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Abstract: The main objective of the presented paper was to evaluate the integrated design strategies applied in refurbishment of the prefabricated residential housing, erected in '70 in the New Belgrade, Serbia, in order to achieve energy savings accompanied with reduction of CO₂ emissions and improvement of households' health and comfort. Conducted study led to the preliminary design of energy refurbishment of the existing building, and its conversion to energy efficient building with minimized loads. Building's dynamic behavior and energy efficiency have been optimized implementing BPS-Building Performance Simulation. Very significant reduction of thermal and cooling loads with the reference to the building's existing status is obtained. Refurbishment encompassed comprehensive optimization of building's envelope structure, natural and mixed ventilation. The implementation of a series of EEL (energy efficiency improvement) measures resulted in significant reduction of buildings energy loads. The investment in energy efficiency retrofitting can improve macroeconomic stability and contribute to the sustainable economic growth. Furthermore, economic analyses were performed for each model, considering present economic situation in Serbia and availability of funds for refurbishment. Presented methodology and results of the performed analyses offer an opportunity to extend their application to other neighborhoods, exploring refurbishment potential results if applied on a greater urban scale.

Economically feasible Energy Refurbishment of Prefabricated Building in Belgrade, Serbia

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The main objective of the presented paper was to evaluate the integrated design strategies applied in refurbishment of the prefabricated residential housing and their economic feasibility, considering current economic situation in Serbia. The aim of the study is architectural re-design using "passive" and "active" measures to improve and optimize the energy efficiency of residential buildings.

Design strategies were applied in order to achieve energy savings accompanied with reduction of CO₂ emissions and improvement of households' health and comfort. By BPS - Building Performance Simulation were analyzed effects of the implementation of a series of EEI (energy efficiency improvement) measures and they resulted in significant reduction of buildings energy loads. Considering present economic situation in Serbia and availability of funds for refurbishment, by analyzing these six different energy efficiency retrofitting models, valuable inputs were obtained for further development of economic models. The results clearly prove that every retrofit scenario is economically feasible.

The corresponding author's publication "RES Integrated Refurbishment of Prefabricated Building in

Belgrade, Serbia" on the Rehva World Congress, Prague 2013, with co-authors Marija S. Todorovic and Jaume Roset Calzada, encompassed comprehensive optimization of building's envelope structure, natural and mixed ventilation, HVAC system and locally available solar (BIPV), on the case study building. The previous study did not include economic analysis of the proposed measures, which were covered in detail in submitted paper.

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1. INTRODUCTION: ENERGY REFURBISHMENT OF RESIDENTIAL BUILDINGS

Increasingly, we are witnessing "weather extremes" with catastrophic consequences. Numerous experts in the field of climatology believe that these events are meteorological - geological manifestation of global warming. Depletion of fossil energy resources, climate change and environment pollution threaten the life support systems on Earth. To stop further progression of these irreversible processes, necessary is further to be developed RES (renewable energy sources) technologies, proceeded with the spreading of their utilization. However their efficient and cost-effective implementation must be preceded by the improvement and optimization of energy efficiency. All kind 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 the overall energy use, and the fact that extremely large potential savings can be obtained particularly in buildings [¹].

After the first energy crisis in 1973 and raised concerns about exhaustion of fossil fuels, most building standards concentrated on energy efficiency, and not any more only on health, safety and occupant comfort. First political acts were brought to America in 1975, (*ASHRAE published Standard 90-75*), and then in Germany in 1977, when the first German regulations on energy saving energy in buildings were introduced [²]. The European Union has played an important role in the development of two major acts, in 1992. The United Nations Convention on Climate Change (UNFCCC) and the Kyoto Protocol, adopted in 1997, under which countries ratify to take target values of quantified emission reduction (GHG) in a certain time. The Kyoto Protocol entered into force in Serbia on 16th February 2005. Until now more than 170 countries have joined it.

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. In 2010, EU did adopt the transposition of the first directive in the form of document (EPBD 2010/31/EU). This innovated EPBD document requires from every Member States to establish new plans to improve the energy efficiency of buildings by introducing a new methodology called "cost optimality" analysis. 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, 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 to win these challenges, and without any doubt their great numerical superiority in relation to the new buildings, represents a major sector for achieving overall goals for energy savings and reduction of Serbia's CO₂ emissions level, as well as globally.

Newly built buildings designed by bioclimatic and self-sustainable principles in architecture are to contribute significantly to the reduction of CO₂ emissions, in particular Zero energy buildings, and even more Energy Plus buildings which have a positive energy balance (the building produces more than it consumes). However, only the reduction of CO₂ emissions that comes from the deep energy refurbishment of the existing buildings, can compensate, in a certain way, an additional increase of CO₂ emissions due to the construction of new buildings - related to the embodied energy of production of materials, components, as well as use of construction machinery, during the construction process of new buildings.

2. NEW BELGRADE'S RESIDENTIAL BLOCKS

The municipality of New Belgrade, one of the 17 districts in Belgrade, occupies 4.096 ha and consists of 72 blocks. The basic physical characteristics of the area's flat terrain are total of 3.47 km² green spaces, which represent 8.5% of its surface. Most of these buildings are residential, apartment buildings built after the World War II, between 1950 and 1980. That was a period of the intensive socialistic construction style of work, and general architectural - modernist approach of that period gave rise to a large number of prefabricated residential buildings, nowadays characterized by the excessive final energy demand. **The aerial view (Figure 1- left) shows the urban planning of these residential blocks and one of the typical façade (Figure 1 – right) nowadays. Most of these buildings didn't have any sort of reconstruction or refurbishment from the beginning of its life cycle.**

Figure 1. Residential blocks in New Belgrade

Architecture and urban planning principles used to design and build New Belgrade, with modest reduced-size of apartments, with spacious green areas between blocks of buildings and natural ventilation, coincide in many points with the current sustainable urban development approach that promotes quality of interior and exterior living space with minimal impacts on the environment.

Unfortunately, the last 20 years, many new buildings were built outside the context of the architectural and urban heritage of New Belgrade, and with improper behavior of the tenants to the building and its surroundings. 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 facades, side by side.

Majority of these buildings have oversized secondary heating systems and boilers or substations if connected to the Belgrade DHS - district heating system. An, recent in depth analysis of measurement and monitoring results of delivered heating energy to the whole building stock within the Belgrade DHS did show that the average values of the annual specific heating consumption (period 2006-2008) was 123 kWh/m² (measured max 253 kWh/m², and min 66 kWh/m² [3]).

During the time, lack of interest of the tenants for building maintenance and improvement, their social and economic status has led to obvious physical deterioration of residential buildings. To restore the previously existing identity of New Belgrade, which these objects make, it is necessary to find an adequate solution for the revitalization and architectural refurbishment, not only in terms of important energy demand and CO₂ emission reduction, but overall improvement of the life conditions and socio - cultural aspects.

There is indispensable necessity to change, unfortunately growing culture and mentality of the typical consumer lifestyle characterized by selfish indifference for other human beings and environment. Adequate initiatives, the availability of information and dissemination of knowledge is a requirement for changing behavior and the formation of environmental awareness and ethical tenants, which should bring the necessary changes, including harmonization of social relationships of the tenants, especially the younger generation, as well as their attitude towards the environment. .

3. AIM OF THE STUDY

The aim of the study is architectural re-design using "passive" and "active" measures to improve and optimize the energy efficiency of residential buildings and bring them to the quality level which could lead to further advanced development of energy-efficient building construction until reaching zero energy status, set as a goal to be achieved around 2020 in the EU: the minimum possible energy needs, simultaneously improving comfort and overall internal environment quality, using affordable and accessible technologies, respecting bi-climatic design principles and historical legacy of modernist architecture.

