ECONOMIC THEMES (2024) 62(1): 45-66

DOI 10.2478/ethemes-2024-0003

COST-BENEFIT ANALYSIS OF BUILDING ENERGY REFURBISHMENT – CASE STUDY OF A MUNICIPAL PUBLIC BUILDING

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[1] This paper is a part of the research funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia, under grant number 451-03-68/2020-14/200090. The research is done under the research labs of the University of Belgrade Faculty of Architecture: building stock laboratory and SaRA (Sustainable and Resilient Architecture).

UDC 69.059:725: 502.12

Original scientific paper

Abstract: For achieving transition towards a climate neutral, cleaner and healthier environment we must tackle the issues which contribute mostly to climate change and pollution, through fossil fuels excessive consumption and inefficient use of other resources. Construction and operation of buildings is certainly one of these issues, with estimation that buildings consume about 40% of the total energy (EU). One of the strategies that is considered most effective in making the building sector more resource and energy efficient is refurbishment of old buildings, which no longer meet criteria for achieving adequate comfort with minimal energy use. Their refurbishment, opposed to their demolition and construction of new ones, brings numerous environmental benefits, and also drives the transitions of entire cities and communities towards a more resilient and better environment. Recent policies (Energy Efficiency Directives, EU Green Deal, The New European Bauhaus initiative) also highlight the importance of building refurbishment and set goals for ambitious refurbishment rates for the entire building stock. At the same time, they highlight the importance of refurbishment of public buildings, because of the positive implications it has in terms of showcase and educational purposes. This paper presents the case study of refurbishment options for a characteristic municipal building, through cost-benefit analysis of different refurbishment scenarios.

Received: 05.02.2024
Accepted: 30.03.2024

Keywords: Energy efficiency, building refurbishment, cost-benefit analysis

JEL classification: R31, Q40, Q58

1. Introduction

Global problems, such as accelerated depletion of non-renewable energy sources and uncontrolled emission of greenhouse gases are some of the main triggers of ecologic, but also economic crises around the world. Cities, as main drivers of social, economic and technological development require enormous amount of energy for its functioning. Cities consume up to 70% of world's energy and generate about 80% of global CO_2 emissions (Pucar, 2019) with the trend of constant rising. The main environmental problems are air pollution and traffic congestions, constant struggle to preserve the remaining scare green areas, fertile land and water sources. Therefore, energy production, distribution and consumption are crucial for all areas of human existence, but also for the social and economic development of each country. Accordingly, it is necessary to come to the sustainable systems for the long-term management of the contemporary cities.

Sustainability, resilience and energy efficiency are terms that are more and more related to the level of city planning as well as single buildings. Currently, buildings and construction sector account for about 39% of greenhouse gases emissions and 36% of the world's final energy consumption, of which 30% is used for the operation of buildings and another part is used for other construction services (Santamouris&Vasilakopoulou, 2021). Due to the extensive effort in retrofitting and rehabilitation of existing stock and set of regulations for new buildings, there was a significant reduction in both energy consumption and greenhouse gas emission during previous decades.

The reductions of energy consumption as well as substitution of fossil fuels with renewables have been defined as goals in several European Directives beginning with the one in 2002 (EC, 2002, 2009, 2010, 2012) and in the national regulations of member countries. The European commission has set ambitious goals related to energy efficiency and climate change back in 2009, where goals for year 2020 have been set to 20% (compared to 1990 levels) in lowering emissions of GHG, increase in the share of renewables and energy efficiency (EC, 2009). Further projections set these percents up to 40% up to the year 2050. Since 2020 has passed, we can now say that some of these targets have been met, like the one for the share of renewables, since the share of renewable energy sources in EU energy consumption had increased from 12.5% in 2010 to 23% in 2022. New goals in the share of renewables are set in the Renewable Energy Directive (EC, 2018) as at least 32% reduction for 2030 and furthermore by the late ones (EC, 2023) which limits the greenhouse gas emissions by at least 55 % by 2030. The targets of reductions set by the goals in the increase of energy efficiency have not been such a success.

