RES Integrated Refurbishment Approach for Low-Rise Residential Prefabricated Building in Belgrade, Serbia

Dubravka Matic¹, Jaume Roset Calzada¹ and Marija S. Todorovic²

¹ ETSAB, Universidad Politécnica de Catalunya, Barcelona, Spain

² Academy of Engineering Science of Serbia and Southeast University, *China*

Corresponding author:

Dubravka Matic, Dept. de Construcciones I, ETSAB, Universitat Politecnica de Catalunya,
Avda. Diagonal, 649, 08028 Barcelona, Spain.
Email: duda.matic@gmail.com

Abstract

The refurbishment of the existing housing stock has a twofold aim: to decrease consumption of fossil fuels and to reduce the CO₂ emissions. The main focus of the presented paper is the evaluation of the integrated design approach applied in scenarios for refurbishment of the prefabricated residential multi-apartment building. The criteria used in searching for the best approach to the RES integrated refurbishment were minimized energy loads, minimized CO₂ emissions and improved indoor environment quality, health and comfort. After in-depth environmental analysis, a series of EEI (energy efficiency improvement) measures were implemented, as a comprehensive optimization of the building's envelope structure, natural and mixed ventilation and source energy delivery. The building's dynamic behaviour and energy efficiency have been analyzed and optimized by the Building Performance Simulation and PV panels' integration for the Typical Meteorological Year of Belgrade, Serbia. Energy refurbishment should be approached in an organized, pragmatic and interdisciplinary way. Hence, the focus should be not only on the latest leading-edge technology, but on the synergy of different practices and principles in order to ensure the path to sustainable development and achieving desired objectives.

Keywords

Energy refurbishment, prefabricated buildings, building's envelope structure, final energy, BPS – building-performance-simulations, renewable energy sources (RES)

Introduction – energy refurbishment of residential buildings

Increasingly, we are witnessing "weather extremes" with catastrophic consequences, described by many as meteorological - geological manifestations of global warming. Depletion of fossil energy resources, climate change and environmental pollution threaten the life support systems on Earth. To stop further progression of these irreversible processes, it is necessary to spread the RES (renewable energy sources) technologies utilization. However, their efficient and cost-effective implementation must be preceded by the improvement and optimization of energy efficiency. All kinds of energy loads are to be reduced to the lowest possible level, by the application of all known available measures, knowledge, technology and energy-efficient systems and equipment. Energy efficiency in buildings is particularly important due to the buildings' highest share in overall energy use, and the fact that extremely large potential savings can be obtained particularly in buildings.^[1]

Buildings account for 40% of the total primary energy consumption and 36% of CO₂ emissions in the EU.^[2]

In 2002 the EU adopted its first directive on the energy performance of buildings (EPBD), which points out the minimum requirements for new buildings and renovation of existing ones. The most current EU plan set new measures and new targets to be achieved - to 2020, when every new building in the EU must be "nearly-zero" energy, and by 2018, when every public building, whether newly-constructed or renovated, must be "nearly-zero" energy with minimized loads covered exclusively by renewable energy sources.

The refurbishment of the existing buildings has a fundamental role in meeting these challenges, and without any doubt their great numerical superiority in relation to the new buildings in Europe represents a major sector for achieving overall goals for energy savings and reduction of Serbia's CO₂ emissions levels, as well as globally.^[3] Without exploiting the huge saving potential of the building stock, the EU will miss its reduction targets.

New Belgrade residential buildings

The municipality of New Belgrade, one of the 17 districts in Belgrade, occupies 4.096 ha and consists of 72 blocks. New Belgrade has a strong issue emerging related to the necessity of rehabilitation of the post-second World War collective housing, built between 1950 and 1980. Architecture and urban planning principles were used to design

and build New Belgrade, with modest reduced sizes of apartments, with spacious green areas between blocks of buildings and natural ventilation, coinciding at many points with the current sustainable urban development approach that promotes quality of interior and exterior living space with minimal impacts on the environment. ^[3]

The interesting fact is that more or less the same building design, technology, material and spatial organization were applied and implemented, which provides wide potential for future refurbishment interventions.

Figure 1. Residential building blocks in New Belgrade

Unfortunately, the last 25 years, many new buildings were built outside the context of the architectural and urban heritage of New Belgrade. Poor maintenance over the years resulted in changed panorama of New Belgrade, as the aesthetically unmatched mix of new "hi-tech" commercial - office buildings and dilapidated residential housing with visibly damaged façades, side by side.