The building located in the "Block 70" in New Belgrade, in the street Jurija Gagarina 73 (hereafter JG73) was selected to serve as "case study building". 14-storey building with useful area of 6725 m², and conditioned

area of 5934 m², with an entrance on the east side and one substation of district heating system "Beogradske elektrane," was selected as one of five typologically different buildings in the neighborhood of block 70.

Energy refurbishment project aim, of the selected building, was to advance the understanding of the energy revitalization process at a larger scale and related scope, the impact on the context of the entire housing "Block 70", and in the end to expand this boundaries on the other blocks of New Belgrade, and thereby acquiring and spreading awareness about the possibilities of reducing CO₂ emissions along with simultaneous improvement of general living conditions in the buildings typologically similar to this example.

Conducted case study encompassed an in-depth analysis of building's structure, definition of several scenarios and models of building's architectural renovation, investigating possibilities to implement several potential validated energy refurbishment models with various measures to significantly improve and optimize building's energy efficiency, and approaches their zero energy status.

Methodology implemented in this included as follows:

1. Collection of architectural and other technical data from the New Belgrade's historical archives for the case study building,
2. Creation of the models for simulation of thermal - energy behavior of the case building in its different states, starting with initial design (1972) with the original materials, volumes, surfaces, etc., and proceeding with models related to the different level of building's improvements.
3. Analysis and energy related optimization of building physics of all created models.
4. Definition of scenarios – models of complex improvement (building structure and HVAC and other technical systems (TS), including energy supply system, and creation of computer models for each of the proposed scenario/models.
5. BPS-Building Performance Simulation: dynamic simulation of the integrated building's/HVAC and TS, energy behavior 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 was +43.1 °C on 24 July 2007).** [4]
6. Determination of the best scenario/model based on the analysis of results obtained in previous step (St.5) and evaluation of:
 - indoor comfort parameters: air temperature and relative humidity,
 - heat losses and heat gains: lighting, people and home appliances, and external solar heat gains,
 - annual final energy demand for heating, cooling, domestic hot water (DHW), and electricity,
 - annual primary energy demand for different purposes and total.

Simulations were conducted using DesignBuilder software. [5]

After definition of the refurbishment scenarios, economic feasibility of the actions will be analyzed.

4. HOUSEHOLDS STATUS IN RESIDENTIAL BUILDING "BLOK 70"

The current state of objects "case study building", in block 70, shows results of a series of actions that are carried out by tenants over the years, such as closing terraces by glazing, renting the premises in the ground floor in order to finance the maintenance of the building; adapting a pantry in the ground floor for residential use; illegal extension in the attic at the expense of the common terraces (this action probably contributed to solving the rainwater and moisture infiltrations on the roof level), the uncontrolled reconstruction of individual apartments, which led to new window openings which caused disruption of the façade, etc. / Figure 2 /.

Specifically at the case study building - object JG73 about 60% of balconies are glazed and too many external units for air-conditioning (approx. 80 % of apartments have split air-conditioning units on the facade and their different ways of positioning ruin the overall look of the building. The roof covering layer is not reconstructed from the date of construction, only were made marginal repairs of roof water infiltrations that have not been solved completely. In the other neighbor buildings, of the same typology, residents (on their own initiative) reconstructed the roof by placing a thermal and hydro insulation, funding from the tenant's budget, and in some cases with a little help from the City Housing Agency that barely meets the basic needs of maintaining about 200,000 flats, for what is in charge.

Figure 2. JG73's facades with visible Illegal housing extension at the attic level; illegal opening on the façade.

5. MODELS AND SCENARIOS OF BUILDING'S ENERGY RENOVATION

Building performance simulations were done for the following models of object JG73: EB - building model based on the original design and a group of six models: Models IB1-IB3 – existing building volume with improved heat transfer coefficients – U [W/m^2K]:

- IB1- model in accordance with JUS [6],
- IB2 - in accordance with the German standard [7],
- IB3 - improved HTC comparing to IB2 and in accordance with the most recent Serbian standard [8],
- IB4 - model with enhanced HTC comparing to the IB3, with the extension of the new residential space in the attic and a green roof;
- IB5 - model similar to the IB4, with the additions of the upgraded functions in the ground floor and glazed terraces (greenhouses)
- IB6-improved over the IB5 with the well ventilated facade on the south and west.

Table 1 presents the heat transfer coefficient HTC [W/m^2K] of the building's structure main elements.

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

Scenarios - MODELS	EB	IB1	IB2	IB3	IB4	IB5	IB6
Structure elements	Heat transfer coefficient $U[W/m^2K]$						
Outer wall 1	1.53	0.52	0.52	0.37	0.37	0.37	0.37
Outer wall 2	2.57	0.61	0.61	0.38	0.38	0.38	0.38
Outer wall 3	1.14	0.47	0.47	0.35	0.35	0.35	0.35
Ground floor	3.89	0.66	0.66	0.33	0.25	0.25	0.25
Roof	0.67	0.36	0.36	0.20	0.20	0.20	0.20
Window	3.16	1.50	1.00	1.00	1.00	1.00	1.00

The facade of the building is built with the three different layers - external walls: precast concrete element - the parapet, placed below the opening in the facade, a wall of clay bricks and reinforced concrete wall with no insulation. Building envelope and the flat roof of the building during the time were attacked by moisture penetration, which is most prominent on the top floor. Presenting different kinds of final energy (for the current state and final optimized state) in Figure 3, simulation results of the current state indicate that the biggest heat losses come from air infiltration, exterior walls without insulation and windows (annual energy demand for heating shown in diagram in Figure 3). **Given value of the simulation results for heating energy demand of the current state of the building (EB=750.05 MWh) is very close to the measured energy consumption in the case building substation of the Belgrade District Heating System (760.88MWh), which confirms the credibility of the simulated model.**

Figure 3. Annual energy demand for different purposes - building's current state EB (up) and final optimized state IB6 (down)

Simulation results for the updated models are shown in the diagrams in Figures 4 and 5. Figure 4 shows that the Heating total design capacity can be reduced by 52 % (IB6). Heating consumption is reduced by implementing thermal insulation in the building envelope and replacing window glazing by 50% (IB3), and that further improvements lead to a reduction of 73% (IB6). (Figure 5)

Figure 4. Heating total design capacity of different building's refurbishment scenario models (left) and Cooling total design capacity (right)

Diagram in Figure 4 (right) shows that reduction of cooling total design capacity by 30% can be achieved by improving the façade envelope with new thermal insulation. By further increasing of the thickness of insulation, it can be noted a "jump up" in design capacity and load for models IB3, IB4 and IB5.

This result is very important confirmation that the energy optimization must be performed as whole year analysis of the energy needs of the building, both for heating and cooling in a climate of Belgrade and Serbia, what regulations and the certification of the energy performance of buildings in Serbia currently does not provide. Optimization must take into account the energy performance of buildings in both extremes and the essence of sustainable design is to find solutions that will help to reduce energy loads for heating and cooling, along with simultaneous availability of daylighting to minimize the need for lighting electricity.

By placing a well-ventilated façade is achieved significant energy savings for refrigeration, up to 35% (diagram in Figure 5). Accomplished savings in electricity consumption for lighting is almost 2 times comparing to the original model, as replacing existing lamps with energy saving lamps with control the intensity (diagram in Figure 5-left). CO₂ emissions per year were reduced by 1.5 times compared to current state condition, from 58784.44 to 38833.88 kg/m² (a). Specific heat losses and specific heat gains in W/m² are presented in Figure 5(right).

Figure 5. Specific annual consumption- heating, cooling and lighting (per m² of occupied space)(left) and specific heat losses and specific heat gains in W/m²(right)

6. INTEGRATED ARCHITECTURAL EEI MEASURES

Architectural measures. The proposed optimal solution to the energy renovation of the building envelope includes the installation of thermal insulation, window and door glazing and carpentry replacement, and implementation of ventilated facades / IB6 / on the south and west, which greatly contributes to reduce heat gains in summer.

