows also ensures significant reduction of heat loss to more than a half of the original value. Total heat loss after the implementation of the first level of energy saving measures is reduced more than a double (from 737,40 W/K to 329,55 W/K) and the same pattern is shown regarding the specific heating energy demand per year which is 52% reduced, i.e. from 210.29

kWh/m²a to 101,20 kWh/m²a. Therefore, the renovated building has the "D" energy class after the first level of improvement which is two energy classes higher than originally.

Table 2: Thermal envelope improvement – energy balance for the free-standing building

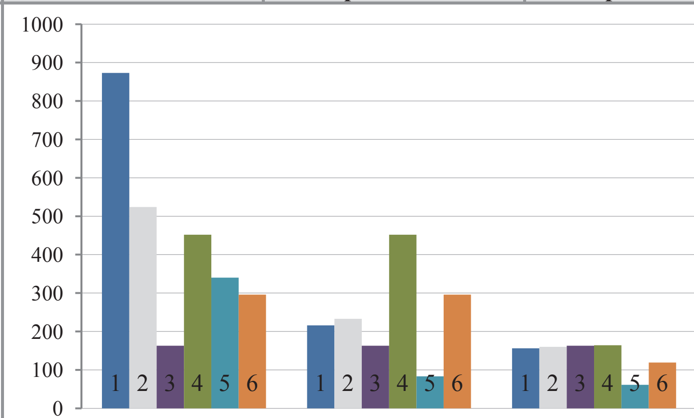
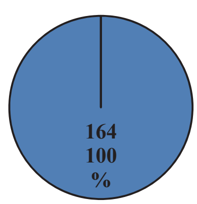
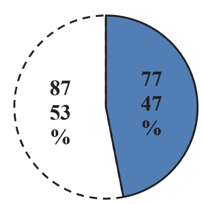
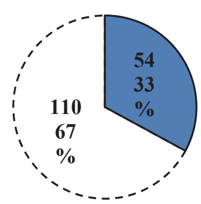
	Present state	Improvement 1	Improvement 2
Heat loss through the thermal envelope [W/K] 1.External Wall 2.Windows 3.Entrance door 4.Wall to unheated staircase 5.Floor construction to unheated basement 6.Pitched roof			
Specific Heating Energy demand per year [kWh/m²/ year] [%]			
Energy class	G	D	C

Through adequate interventions on all of the elements of thermal envelope, which were the improvement measures foreseen in the second level of improvement, total heat losses were four times lower than originally (from 737,40 W/K they were reduced to 170,94 W/K). The specific heating energy demand per year was reduced to 65,14 kWh/m²a after this level of intervention, resulting with 69% of energy saving from the original state of the building. With such renovation the building would be rated as "C" energy class and therefore in accordance with the regulations.

Other building that was analyzed represents a string composed of six residential units that are in shape and in size equal to the freestanding building. However, due to its size, volume and wall to window ratio, this building as a whole has much favorable energy performances than the free-standing one and higher energy class - „F". Table 3 shows the effects of the two levels of energy improvement of the *lamela* type building.

As in the case of the free-standing building, the greatest savings are achieved by proposed façade wall insulation, followed with window replacement. After the first phase of energy renovation, heat losses through façade walls were reduced four times, while those through windows became half of original ones. Total heat loss after this phase was reduced to almost a half (from 2648,6 W/K to 1443,18 W/K), as well as the specific heating energy demand per year which was decreased from 164,39 kWh/m²a to 76,9 kWh/m²a, resulting with 53% of energy saving and „D“ energy class of the renovated building.

Table 3: Thermal envelope improvement – energy balance for the lamela type building

	Present state	Improvement 1	Improvement 2
Heat loss through the thermal envelope [W/K] 1.External Wall 2.Windows 3.Entrance door 4.Wall to unheated staircase 5.Floor construction to unheated basement 6.Pitched roof			
Specific Heating Energy demand per year [kWh/m²/ year] [%]			
Energy class	F	D	C

In the second phase of energy renovation, proposed intervention on all the elements of the thermal envelope resulted with triple reduction of the total heat loss compared to the original state (from 2648,6 W/K to 822,19 W/K). The specific heating energy demand per year was reduced to 53,84 kWh/m²a, which is 67% less than in the original state. The building was transformed into the energy class "C" building, becoming in this way in accordance with the regulations.

Conclusions

Analysis of selected buildings from the early 20th century through two phases of energy refurbishment shows that the standard level of intervention does not meet the more severe requirements of the energy efficiency of buildings. However, the implementation of new demands becomes possible only by applying the enhanced measures where interventions are done on all elements of the thermal envelope through application of the maximal extent of thermal protection measures. The chosen examples were basically more convenient for energy refurbishment due to their shallow architectural decoration on a façade that enabled their reconstruction by addition of external thermo insulating layer. Unlike them, buildings with rich façade mouldings that were typical for the time require interventions from the internal side of the building which could be am aggravating factor in achieving requirements of the present energy efficiency regulations. Possible solution in such cases could be found in appropriate application of some innovative thermo insulating materials which provide a high level of thermal protection with thin layers of materials, and/or allow internal application.

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