During the life cycle of these prefabricated buildings, tenants' lack of interest for building maintenance and improvement, their social and economic status had led to obvious physical deterioration and decrepitude of these buildings, that cause a sense of desertedness and rejection as well as a lack of hope that changes are possible, since there are no adequate institutions that would offer citizens the models for solving their inadequate housing conditions. Many of them have visibly damaged façades, moisture penetration into the walls and lack of indoor comfort, primarily inadequate air temperature with high infiltration of outdoor air, regardless of extremely high energy consumption for heating from the Belgrade district heating system and high consumption of energy for air-conditioning units.

Buildings' façades, as reflection of the modernist approach of the époque, are characterized with stiffness and architectural repetition in terms of aesthetics, and nowadays are visibly damaged due to series of inadequate actions performed by apartment owners – closing terraces by glazing, without any consideration of visual identity of the building, illegal new opening on the façades, expanding private gardens at the expense of public/community green areas, etc.

These building are the ones that represent the identity of New Belgrade, and it is necessary to find a solution for the future architectural revitalization, not only in order

to preserve the buildings, but also to improve residents' thermal and health comfort, as well as provision of cleaner and healthier indoor environment, along with reduction of energy consumption and aesthetic qualities.

Aim of the study and methodology

The study aim encompass: architectural re-design using "passive" and "active" measures to rectify energy efficiency issues of residential buildings, bringing them to the level which could lead to their **deep (RES integrated) energy refurbishment**; generating a dynamic and contemporary image of the housing and the surrounding area, while respecting bioclimatic principles; improvement of the overall internal environment quality while dealing with the daily life of its inhabitants; providing a unique response to the façade design to break its rigidity while respecting the historical legacy of modernist architecture.

Deep Energy Renovation of a building implies energy renovation which minimizes the energy needs of the building to the level of zero or net zero energy and presumes simultaneous integration of technologies using renewable energy sources in, on or near the building itself to provide satisfaction to all residual energy needs. ^[4]

Methodology

Conducted study encompassed an analysis of building's structure, definitions of several scenarios and models of the building's architectural renovation, investigation of the potential energy refurbishment models and EEI measures.

The framework for methodology included:

1. Recollection of the technical data from new Belgrade's historical archive for case study building. In-depth analysis for the existing state of the case study building.
2. Creation of a building model for simulation of the existing status of the asset, considering initial design of the building with its original materials and thermos-physical properties; Every floor and apartment with correspondent thermal zones and subdivisions, clearly indicating heated and non-heated zones; Existing HVAC system (district heating + split air-conditioning) with its respective schedules.
3. Building physics' optimization of all created models.
4. Definitions of scenarios (models) for complex energy improvement used for BPS-Building Performance Simulation using DesignBuilder software ^[5] for the typical meteorological year (TMY) of Belgrade. (Belgrade has a moderate continental climate with average annual air temperature of 11.7°C. Winter is not so severe, with an average of 21 days

with temperature below zero. January is the coldest month, with average temperature of -0.5°C . The hottest month July has an average temperature of 21.7°C and the highest officially recorded temperature was $+43.1^{\circ}\text{C}$ on 24 July 2007). ^[6] Simulation is performed on the whole building, output intervals are daily and simulation period for the whole year.

5. The best model was determined after results evaluation (indoor comfort parameters, heating and cooling loads, annual energy demands, internal loads of lighting, people and home appliances, sanitary water heating, primary energy demand) obtained in the previous step.

Household existing status

The building is located in the "Block 70" in New Belgrade, in the street Omladinskih Brigada 164-174 (**hereafter OB172**) was selected as a “case study building”. A four-storey building with a useful area of 6683 m^2 , it consists of three wings that form a “U” shape in the floorplan (**Figure 2(b)**), with attached one-floor garages at corners, and with one substation of BE-DHS for all six entrances. It was selected as one of five typologically different buildings in the neighborhood of block 70.