In addition to energy renovation are also considered options to improve the building in architectural terms, adding new features and functions in the ground floor and on the roof, bearing in mind changes that residents themselves have done over the years and how much they can contribute to the improvement, if implemented and controlled by considering entire building.

The scenario model IB5 and IB6 propose terrace glazing, transforming them into greenhouses, with the possibility of integration of photovoltaic panels in the parapet area (on the south and west facade) and setting semi-transparent glazing. Certain areas in the ground floor that tenants use for the purposes of storage, with current state very neglected, functionally could be changed into common laundry area, game room for children or gymnastics and recreational area for adults.

Reviving roofs by greening, not only solves the rainwater infiltration problems, but could open possibility to rainwater collection and recycling, and use of these areas as a common space for all the necessary socialization today, which can enjoy all the tenants of the building. Adding an optional Roof Top Greenhouses with a light weight construction, as urban agricultural garden, has a large contribution to reducing CO₂ emissions. [9]. Re-designing these spaces and their activation, a part from environmental, has a social contribution- to encourage residents to participate in maintenance of the building and raise their awareness about environment.

7. THE ECONOMIC RATIONALE FOR ENERGY REFURBISHMENT INVESTMENT - METHODOLOGY OF THE ECONOMIC ANALYSIS

Feasibility of refurbishment actions needs to be perceived and analyzed within the existing economic outlook of Serbia. The economic crisis in Serbia reopened and amplified old structural problems [10] and it is certainly difficult to estimate when the period of sustainable economic development and growth will recommence. The economic recovery had not happened in the previous 5 years and the additional measures are now needed in order to stimulate economic growth and to improve the trade balance and decrease the unemployment rate.

The need for improvement of resource management is strong in countries that rely heavily on the import of the necessary resources. This is definitely applicable in the case of Serbia, a net importer of energy. Serbian energy balance is deeply affected by the weather conditions and without the implementation of retrofitting and energy savings schemes, Serbia would remain very vulnerable. The official estimates show that 83% [11] of the Serbian natural gas demand in 2013 is imported, mainly from Russia with supplementary amounts from Hungary and Switzerland. Serbia is traditionally [12] a net importer of electricity due to the widespread use of electricity for heating in wintertime and cooling in summertime. Comparison of the statistical data on natural gas and electricity trade balance [13] for 2012 and 2013 brings us to conclusion that the trade account deficit has been decreased by 407 million dollars, which equals around 1% [14] of the GDP. Such high level of energy consumption volatility provides an additional argument for state intervention and private sector involvement in energy efficiency retrofitting projects implementation in Serbia. The investment in energy efficiency retrofitting can improve macroeconomic stability and contribute to the sustainable economic growth [15].

The following assessment of the different microeconomic effects by applying six different energy efficiency retrofitting models provides valuable inputs for further development of economic models.

For all calculations average mid-value exchange rate of the National Bank of Serbia for 2013 was used, 1€ = 113.14 dinars. [16] To calculate price of heating energy, the following values were used: $P_{hn} = 12.091\text{€}/\text{m}^2$, $P_{hf} = 4.335\text{€}/\text{m}^2$, $P_{hv} = 0.06028\text{€}/\text{kWh}$. [17] Reduced rate of the value added tax (VAT) of 10%, which is applied for heating energy, [18] is included. For the purpose of financing the renovation and retrofit, the interest rate used is 8.303%. This is the arithmetic mean of interest rates of publicly available energy efficiency related lines of credit from three major banks in the country. [19,20,21] Down payment required is taken at 16.67%, as some banks ask for larger portion to be paid in advance, whilst some waive this request entirely.

Two distinct financing models are applied – one where owners bear the entire cost of the retrofit, and the other where a commercial loan facility is used. Also, a government subsidy is considered. As there are no subsidies presently available, although certain announcements in this regard have been made, [22] we decided to assume that this subsidy would be conservative, i.e. fiscally neutral and would amount to the VAT that would have been collected for the retrofit – the 16.67% down payment.¹ This cash subsidy would be returned to the government during the course of the retrofit, as VAT is being charged for construction works and material; at the end of the retrofit, the government would have received its money back.

Savings which are the outcome of the retrofit are calculated solely as the reduction in the heating energy bill, i.e. the summer electricity bill which reflects the energy used for air-condition split systems for cooling, is not taken into account – in part due to low prevalence of split systems elaborated by Bojić et al., [23] but additionally, as there is no reliable data with regard to how much electric energy is spent for cooling during summer months in this building. Evidently, taking these saving into account would simply make the investment more viable.

Reduction of the heating bill is calculated as $C_C - C_R$.

Furthermore, we assume that the building will switch to payment according to consumption prior to the end of the retrofit process. Otherwise, any investment would be unreasonable, as ROI would stand at 0%. The difference between C_C and C_N is also worth observing, as it might influence C_C prior to the retrofit, once tenants realize how their habits can impact the heating bill. Currently, the entire building is charged $C_N = 60,775\text{€}$ annually; so as to maintain the same level of comfort, should the building switch to allocated cost model, the charge would amount to $C_C = 65,361\text{€}$ annually. These figures include the 5% discount consumers are entitled to if they pay their bills on time. Therefore, using C_C increases value of the investment slightly, yet in time all consumers are expected to migrate to one of the pay per consumption models, rendering C_N obsolete.

The methods used for economic analysis of the retrofit measures are the Net Present Value (NPV), the Simple Payback period (SPB) and the Depreciated Payback Period (DPB). While researches, such as Malatji et al. [24] use more advanced methods to measure the cost effectiveness of multiple retrofit alternatives, the options given in this paper (IB1-IB6) are predetermined, not a menu to choose from. This is why simpler methods, as in Nikolaidis et al., [25] are being applied and NPV and DPB are calculated for each of the retrofit actions. Formula used for determining the NPV is:

$$NPV = -I_0 + \sum_{t=1}^n \frac{F_t}{(1+p)^t}$$

where t is the time period, one year, I_0 the discounted value of the entire loan with added interest, i.e. the initial investment, F_t the net cash flow for the year t (difference between benefits and costs), p the price of capital and n the number of years for which the analysis is performed.

As in Verbeeck et al., [26] we assume that the life cycle of the investment is 30 years and no additional assumptions are made on the destiny of the building after the year 30, whether it should be retrofitted again, demolished or left in current state. NPV does not take into account any value the retrofit actions might have at the end of this cycle of 30 years, corresponding approximately to one generation.

SPB and DPB are used for illustrative purposes only, as the choice of the economically soundest investment is made by way of NPV. While payback periods cannot reveal the (future) value of an investment, it does show how much time is needed to recover I_0 , given the price of capital p ² and the net cash flow F_t , which is considered to be unchanged for every t :

$$DPB = \frac{-\ln(1 - \frac{pI_0}{F_t})}{\ln(1+p)}$$

¹ 16.67% is equal to VAT revenues generated from the cost of the refurbishment action

² p is considered only in the DPP

$$SPB = I_0/F_t$$

Furthermore, due to economic constraints, commercial loan facility might have to be used, if the amount for I_0 is not available in advance. This is why I_0 denotes a sum of down payment required (which is omitted if the government subsidy is available, as we are evaluating investment from the point of final consumers) and the present value of future annuities:

$$I_0 = A_d + A_l \left[\frac{(1+p)^n - 1}{p} \right] * (1+p)$$

where A_d is the down payment, A_l the annuity due each payment cycle, a month in this case and n is the number of payments due. Price of capital p is adjusted so as to reflect the monthly, rather than the annual interest rate.