2. Energy efficiency in buildings

But what is actually energy efficiency in buildings? International energy agency classifies an item as more energy efficient if it provides more services for the same value of energy input or the same services for the lower energy input (Herring, 1999). Therefore, energy efficiency is a way to manage and lower growth in energy consumption. When speaking of energy efficient buildings, then we also speak about buildings that consume less energy for maintaining the defined levels of human comfort for work and living in indoor spaces. Under the measures of energy efficiency are considered the measures applied with the aim to lower energy consumption. These measures, weather technical or non-technical always result in the same or even higher level of achieved human comfort. Therefore, in the domain of energy efficiency, we do not consider savings which imply restriction of some aspects of human comfort, which, on the other hand, reflect on the level of the achieved human comfort (Ionescu et al., 2015). Energy efficiency in buildings became a dominant topic in research and practice after the oil embargo and energy crisis in 1973, when the developed countries became aware of their dependance on the fossil fuels which were mostly being imported. But most of all, people realized how inadequately, in terms of energy consumption, they had been raising their buildings since the revolutionary industrialized technologies became dominant in the construction industry. The heritage of centuries old experiences in building adequately to local climate and customs, with easily available building technologies, has been put aside in favor of the contemporary building technology and the imported models of the same buildings throughout different cultures and climates. This has set the ground for the definition of goals for sustainable development (WCED, 1987), and the foundations for the development of sustainable or green architecture that will have become a dominant paradigm in architecture theory and practice by the end of XXI century. The definition of energy efficiency as the **first fuel** was formulated within the *trias energetica* concept in 1979. at TU Delft and represented an academically acknowledged three-step priority strategy: (1) reduce the demand, (2) use renewable energy sources and (3) solve the residual demand efficiently and cleanly. (Mlecnik, 2012).

During the past decade, the EU regulations, concerning the energy efficiency, has been significantly strengthened. After the Directive from 2002 (EC, 2002), its recast (EC, 2010) and the first Renewable energy Directive (EC, 2009) were issued defining the characteristics of nearly zero energy buildings (nZEB), both for the new and the refurbished buildings. Nearly zero energy building means a building that has a very high energy performance, while the very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including the energy from the renewable sources produced on-site or nearby (EC, 2009). The projections of the same directive, that by the end of 2020 all new buildings should be nZEBs and by the end of 2018 all public buildings should be of this energy performance level, proved to be unachievable.

Also, the refurbishment has been emphasized as a key factor in reaching the ambitious goals in energy savings, as stated in the Energy Efficiency Directive (EC, 2012), where the targets are set for 2050 as the energy consumption reduction of 80%, through the gradual and systematic improvement of the energy performance of all buildings through the implementation of the national building renovation strategies. Furthermore, this directive emphasizes the importance of public buildings, as the ones whose the refurbishment levels should provide the leading example of the public sector. The previously mentioned Renewable Energy Directive (EC, 2009) also underlines the importance of public buildings and their refurbishment, which should have an exemplary role.

The renovation of the existing building stock is a key strategy for achieving energy savings on a global level. However, the slow pace of energy renovation of the existing building stock has led to the adoption of the latest European strategy - A Renovation Wave for Europe (COM, 2020) published in October 2020, as part of the European Green Deal (COM, 2019), with the main goal of doubling the building stock renovation rate in the next 10 years and the ambitious level of decarbonization of the buildings by 2050. Since the European building stock is extremely heterogeneous and old, it is emphasized that 85-95% of the buildings that exist today will still be in use in 2050, even though 75% of the existing EU buildings are not energy efficient. One way to encourage the refurbishment at the EU level is to uniformly certify the existing buildings and make that data more apparent, transparent and useful, as it is proved that it boosts the improvements in energy performance of public buildings (Bull&Chang, 2012). Therefore, it is clear that the policies aimed to improve the level of energy efficiency in buildings represent a significant source of potential energy savings both on local and national level. These public policies are numerous and have already been widely adopted throughout the EU as incentives for the homeowners to invest into measures of improving the energy efficiency in their buildings. Also, since the inefficiency of building stock is often related to poor indoor comfort, the national energy efficiency projects are specifically aimed at the refurbishment of public buildings, as the buildings that are being used by the general public and whose refurbishment will have a significant wider impact on the general awareness of significance of the investments into the energy efficiency in buildings (Botzler&Dahmen, 2017).

2.1 Energy efficiency in Serbia

The state of the energy efficiency in Serbia significantly improved during the last decade but still needs continuous advancement. As a contracting party of Energy Community, it is continuously improving its legislative and economic framework towards more efficient production, transport and use of energy, promotion of renewables.

Serbia, as the candidate country, started the process of harmonization with the EU regulations in the field of energy efficiency more than a decade ago, by introducing several laws and ordinances: Law on planning and construction (Ministry of Construction, Transport and Infrastructure of Republic of Serbia, 2009), Law on efficient use of energy (Ministry of Energy and Mining of Republic of Serbia, 2013), Strategy for energy development and National Renewable Energy Action Plan (Ministry of Energy, Development and Environmental Protection,2013). Now, these are being further developed through subsequent upgrades (Law on planning and construction, 2020, 2023) preparation of National Energy and Climate Plan which is being drafted, adopted Law on energy efficiency and rational use of electric energy (Ministry of Mining and Energy, 2021), as well as relevant sub-laws and ordinances.