Figure 2. Building section (a) and ground floor (b), 1-4th floor plan (c) and street façade (d)

The current status shows obvious façade deterioration due to negligence and a series of changes carried out by tenants, such as closing terraces by glazing and illegal

openings causing disruption of the façade. The roof covering layer is not reconstructed from the date of construction; only marginal repairs were made to roof water infiltrations that have not been repaired completely. Approximately 80% of apartments have split air-conditioning units installed differently on the façade. Almost every flat on the ground level has extended differently its garden surface at the expense of the public garden area between three building wings, making an image of disorder at exterior level. (Figure 3)

Figure 3. Current state of the façades of the case study building

Models and scenarios of the building's energy renovation

After the preliminary study of the existing building and the possible passive EEI and architectural measures to be applied on each case study building, the following models-scenarios were created. Building performance simulations were done for the following models of building **OB172**: the **EB** – existing building model based on the original design and a group of six models. Models **IB1-IB3** models of existing building volume but thermally improved envelope (Improved Building): (**IB1**- model in accordance with JUS-previous Serbian standard [7], **IB2** - in accordance with the German standard [8], **IB3** - in accordance with the most recent Serbian standard [9], **IB4** - Model with enhanced "U" coefficients of the model **IB3**, a glazed terrace and green roof; **IB5** - Model with coefficients **IB4**, with improved program in the ground floor facilities as garages and storage rooms ; **IB6**-improved model over the **IB5** with ventilated façade on the outside facade east and west side.

Table 1 presents the heat transfer coefficient “U” [W/m²K] of the building's main structure elements.

Table 1. Heat transfer coefficient U of the building's structure elements

Models	EB	IB1	IB2	IB3	IB4	IB5	IB6
Structure elements	Heat transfer coefficient U [W/m ² K]						
External wall 1	1.66	0.54	0.38	0.28	0.28	0.28	0.28
External wall 2	1.93	0.61	0.4	0.19	0.38	0.38	0.38
Ground floor	1.2	0.66	0.26	0.26	0.26	0.26	0.26
Roof	2.34	0.36	0.41	0.24	0.24	0.24	0.24
Window	3.20	1.5	1.5	0.8	0.8	0.8	0.8

Energy optimization results of the low-rise prefabricated building

Simulation results for upgraded models are presented in diagrams in Figures 4, 5 and 6. Presented simulation results of different types of final energy demand in Figure 4 (a), show that the building's current state has the biggest heat losses from air infiltration, exterior walls without insulation and windows. Figure 4 (b) clearly shows the savings achievement in the final simulation model IB6, in different final energy demands compared to the current state.

Figure 4. (a) Annual energy demand for different purposes - building's current state and (b) Annual energy demand for different purposes - building's final optimized model IB6

Figure 5 clearly presents improvement in heat losses (44%) and in heat gains (42%) of savings for the last two models – IB5 and IB6.

Figure 5. Specific heat losses and specific heat gains in W/m²

The diagram in **Figure 6(a)** shows that reduction of specific annual cooling consumption by 38% is achievable by upgrading the façade envelope, but increasing the thickness of insulation to a certain level brings a jump up in related cooling values (model IB4). After applying other measures, like placing a well-ventillated facade, 34% of savings is achieved (IB6). **Figure 6(b)** also shows that specific annual energy needs for heating can be reduced by 57% (IB4) only treating the building envelope, while the application of other measures reaches 59% savings (IB6). This result is very important confirmation that the energy optimization must be performed as a whole year analysis of the energy needs of the building, both for heating and cooling in a climate of Belgrade and Serbia.

Figure 6. Specific annual consumption: (a) Cooling, (b) Heating

A similar study conducted in 2009 for the four-floor building situated at 23–35 Aleksinackih Rudara Street/New Belgrade ^[10], with the similar structure and typology as case study building OB172, shows that the annual energy consumption for heating might be reduced by four times only by improving the façade envelope, and required cooling or air-conditioning power indicates possible decrease of the same by about five times. This building was an object of the research of several potentially interesting models for the implementation of the measures intended to improve energy efficiency

and identify a possibility of optimizing the energy efficiency of the existing residential building for the RES integration.

Architectural measures

Presented scenarios studied globally, a part from sustainable EEI measures, local construction practices, and gave models of improvement suitable for this region. The proposed solution for the energy renovation of the building envelope includes the installation of thermal insulation composite system, window and door glazing and carpentry replacement (from single glazing to double (**IB1**, **IB2**) and triple low-e glazing (**IB3**)), and implementation of ventilated façades / **IB6** / on the east and west.