In case where the owners bear the cost of the retrofit upfront, I_0 is simply the entire cost of the investment, unadjusted for future value or price of capital.

8. ECONOMIC ANALYSIS AND RESULTS

In Figure 7 we present the fluctuation of the NPV for all the retrofit actions tested, considering a cost of capital of 2.176%. This might seem as a curiously low p , however, this analysis evaluates benefits for final consumers. Having in mind that investment per dwelling is essentially low (approximately 3,735€ for action IB1, 5,913€ for IB6; without interest added), it is hardly conceivable that this limited amount of capital might be used for an investment into a business endeavor. Rather, we have used an interest paid for certificate of deposit in euro, maturing after 36 months, available at a major commercial bank, reduced for payable tax.^[27] This can be further justified by a very low risk premium, entirely comparable to that associated with bank deposits.

Analysis of the NPV of different actions demonstrates, also in Figure 7, that all investments are depreciated at some point – depending on the type of loan and the action – DPB varies from 10.6 to 23.7 years (or 10.2 to 20.2 years using the government subsidy). Also, it points to the fact that the more elaborate (and expensive) the retrofit action is, it will depreciate more quickly – with the notable exception of action IB6, where substantial increase in cost is not met with an equal improvement in energy savings.

Table 2. DPB for all retrofit actions, considering the use and length of the loan and the use of the government subsidy

Loan maturity (years)	DPB (years)								
	Without government subsidy					With government subsidy			
	No loan	5	8	10	15	5	8	10	15
IB1	15.4	18.0	19.6	20.7	23.7	14.8	16.3	17.4	20.2
IB2	13.3	15.3	16.7	17.6	20.0	12.7	14.0	14.9	17.2
IB3	12.8	14.8	16.1	16.9	19.3	12.3	13.5	14.3	16.5
IB4	12.9	14.9	16.2	17.0	19.4	12.4	13.6	14.4	16.6
IB5	10.6	12.2	13.2	13.9	15.7	10.2	11.1	11.8	13.5
IB6	14.4	16.7	18.2	19.2	22.0	13.9	15.3	16.2	18.8

The results of evaluation according to DPB are shown in Table 2 and reveal quite a peculiar situation – every assessed scenario is economically feasible, it is just a question of time or finding a better alternative to invest in. Naturally, DPB is quite sensitive on shifts in p and the accumulated interest that is levied on the energy efficiency loan lines. While the most cost-efficient retrofit action (IB5) takes 10.6 years to depreciate, DPB rises to 15.7 years for a 15-year loan, evidently due to interest paid. The least viable option, although it also ends up being profitable, is the least energy-efficient retrofit model, IB1 – it is depreciated only after 15.4 years (or 23.7 years using the 15-year loan facility).

Table 3. SPB for all retrofit actions, considering the use and length of the loan.

Loan maturity (years)	SPB (years)				
	No loan	5	8	10	15
IB1	13.0	14.7	15.8	16.5	18.4
IB2	11.4	12.9	13.9	14.5	16.1
IB3	11.1	12.5	13.4	14.1	15.6

IB4	11.1	12.6	13.5	14.1	15.7
IB5	9.3	10.6	11.4	11.9	13.2
IB6	12.3	13.9	14.9	15.6	17.3

Simple payback period, naturally yield similar results, albeit with slightly shorter time of depreciation, due to the absence of p . Again, with SPP of only 9.3 years, IB5 is the most cost-efficient retrofit scenario.

Figure 6. Fluctuation of the NPV for all retrofit actions, without using the commercial loan facility or government subsidy, $p = 2.176\%$.

Data presented in Figure 6 clearly proves that every retrofit scenario is economically feasible. Furthermore, the difference in the investments between the IB1 and IB5 is relatively modest (IB5 takes only 20% more money than IB1), while energy savings are substantial. This makes IB5 the soundest investment scenario – it is not the least expensive one, however, even at this low level of energy prices, its economic benefits will surpass that of all other scenarios in no more than 5 years. While IB6 is significantly more expensive investment (33% higher than IB5), it provides merely additional 1pp. of energy savings. This is why its benefits will surpass those of IB1-IB4 only after two decades, but never those of IB5, which clearly remains economically most prudent choice.

It is worth noting that all economic indicators show very similar performance for IB3 and IB4 and it is difficult even to distinguish between these corresponding lines on the figure 7. Having that in mind, scenario with more energy benefits should be chosen for implementation (IB4).

Government subsidy will generally shave off 2 to 3.5 years of DPB, making the investment depreciate faster. Additional subsidies could take different forms, such as applying reduced VAT rate for construction material needed for the retrofitting or subsidizing credit lines in order to offer more favorable interest rates than those commercially available at present.

Perhaps the most significant impact on fluctuation of NPV is from the heating energy prices. They are heavily subsidized by the local governments (in different amounts across the country) as it is, and given the fact that Serbia is not energy independent, these prices are likely to increase over time. In Figure 7, we examine the possible increase in variable part of the price of heating using the heat allocation model – even the slightest increase has a substantial effect on NPV. Prospect of the price increase in the future renders the retrofit even more feasible.

Figure 7. Fluctuation of NPV for action IB5, using a 10-year loan facility with changes in P_{hv} (currently at $P_{hv} = 0.06028\text{€}$), with $p = 2.176\%$.

9. CONCLUSION

Energy renovation of the building in order to increase energy efficiency and reduce energy needs for approaching Zero Energy Status of the building is a complex process, not only a challenge for the mechanical engineers but even more attractive opportunity for building integrated re-design together with architects and civil engineers. Therefore, it should be approached in an organized, pragmatic and interdisciplinary way. The focus should not only be on the latest leading-edge technology, but the synergy of different practices and principles in order to ensure the path to sustainable development and achieve desired objectives.

Minimizing energy loads by "passive" actions highlights that bio-climatic renovation of residential buildings may have an important role but only in the synergy of passive and active means it will be possible to approach zero energy status.

Economic analysis of the presented models shows clearly that the proposed energy-efficient actions are feasible. Considering that the retrofit budget is very similar for all proposed actions (with exception of IB6), regardless of the interest rates or any government subsidies, if the funds are available, economic analysis clearly suggest implementing action IB5, followed by less expensive actions in their respective order. Action IB6, with a larger initial cost, surpasses actions IB1-IB4 only after two decades, but remains inferior to economic benefits of IB5.

Introducing subsidies improves economic performance of the retrofit actions, but they are sustainable on their own. However, investment is repaid considerably quicker if subsidies are available. Finally, should the prices of heating increase over time as is expected, their effect on viability of the retrofit investment is potentially enormous – with every increase, investment becomes more appealing.

Papers ([1], [3], [27]) present potential reduction of heating and cooling energy use by the energy renovation and improvement of indoor comfort in residential blocks, and New Belgrade, with its great architectural and urban potential, is a municipality that could be leader in energy renovation of existing residential buildings. [28]

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Nomenclature

- C_N Heating energy bill, nominal charge
- C_C Heating energy bill, prior to the retrofit, allocated cost model
- C_R Heating energy bill, after the retrofit
- P_{hf} Price of heating – fixed component, annually, (€/m^2)
- P_{hv} Price of heating – variable component, (€/kWh)

P_{hn} Price of heating – nominal charge, annually, (€/m²)
 ROI Return on investment

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Economically feasible Energy Refurbishment of Prefabricated Building in Belgrade, Serbia

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1. INTRODUCTION: ENERGY REFURBISHMENT OF RESIDENTIAL BUILDINGS

Increasingly, we are witnessing "weather extremes" with catastrophic consequences. Numerous experts in the field of climatology believe that these events are meteorological - geological manifestation of global warming. Depletion of fossil energy resources, climate change and environment pollution threaten the life support systems on Earth. To stop further progression of these irreversible processes, necessary is further to be developed RES (renewable energy sources) technologies, proceeded with the spreading of their utilization. However their efficient and cost-effective implementation must be preceded by the improvement and optimization of energy efficiency. All kind 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 the overall energy use, and the fact that extremely large potential savings can be obtained particularly in buildings [¹].

After the first energy crisis in 1973 and raised concerns about exhaustion of fossil fuels, most building standards concentrated on energy efficiency, and not any more only on health, safety and occupant comfort. First political acts were brought to America in 1975, (*ASHRAE published Standard 90-75*), and then in Germany in 1977, when the first German regulations on energy saving energy in buildings were introduced [²]. The European Union has played an important role in the development of two major acts, in 1992. The United Nations Convention on Climate Change (UNFCCC) and the Kyoto Protocol, adopted in 1997, under which countries ratify to take target values of quantified emission reduction (GHG) in a certain time. The Kyoto Protocol entered into force in Serbia on 16th February 2005. Until now more than 170 countries have joined it.

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. In 2010, EU did adopt the transposition of the first directive in the form of document (EPBD 2010/31/EU). This innovated EPBD document requires from every Member States to establish new plans to improve the energy efficiency of buildings by introducing a new methodology called "cost optimality" analysis. 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, 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 to win these challenges, and without any doubt their great numerical superiority in relation to the new buildings, represents a major sector for achieving overall goals for energy savings and reduction of Serbia's CO₂ emissions level, as well as globally.

Newly built buildings designed by bioclimatic and self-sustainable principles in architecture are to contribute significantly to the reduction of CO₂ emissions, in particular Zero energy buildings, and even more Energy Plus buildings which have a positive energy balance (the building produces more than it consumes). However, only the reduction of CO₂ emissions that comes from the deep energy refurbishment of the existing buildings, can compensate, in a certain way, an additional increase of CO₂ emissions due to the construction of new buildings - related to the embodied energy of production of materials, components, as well as use of construction machinery, during the construction process of new buildings.

2. NEW BELGRADE'S RESIDENTIAL BLOCKS

The municipality of New Belgrade, one of the 17 districts in Belgrade, occupies 4.096 ha and consists of 72 blocks. The basic physical characteristics of the area's flat terrain are total of 3.47 km² green spaces, which represent 8.5% of its surface. Most of these buildings are residential, apartment buildings built after the World War II, between 1950 and 1980. That was a period of the intensive socialistic construction style of work, and general architectural - modernist approach of that period gave rise to a large number of prefabricated residential buildings, nowadays characterized by the excessive final energy demand. The aerial view (Figure 1- left) shows the urban planning of these residential blocks and one of the typical façade (Figure 1 – right) nowadays. Most of these buildings didn't have any sort of reconstruction or refurbishment from the beginning of its life cycle.

Figure 1. Residential blocks in New Belgrade

Architecture and urban planning principles used to design and build New Belgrade, with modest reduced-size of apartments, with spacious green areas between blocks of buildings and natural ventilation, coincide in many points with the current sustainable urban development approach that promotes quality of interior and exterior living space with minimal impacts on the environment.

Unfortunately, the last 20 years, many new buildings were built outside the context of the architectural and urban heritage of New Belgrade, and with improper behavior of the tenants to the building and its surroundings. 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 facades, side by side.

Majority of these buildings have oversized secondary heating systems and boilers or substations if connected to the Belgrade DHS - district heating system. An, recent in depth analysis of measurement and monitoring results of delivered heating energy to the whole building stock within the Belgrade DHS did show that the average values of the annual specific heating consumption (period 2006-2008) was 123 kWh/m² (measured max 253 kWh/m², and min 66 kWh/m² [3]).

During the time, lack of interest of the tenants for building maintenance and improvement, their social and economic status has led to obvious physical deterioration of residential buildings. To restore the previously existing identity of New Belgrade, which these objects make, it is necessary to find an adequate solution for the revitalization and architectural refurbishment, not only in terms of important energy demand and CO₂ emission reduction, but overall improvement of the life conditions and socio - cultural aspects.

There is indispensable necessity to change, unfortunately growing culture and mentality of the typical consumer lifestyle characterized by selfish indifference for other human beings and environment. Adequate initiatives, the availability of information and dissemination of knowledge is a requirement for changing behavior and the formation of environmental awareness and ethical tenants, which should bring the necessary changes, including harmonization of social relationships of the tenants, especially the younger generation, as well as their attitude towards the environment. .

3. AIM OF THE STUDY

The aim of the study is architectural re-design using "passive" and "active" measures to improve and optimize the energy efficiency of residential buildings and bring them to the quality level which could lead to further advanced development of energy-efficient building construction until reaching zero energy status, set as a goal to be achieved around 2020 in the EU: the minimum possible energy needs, simultaneously improving comfort and overall internal environment quality, using affordable and accessible technologies, respecting bi-climatic design principles and historical legacy of modernist architecture.

The building located in the "Block 70" in New Belgrade, in the street Jurija Gagarina 73 (hereafter JG73) was selected to serve as "case study building". 14-storey building with useful area of 6725 m², and conditioned

area of 5934 m², with an entrance on the east side and one substation of district heating system "Beogradske elektrane," was selected as one of five typologically different buildings in the neighborhood of block 70.

Energy refurbishment project aim, of the selected building, was to advance the understanding of the energy revitalization process at a larger scale and related scope, the impact on the context of the entire housing "Block 70", and in the end to expand this boundaries on the other blocks of New Belgrade, and thereby acquiring and spreading awareness about the possibilities of reducing CO₂ emissions along with simultaneous improvement of general living conditions in the buildings typologically similar to this example.

Conducted case study encompassed an in-depth analysis of building's structure, definition of several scenarios and models of building's architectural renovation, investigating possibilities to implement several potential validated energy refurbishment models with various measures to significantly improve and optimize building's energy efficiency, and approaches their zero energy status.

Methodology implemented in this included as follows:

1. Collection of architectural and other technical data from the New Belgrade's historical archives for the case study building,
2. Creation of the models for simulation of thermal - energy behavior of the case building in its different states, starting with initial design (1972) with the original materials, volumes, surfaces, etc., and proceeding with models related to the different level of building's improvements.
3. Analysis and energy related optimization of building physics of all created models.
4. Definition of scenarios – models of complex improvement (building structure and HVAC and other technical systems (TS), including energy supply system, and creation of computer models for each of the proposed scenario/models.
5. BPS-Building Performance Simulation: dynamic simulation of the integrated building's/HVAC and TS, energy behavior 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 was +43.1 °C on 24 July 2007). [4]
6. Determination of the best scenario/model based on the analysis of results obtained in previous step (St.5) and evaluation of:
 - indoor comfort parameters: air temperature and relative humidity,
 - heat losses and heat gains: lighting, people and home appliances, and external solar heat gains,
 - annual final energy demand for heating, cooling, domestic hot water (DHW), and electricity,
 - annual primary energy demand for different purposes and total.

Simulations were conducted using DesignBuilder software. [5]

After definition of the refurbishment scenarios, economic feasibility of the actions will be analyzed.

4. HOUSEHOLDS STATUS IN RESIDENTIAL BUILDING "BLOK 70"

The current state of objects "case study building", in block 70, shows results of a series of actions that are carried out by tenants over the years, such as closing terraces by glazing, renting the premises in the ground floor in order to finance the maintenance of the building; adapting a pantry in the ground floor for residential use; illegal extension in the attic at the expense of the common terraces (this action probably contributed to solving the rainwater and moisture infiltrations on the roof level), the uncontrolled reconstruction of individual apartments, which led to new window openings which caused disruption of the façade, etc. / Figure 2 /.