Model **IB4** proposed to change the roof into extensive green roof which have a big influence on the thermal inertia of the building and resolves the issues of the current rainwater infiltrations. Green roofs have been shown to impact positively on a building's energy consumption by improving the roofs thermal performance. ^[11] These areas could be used as community areas for the tenants.

One of the essential elements proposed was the glazed enclosure of the balconies, which affected on global change of appearance of the building envelope, by means of sliding glass elements, which creates a thermal buffer zone in the winter (**IB4**, **IB5**, **IB6**). Ventilation and daylighting are not compromised by such intervention and shading devices are incorporated to improve comfort in summertime. Anyway, intensive ventilation is required to prevent additional heat overload.

In the complex of the building **OB172** tenants mainly use garages as storage rooms, poorly maintained, whose promotion and change of utility - for example, to sports centres, recreational areas, shops or just for rent - would raise the aesthetic level of the building and of course the residents' standard of living.

The public space between the wings, to which all terraces are oriented, is initially designed as a park and playground for kids, but is currently pretty much abandoned. It is possible to install a greenhouse with lightweight construction for growing plants and vegetables which, besides its environmental advantages, could encourage tenants to participate in the maintenance of the building and its surroundings, and has added value to the asset, but it's necessary to be restored. The advantage of this building typology is better integration of the building with the environment and surrounding, providing greater comfort of tenants.

One of the major benefits of the rehabilitation of the low-rise buildings, as in the case with **OB172**, is the possibility to build one or two floor levels over existing floors, depending on the structure, which can solve the roof leaking problems and also can financially contribute to the renovation itself. Proposed models of improvements did not consider this intervention because the objective was to look for minimum building surface increment.

Although residents tried to achieve their needs for internal space redesigning on their own, all those interventions should be reconsidered in eventual future renewal activities. Any future refurbishment actions should be based on structural evaluation as well as potential of multifamily housing quality improvement, in order to achieve optimal service life and durability of buildings.

Building integrated photovoltaic design (bipv) and performance

Conversion of the solar energy and other renewable resources to electrical energy is of high interest due to the big electricity demand in buildings, and integration of the renewable energy's technologies has an important role in providing a long-term energy supply.

Serbia has average annual energy influx of global solar radiation on horizontal surface of 1,387 kWh/m² and the sun shines 2096 hours per annum. The solar radiation average is around 40 per cent higher than the European average. The building location is 44°47'54"N 20°23'49"E, elevation - 80 m above sea level, with annual irradiation on horizontal plane per day -3630 (Wh/m²/day), on optimally inclined plane - 4130 (Wh/m²/day) and on plane at angle 90 degrees - 2760 (Wh/m²/day) ^[12].

Concerning the construction works and existing building structure statics, low weight PV cells and the PV system's simplicity would make it the most appropriate of the solar technologies candidates to be integrated in the renewed façade.

Surfaces for the façades' PV arrays integration have been determined, taking into account existing obstructions to the incident solar radiation. In the case of this low-rise building, implementation of a grid-connected subsystem of Building Integrated Photovoltaics (BIPV) was taken into account, meaning PV modules integrated into the building envelope surfaces, such as the roof and façades, properly oriented towards the sun, which simultaneously serve as envelope material and save the cost for external rendering layers. The BIPV integration system was defined: Integration of the BIPV on the outer façade within the ventilated façade (90°) on the east and west, resulting in 44.30 MWh (Table 2) potential annual PV produced electrical energy. Available areas on the roof level with PV array optimal inclination, resulting in 93.66 MWh (Table 2). For the glazed terraces overlooking the garden, PV installation is not proposed because of aesthetic reasons, keeping the built-in pots as a part of the building's identity. In the case of a low-rise building of this type, more area for PV integration is available on the roof, which has no obstruction in insolation, while efficiency of the façade-integrated panels is affected by the greenery/trees which are positioned along the façade.

Table 2. PV panel areas, installed PV power and produced electricity

	Pv type- Sharp ND-Q0E7H Solar Panel			
	PV panels (m ²)	Installed power [kW]	Produced electricity (kWh/m ²)	Produced electricity (MWh)
Roof – South (33°)	577.71	70.56	162.06	93.66
East (90°)	243	29.6	91.13	22.15
West (90°)	243	29.6	91.13	22.15
South (90°)	0	0	0.00	0.00
Total	1063.71	129.76	344.32	137.96

Figure 7 shows the current state of the building (a), possible integration of the BIPV (b) and glazed terraces overlooking the public garden (c).