Specifically at the case study building - object JG73 about 60% of balconies are glazed and too many external units for air-conditioning (approx. 80 % of apartments have split air-conditioning units on the facade and their different ways of positioning ruin the overall look of the building. The roof covering layer is not reconstructed from the date of construction, only were made marginal repairs of roof water infiltrations that have not been solved completely. In the other neighbor buildings, of the same typology, residents (on their own initiative) reconstructed the roof by placing a thermal and hydro insulation, funding from the tenant's budget, and in some cases with a little help from the City Housing Agency that barely meets the basic needs of maintaining about 200,000 flats, for what is in charge.

Figure 2. JG73's facades with visible Illegal housing extension at the attic level; illegal opening on the façade.

5. MODELS AND SCENARIOS OF BUILDING'S ENERGY RENOVATION

Building performance simulations were done for the following models of object JG73: EB - building model based on the original design and a group of six models: Models IB1-IB3 – existing building volume with improved heat transfer coefficients – U [W/m^2K]:

- IB1- model in accordance with JUS [6],
- IB2 - in accordance with the German standard [7],
- IB3 - improved HTC comparing to IB2 and in accordance with the most recent Serbian standard [8],
- IB4 - model with enhanced HTC comparing to the IB3, with the extension of the new residential space in the attic and a green roof;
- IB5 - model similar to the IB4, with the additions of the upgraded functions in the ground floor and glazed terraces (greenhouses)
- IB6-improved over the IB5 with the well ventilated facade on the south and west.

Table 1 presents the heat transfer coefficient HTC [W/m^2K] of the building's structure main elements.

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

Scenarios - MODELS	EB	IB1	IB2	IB3	IB4	IB5	IB6
Structure elements	Heat transfer coefficient $U[W/m^2K]$						
Outer wall 1	1.53	0.52	0.52	0.37	0.37	0.37	0.37
Outer wall 2	2.57	0.61	0.61	0.38	0.38	0.38	0.38
Outer wall 3	1.14	0.47	0.47	0.35	0.35	0.35	0.35
Ground floor	3.89	0.66	0.66	0.33	0.25	0.25	0.25
Roof	0.67	0.36	0.36	0.20	0.20	0.20	0.20
Window	3.16	1.50	1.00	1.00	1.00	1.00	1.00

The facade of the building is built with the three different layers - external walls: precast concrete element - the parapet, placed below the opening in the facade, a wall of clay bricks and reinforced concrete wall with no insulation. Building envelope and the flat roof of the building during the time were attacked by moisture penetration, which is most prominent on the top floor. Presenting different kinds of final energy (for the current state and final optimized state) in Figure 3, simulation results of the current state indicate that the biggest heat losses come from air infiltration, exterior walls without insulation and windows (annual energy demand for heating shown in diagram in Figure 3). Given value of the simulation results for heating energy demand of the current state of the building (EB=750.05 MWh) is very close to the measured energy consumption in the case building substation of the Belgrade District Heating System (760.88MWh), which confirms the credibility of the simulated model.

Figure 3. Annual energy demand for different purposes - building's current state EB (up) and final optimized state IB6 (down)

Simulation results for the updated models are shown in the diagrams in Figures 4 and 5. Figure 4 shows that the Heating total design capacity can be reduced by 52 % (IB6). Heating consumption is reduced by implementing thermal insulation in the building envelope and replacing window glazing by 50% (IB3), and that further improvements lead to a reduction of 73% (IB6). (Figure 5)

Figure 4. Heating total design capacity of different building's refurbishment scenario models (left) and Cooling total design capacity (right)

Diagram in Figure 4 (right) shows that reduction of cooling total design capacity by 30% can be achieved by improving the façade envelope with new thermal insulation. By further increasing of the thickness of insulation, it can be noted a "jump up" in design capacity and load for models IB3, IB4 and IB5.

This result is very important confirmation that the energy optimization must be performed as whole year analysis of the energy needs of the building, both for heating and cooling in a climate of Belgrade and Serbia, what regulations and the certification of the energy performance of buildings in Serbia currently does not provide. Optimization must take into account the energy performance of buildings in both extremes and the essence of sustainable design is to find solutions that will help to reduce energy loads for heating and cooling, along with simultaneous availability of daylighting to minimize the need for lighting electricity.

By placing a well-ventilated façade is achieved significant energy savings for refrigeration, up to 35% (diagram in Figure 5). Accomplished savings in electricity consumption for lighting is almost 2 times comparing to the original model, as replacing existing lamps with energy saving lamps with control the intensity (diagram in Figure 5-left). CO₂ emissions per year were reduced by 1.5 times compared to current state condition, from 58784.44 to 38833.88 kg/m² (a). Specific heat losses and specific heat gains in W/m² are presented in Figure 5(right).

Figure 5. Specific annual consumption- heating, cooling and lighting (per m² of occupied space)(left) and specific heat losses and specific heat gains in W/m²(right)

6. INTEGRATED ARCHITECTURAL EEI MEASURES

Architectural measures. The proposed optimal solution to the energy renovation of the building envelope includes the installation of thermal insulation, window and door glazing and carpentry replacement, and implementation of ventilated facades / IB6 / on the south and west, which greatly contributes to reduce heat gains in summer.

In addition to energy renovation are also considered options to improve the building in architectural terms, adding new features and functions in the ground floor and on the roof, bearing in mind changes that residents themselves have done over the years and how much they can contribute to the improvement, if implemented and controlled by considering entire building.

The scenario model IB5 and IB6 propose terrace glazing, transforming them into greenhouses, with the possibility of integration of photovoltaic panels in the parapet area (on the south and west facade) and setting semi-transparent glazing. Certain areas in the ground floor that tenants use for the purposes of storage, with current state very neglected, functionally could be changed into common laundry area, game room for children or gymnastics and recreational area for adults.

Reviving roofs by greening, not only solves the rainwater infiltration problems, but could open possibility to rainwater collection and recycling, and use of these areas as a common space for all the necessary socialization today, which can enjoy all the tenants of the building. Adding an optional Roof Top Greenhouses with a light weight construction, as urban agricultural garden, has a large contribution to reducing CO₂ emissions. [9]. Re-designing these spaces and their activation, a part from environmental, has a social contribution- to encourage residents to participate in maintenance of the building and raise their awareness about environment.

7. THE ECONOMIC RATIONALE FOR ENERGY REFURBISHMENT INVESTMENT - METHODOLOGY OF THE ECONOMIC ANALYSIS

Feasibility of refurbishment actions needs to be perceived and analyzed within the existing economic outlook of Serbia. The economic crisis in Serbia reopened and amplified old structural problems [10] and it is certainly difficult to estimate when the period of sustainable economic development and growth will recommence. The economic recovery had not happened in the previous 5 years and the additional measures are now needed in order to stimulate economic growth and to improve the trade balance and decrease the unemployment rate.

The need for improvement of resource management is strong in countries that rely heavily on the import of the necessary resources. This is definitely applicable in the case of Serbia, a net importer of energy. Serbian energy balance is deeply affected by the weather conditions and without the implementation of retrofitting and energy savings schemes, Serbia would remain very vulnerable. The official estimates show that 83% [11] of the Serbian natural gas demand in 2013 is imported, mainly from Russia with supplementary amounts from Hungary and Switzerland. Serbia is traditionally [12] a net importer of electricity due to the widespread use of electricity for heating in wintertime and cooling in summertime. Comparison of the statistical data on natural gas and electricity trade balance [13] for 2012 and 2013 brings us to conclusion that the trade account deficit has been decreased by 407 million dollars, which equals around 1% [14] of the GDP. Such high level of energy consumption volatility provides an additional argument for state intervention and private sector involvement in energy efficiency retrofitting projects implementation in Serbia. The investment in energy efficiency retrofitting can improve macroeconomic stability and contribute to the sustainable economic growth [15].

The following assessment of the different microeconomic effects by applying six different energy efficiency retrofitting models provides valuable inputs for further development of economic models.

For all calculations average mid-value exchange rate of the National Bank of Serbia for 2013 was used, 1€ = 113.14 dinars. [16] To calculate price of heating energy, the following values were used: $P_{hn} = 12.091\text{€}/\text{m}^2$, $P_{hf} = 4.335\text{€}/\text{m}^2$, $P_{hv} = 0.06028\text{€}/\text{kWh}$. [17] Reduced rate of the value added tax (VAT) of 10%, which is applied for heating energy, [18] is included. For the purpose of financing the renovation and retrofit, the interest rate used is 8.303%. This is the arithmetic mean of interest rates of publicly available energy efficiency related lines of credit from three major banks in the country. [19,20,21] Down payment required is taken at 16.67%, as some banks ask for larger portion to be paid in advance, whilst some waive this request entirely.

Two distinct financing models are applied – one where owners bear the entire cost of the retrofit, and the other where a commercial loan facility is used. Also, a government subsidy is considered. As there are no subsidies presently available, although certain announcements in this regard have been made, [22] we decided to assume that this subsidy would be conservative, i.e. fiscally neutral and would amount to the VAT that would have been collected for the retrofit – the 16.67% down payment.¹ This cash subsidy would be returned to the government during the course of the retrofit, as VAT is being charged for construction works and material; at the end of the retrofit, the government would have received its money back.

Savings which are the outcome of the retrofit are calculated solely as the reduction in the heating energy bill, i.e. the summer electricity bill which reflects the energy used for air-condition split systems for cooling, is not taken into account – in part due to low prevalence of split systems elaborated by Bojić et al., [23] but additionally, as there is no reliable data with regard to how much electric energy is spent for cooling during summer months in this building. Evidently, taking these saving into account would simply make the investment more viable.

Reduction of the heating bill is calculated as $C_C - C_R$.

Furthermore, we assume that the building will switch to payment according to consumption prior to the end of the retrofit process. Otherwise, any investment would be unreasonable, as ROI would stand at 0%. The difference between C_C and C_N is also worth observing, as it might influence C_C prior to the retrofit, once tenants realize how their habits can impact the heating bill. Currently, the entire building is charged $C_N = 60,775\text{€}$ annually; so as to maintain the same level of comfort, should the building switch to allocated cost model, the charge would amount to $C_C = 65,361\text{€}$ annually. These figures include the 5% discount consumers are entitled to if they pay their bills on time. Therefore, using C_C increases value of the investment slightly, yet in time all consumers are expected to migrate to one of the pay per consumption models, rendering C_N obsolete.

The methods used for economic analysis of the retrofit measures are the Net Present Value (NPV), the Simple Payback period (SPB) and the Depreciated Payback Period (DPB). While researches, such as Malatji et al. [24] use more advanced methods to measure the cost effectiveness of multiple retrofit alternatives, the options given in this paper (IB1-IB6) are predetermined, not a menu to choose from. This is why simpler methods, as in Nikolaidis et al., [25] are being applied and NPV and DPB are calculated for each of the retrofit actions. Formula used for determining the NPV is:

$$NPV = -I_0 + \sum_{t=1}^n \frac{F_t}{(1+p)^t}$$

where t is the time period, one year, I_0 the discounted value of the entire loan with added interest, i.e. the initial investment, F_t the net cash flow for the year t (difference between benefits and costs), p the price of capital and n the number of years for which the analysis is performed.

As in Verbeeck et al., [26] we assume that the life cycle of the investment is 30 years and no additional assumptions are made on the destiny of the building after the year 30, whether it should be retrofitted again, demolished or left in current state. NPV does not take into account any value the retrofit actions might have at the end of this cycle of 30 years, corresponding approximately to one generation.

SPB and DPB are used for illustrative purposes only, as the choice of the economically soundest investment is made by way of NPV. While payback periods cannot reveal the (future) value of an investment, it does show how much time is needed to recover I_0 , given the price of capital p ² and the net cash flow F_t , which is considered to be unchanged for every t :

$$DPB = \frac{-\ln(1 - \frac{pI_0}{F_t})}{\ln(1+p)}$$

¹ 16.67% is equal to VAT revenues generated from the cost of the refurbishment action

² p is considered only in the DPP

$$SPB = I_0/F_t$$

Furthermore, due to economic constraints, commercial loan facility might have to be used, if the amount for I_0 is not available in advance. This is why I_0 denotes a sum of down payment required (which is omitted if the government subsidy is available, as we are evaluating investment from the point of final consumers) and the present value of future annuities:

$$I_0 = A_d + A_l \left[\frac{(1+p)^n - 1}{p} \right] * (1+p)$$

where A_d is the down payment, A_l the annuity due each payment cycle, a month in this case and n is the number of payments due. Price of capital p is adjusted so as to reflect the monthly, rather than the annual interest rate.

In case where the owners bear the cost of the retrofit upfront, I_0 is simply the entire cost of the investment, unadjusted for future value or price of capital.

8. ECONOMIC ANALYSIS AND RESULTS

In Figure 7 we present the fluctuation of the NPV for all the retrofit actions tested, considering a cost of capital of 2.176%. This might seem as a curiously low p , however, this analysis evaluates benefits for final consumers. Having in mind that investment per dwelling is essentially low (approximately 3,735€ for action IB1, 5,913€ for IB6; without interest added), it is hardly conceivable that this limited amount of capital might be used for an investment into a business endeavor. Rather, we have used an interest paid for certificate of deposit in euro, maturing after 36 months, available at a major commercial bank, reduced for payable tax.^[27] This can be further justified by a very low risk premium, entirely comparable to that associated with bank deposits.

Analysis of the NPV of different actions demonstrates, also in Figure 7, that all investments are depreciated at some point – depending on the type of loan and the action – DPB varies from 10.6 to 23.7 years (or 10.2 to 20.2 years using the government subsidy). Also, it points to the fact that the more elaborate (and expensive) the retrofit action is, it will depreciate more quickly – with the notable exception of action IB6, where substantial increase in cost is not met with an equal improvement in energy savings.

Table 2. DPB for all retrofit actions, considering the use and length of the loan and the use of the government subsidy

Loan maturity (years)	DPB (years)								
	Without government subsidy					With government subsidy			
	No loan	5	8	10	15	5	8	10	15
IB1	15.4	18.0	19.6	20.7	23.7	14.8	16.3	17.4	20.2
IB2	13.3	15.3	16.7	17.6	20.0	12.7	14.0	14.9	17.2
IB3	12.8	14.8	16.1	16.9	19.3	12.3	13.5	14.3	16.5
IB4	12.9	14.9	16.2	17.0	19.4	12.4	13.6	14.4	16.6
IB5	10.6	12.2	13.2	13.9	15.7	10.2	11.1	11.8	13.5
IB6	14.4	16.7	18.2	19.2	22.0	13.9	15.3	16.2	18.8

The results of evaluation according to DPB are shown in Table 2 and reveal quite a peculiar situation – every assessed scenario is economically feasible, it is just a question of time or finding a better alternative to invest in. Naturally, DPB is quite sensitive on shifts in p and the accumulated interest that is levied on the energy efficiency loan lines. While the most cost-efficient retrofit action (IB5) takes 10.6 years to depreciate, DPB rises to 15.7 years for a 15-year loan, evidently due to interest paid. The least viable option, although it also ends up being profitable, is the least energy-efficient retrofit model, IB1 – it is depreciated only after 15.4 years (or 23.7 years using the 15-year loan facility).

Table 3. SPB for all retrofit actions, considering the use and length of the loan.