Figure 7. (a) Existing façade, (b) BIPV panel integration (outer façade), (c) Glazed terraces overlooking the interior garden

Conclusion

The presented preliminary results more than convincingly confirm and emphasize the significance and magnitude of possible effects of the project implementation, not only on the energy of residential buildings, but on the entire complex energy consumption in New Belgrade.

Minimizing energy loads by "passive" actions is the first step of the bio-climatic renovation of residential buildings, which has to be complemented by integration of the RES energy sources to be able to approach zero energy status.

Simulation results stressed possible heating reduction by 60% only by "passive" actions, and further intervention by HVAC EEI measures could provide more reduction over IB6 model, by improving heating system with mechanical ventilation with heating

recovery. Cooling loads can be minimized by 38% even without changing existing HVAC system. Optimizing energy refurbishment measures for a different building types is of crucial importance, so the existing building stock can be treated in a systematic manner in order to achieve full energy savings potential.

Using existing buildings rather than demolishing and building new structures preserves their embodied energy, decreasing primary energy use and, therefore, atmospheric carbon dioxide emissions.

The implementation of the preliminary architectural and EE improvements in the building would have the following additional benefits: increase of the flat (housing space) market value and positive social effects and incentive resident's awareness on energy consumption. EE measures targeted at buildings can also improve higher IA (indoor air) and indoor environment (IE) quality, with corresponding health benefit. In addition to direct cost savings, sustainable refurbishment can provide indirect economic benefits to both the building owner and society.

Creating a new image of the environment, with dynamic changes in the architecture and promising possible energy improvements, this case study building is a good reference for refurbishment practices in this neighbourhood. With its great architectural and urban potential, New Belgrade is a municipality with huge opportunities for energy savings, and could be a leader in RES, particularly BIPV energy renovation of existing residential buildings.

Acknowledgement

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Declaration

The Authors declare that there is no conflict of interest.

References

- [1] Todorovic S. M.: Large Scale Residential/Municipal RES Integrated Refurbishment Construction and HVAC Systems Engineering R&D Needs, PUBLISHED ASHRAE Transactions, Volume 118, Part 1, 2012.
- [2] Atanasiu B. Principles for nearly zero-energy Buildings. Buildings Performance Institute Europe (BPIE), Belgium, 2011
- [3] Matic, D.; Todorovic, M.S.; Roset, J. RES integrated refurbishment of prefabricated building in Belgrade, Serbia. A: REHVA World Congress. "Clima 2013: 11th REHVA World Congress & 8th International Conference on IAQVEC: energy, efficient, smart & healthy buildings: proceedings". Praga: 2013, p. A0971-1-A0971-11.
- [4] Joyce A The Fundamental Importance of Buildings in Future EU Energy Saving Policies, REHVA Journal 2010; 47(5):14-22.
- [5] Design Builder software, <http://www.designbuilder.co.uk/> (Accessed 15 August 2013)

- [6] <http://www.beograd.rs/en/discover-belgrade/201193-climate/> (accessed 10 October 2013)
- [7] JUS U.J5.600:1998, Heat in civil engineering - Requirements for design and manufacturing of buildings National registry: 7/98 (19.01.1998.), Belgrade ,Serbia (Previous Serbian standard).
- [8] EnEV2002 (Energieeinsparverordnung 2002), Federal Gazzete, Bonn, Germany (01.02.2002.)
- [9] SRPS EN ISO 13790:2010 Energy performance of buildings - Calculation of energy use for space heating and cooling (ISO 13790:2008). Institute for standardization of Serbia, National registry: 06/10 (29.01.2010.), Belgrade, Serbia
- [10] Todorovic SM, Ilincic N, Martinovic I.and Ecim O. Photovoltaic Integrated Energetic, Architectural And Constructional Optimization Of Existing Residential New Belgrade's Buildings, SMEITS. HVAC Journal 2009; 3: 41-49.
- [11] Castleton HF, Stovin V, Beck SBM, Davison JB, Green roofs; building energy savings and the potential for retrofit, Energy and Buildings,42 (2010) 1582-1591
- [12] (PVGIS). Photovoltaic Geographical Information System.
<http://re.jrc.ec.europa.eu/pvgis/imaps/index.htm> (Accessed 10 March 2013).