Loan maturity (years)	SPB (years)				
	No loan	5	8	10	15
IB1	13.0	14.7	15.8	16.5	18.4
IB2	11.4	12.9	13.9	14.5	16.1
IB3	11.1	12.5	13.4	14.1	15.6

IB4	11.1	12.6	13.5	14.1	15.7
IB5	9.3	10.6	11.4	11.9	13.2
IB6	12.3	13.9	14.9	15.6	17.3

Simple payback period, naturally yield similar results, albeit with slightly shorter time of depreciation, due to the absence of p . Again, with SPP of only 9.3 years, IB5 is the most cost-efficient retrofit scenario.

Figure 6. Fluctuation of the NPV for all retrofit actions, without using the commercial loan facility or government subsidy, $p = 2.176\%$.

Data presented in Figure 6 clearly proves that every retrofit scenario is economically feasible. Furthermore, the difference in the investments between the IB1 and IB5 is relatively modest (IB5 takes only 20% more money than IB1), while energy savings are substantial. This makes IB5 the soundest investment scenario – it is not the least expensive one, however, even at this low level of energy prices, its economic benefits will surpass that of all other scenarios in no more than 5 years. While IB6 is significantly more expensive investment (33% higher than IB5), it provides merely additional 1pp. of energy savings. This is why its benefits will surpass those of IB1-IB4 only after two decades, but never those of IB5, which clearly remains economically most prudent choice.

It is worth noting that all economic indicators show very similar performance for IB3 and IB4 and it is difficult even to distinguish between these corresponding lines on the figure 7. Having that in mind, scenario with more energy benefits should be chosen for implementation (IB4).

Government subsidy will generally shave off 2 to 3.5 years of DPB, making the investment depreciate faster. Additional subsidies could take different forms, such as applying reduced VAT rate for construction material needed for the retrofitting or subsidizing credit lines in order to offer more favorable interest rates than those commercially available at present.

Perhaps the most significant impact on fluctuation of NPV is from the heating energy prices. They are heavily subsidized by the local governments (in different amounts across the country) as it is, and given the fact that Serbia is not energy independent, these prices are likely to increase over time. In Figure 7, we examine the possible increase in variable part of the price of heating using the heat allocation model – even the slightest increase has a substantial effect on NPV. Prospect of the price increase in the future renders the retrofit even more feasible.

Figure 7. Fluctuation of NPV for action IB5, using a 10-year loan facility with changes in P_{hv} (currently at $P_{hv} = 0.06028\text{€}$), with $p = 2.176\%$.

9. CONCLUSION

Energy renovation of the building in order to increase energy efficiency and reduce energy needs for approaching Zero Energy Status of the building is a complex process, not only a challenge for the mechanical engineers but even more attractive opportunity for building integrated re-design together with architects and civil engineers. Therefore, it should be approached in an organized, pragmatic and interdisciplinary way. The focus should not only be on the latest leading-edge technology, but the synergy of different practices and principles in order to ensure the path to sustainable development and achieve desired objectives.

Minimizing energy loads by "passive" actions highlights that bio-climatic renovation of residential buildings may have an important role but only in the synergy of passive and active means it will be possible to approach zero energy status.

Economic analysis of the presented models shows clearly that the proposed energy-efficient actions are feasible. Considering that the retrofit budget is very similar for all proposed actions (with exception of IB6), regardless of the interest rates or any government subsidies, if the funds are available, economic analysis clearly suggest implementing action IB5, followed by less expensive actions in their respective order. Action IB6, with a larger initial cost, surpasses actions IB1-IB4 only after two decades, but remains inferior to economic benefits of IB5.

Introducing subsidies improves economic performance of the retrofit actions, but they are sustainable on their own. However, investment is repaid considerably quicker if subsidies are available. Finally, should the prices of heating increase over time as is expected, their effect on viability of the retrofit investment is potentially enormous – with every increase, investment becomes more appealing.

Papers ([1], [3], [27]) present potential reduction of heating and cooling energy use by the energy renovation and improvement of indoor comfort in residential blocks, and New Belgrade, with its great architectural and urban potential, is a municipality that could be leader in energy renovation of existing residential buildings. [28]

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Nomenclature

- C_N Heating energy bill, nominal charge
- C_C Heating energy bill, prior to the retrofit, allocated cost model
- C_R Heating energy bill, after the retrofit
- P_{hf} Price of heating – fixed component, annually, (€/m^2)
- P_{hv} Price of heating – variable component, (€/kWh)

P_{hn} Price of heating – nominal charge, annually, (€/m²)
 ROI Return on investment

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1. Implementation of a series of EEI (energy efficiency improvement) measures in building refurbishment resulted in significant reduction of buildings energy loads
- 2 .Minimizing energy loads by "passive" actions highlights that bio-climatic renovation of residential buildings may have an important role but only in the synergy of passive and active means it will be possible to approach zero energy status.
3. Economic analysis of the presented refurbishment energy efficiency models clearly shows their feasibility

Figure 1. Residential blocks in New Belgrade

Figure 2. JG73's facades with visible Illegal housing extension at the attic level; illegal opening on the façade.

Figure 1. Annual energy demand for different purposes - building's current state EB (up) and final optimized state IB6 (down)

**Figure 4. Heating total design capacity of different building's refurbishment scenario models (left)
and Cooling total design capacity (right)**

Figure 5. Specific annual consumption- heating, cooling and lighting (per m² of occupied space)(left) and specific heat losses and specific heat gains in W/m²(right)

Figure 6. Fluctuation of the NPV for all retrofit actions, without using the commercial loan facility or government subsidy, $p = 2.176\%$.

Figure 7. Fluctuation of NPV for action IB5, using a 10-year loan facility with changes in P_{hv} (currently at $P_{hv} = 0.06028\text{€}$), with $p = 2.176\%$.

Table 1. Heat transfer coefficient HTC of the building’s structure elements

Scenarios - MODELS	EB	IB1	IB2	IB3	IB4	IB5	IB6
Structure elements	Heat transfer coefficient U[W/m ² K]						
Outer wall 1	1.53	0.52	0.52	0.37	0.37	0.37	0.37
Outer wall 2	2.57	0.61	0.61	0.38	0.38	0.38	0.38
Outer wall 3	1.14	0.47	0.47	0.35	0.35	0.35	0.35
Ground floor	3.89	0.66	0.66	0.33	0.25	0.25	0.25
Roof	0.67	0.36	0.36	0.20	0.20	0.20	0.20
Window	3.16	1.50	1.00	1.00	1.00	1.00	1.00

Table 2. DPB for all retrofit actions, considering the use and length of the loan and the use of the government subsidy

p=2.176%	DPB (years)								
	Without government subsidy					With government subsidy			
Loan maturity (years)	No loan	5	8	10	15	5	8	10	15
IB1	15.4	18.0	19.6	20.7	23.7	14.8	16.3	17.4	20.2
IB2	13.3	15.3	16.7	17.6	20.0	12.7	14.0	14.9	17.2
IB3	12.8	14.8	16.1	16.9	19.3	12.3	13.5	14.3	16.5
IB4	12.9	14.9	16.2	17.0	19.4	12.4	13.6	14.4	16.6
IB5	10.6	12.2	13.2	13.9	15.7	10.2	11.1	11.8	13.5
IB6	14.4	16.7	18.2	19.2	22.0	13.9	15.3	16.2	18.8

Table 3. SPB for all retrofit actions, considering the use and length of the loan.

	SPB (years)				
Loan maturity (years)	No loan	5	8	10	15
IB1	13.0	14.7	15.8	16.5	18.4
IB2	11.4	12.9	13.9	14.5	16.1
IB3	11.1	12.5	13.4	14.1	15.6
IB4	11.1	12.6	13.5	14.1	15.7
IB5	9.3	10.6	11.4	11.9	13.2
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