In the field of energy efficient regulations in the building pace of modernization and harmonization with the EU regulations has been similar. According to global tendencies, Serbia has followed the pace of adoption of relevant legislation in the field of energy efficiency in buildings, since the first ones in 1970s (Radivojević et al., 2003), which defined the basic characteristics in terms of thermal protection for the elements of building the thermal envelope. Another generation of more stringent regulations was adopted in 1980s, and they have been used until the last harmonization with the EU regulation in this field, in 2011. The biggest impact was made by introducing two rulebooks: Rulebook on energy efficiency in buildings and Rulebook on conditions, content and method of issuing energy performance certificates (Ministry of Construction, Transport and Infrastructure of Republic of Serbia, 2011 and 2012) which introduce energy performance certificates for buildings, methodology for calculation of energy need of buildings (although only for heating), set levels of thermal protection qualities of the thermal envelope (U-values) and requirements in energy levels for new buildings and those being refurbished. This has made a significant impact on building practice in the past decade, especially raising the standard in the construction of new buildings from the standpoint of thermal protection and the efficient use of energy. Now, after more than a decade of their use, it is evident that they have influenced the rise of energy efficiency in the building sector, but there is still a need for their update and harmonization with the EU legislation, mainly in the aspect of including also energy need for cooling in the calculations.

As defined by the current legislation, refurbishment standards have been set rather low (upgrade in energy class only by one) and no significant breakthrough in building refurbishment hasn’t been made, especially in the sector of multifamily collective housing. There have been numerous showcase projects, mostly in public buildings (schools, administrative buildings etc.), as well as studies of possible retrofit scenarios and complex refurbishment options for multi-family buildings (Lević et al., 2023), but without many examples in practice. Excessive research have been conducted with the aim of examination and structuring building stock in order to define an adequate strategy and refurbishment methodology, first for residential buildings (Jovanović Popović et. al, 2013; Ignjatović et al, 2021) and then for the public buildings (Jovanović Popović et. al, 2018, 2018a; Ćuković-Ignjatović et al., 2020; Đukanović et al, 2022). The main results show that the thermal performance of the existing building stock is rather poor, with very low current energy performance levels, ranging from E to G (above 200 kwh/m^{2}a). At the same time, improvement potentials are great, with reduction through basic retrofits by 30-35%, while a deep renovation cuts their energy demands by 75-80%. The results of these studies have been integrated in the LTRS: *Long term building renovation strategy Republic of Serbia until 2050* (Ministry of Construction, Transport and Infrastructure of Republic of Serbia, 2022) which concludes that only the most ambitious scenarios of building refurbishment, with the pace of refurbishment of about 4-6 million m^2 per year and all available financial mechanisms and subsidies, lead to both CO_2 emissions reductions and primary energy consumption reduction. This refurbishment action needs to address all types of buildings: residential, both of single family and multifamily housing typology, as well as public buildings.

2.2 Energy refurbishment of public buildings

In Serbia, the local issues of energy poverty and outdated building stock desperate for refurbishment only highlight the urgency of this issue. Beside the problems of non-rational energy consumption, extreme levels of air pollution in cities are also an issue demanding an urgent action (WHO, 2019). Energy consumption in buildings, residential mainly, but also in public ones, is significantly contributing to this issue.

Although public buildings account for less than 3% of the building stock in Serbia (about 11 million m^2 according to LTRS), they consume about 25% of energy in total building stock (Jovanović Popović et. al, 2018) and the influence of their refurbishment is diverse. Their variety, in terms of types and number and profile of occupants, is very heterogenous: from administrative to educational buildings and hospitals. Therefore, beside direct benefits such as lowering energy consumption and pollution, wider benefits of their refurbishment reach out to general public on many levels, of which only some can be quantified through cost-optimal analysis (Mihić et al., 2012). The requests made by the EU directives (EC, 2012) for the refurbishment of public buildings in Serbia apply only to the buildings owned by the central government, which makes up only 4.5% of public buildings. That number is very low regarding the fact that it should provide an example and guide for further building energy renovation (Jovanović Popović et al., 2018b). This is why the refurbishment of public buildings should take into account different types of buildings, in order to demonstrate to different user groups, the benefits and importance of building refurbishment.

There have been many projects focused on the refurbishment of public buildings in the previous decade. One of the largest conducted projects of public building refurbishment was Serbia Energy Efficiency Project (SEEP) where 60 buildings (schools, health care centers and social care institutions) were refurbished, with the reductions in annual gross final energy consumption by 47%, with 11.6 million EUR investment (Petrović Bećirović&Vasić, 2013). Other projects include those financed through the budgetary fund for energy efficiency, founded in 2014, through the annual calls to local self-governments, as well as similar calls by the Ministry of Mining and Energy and the Ministry of Construction, Transport and Infrastructure, since 2018. In 2014 The office for public investments was established, and so far, more than 100 buildings were refurbished, funded by various sources: EBRD, kfW, UNDP, World Bank and different foundations (LTRS, 2022).

The existing municipal administrative buildings represent a specific portion of the public building fund marked by a high diversity in typological, structural and material characteristics as defined by the design principles and available technology of the time of construction. Many of these structures were not purposely designed for the function they now serve and have undergone various alterations and modifications which have largely changed their original state. As they provide socially significant services, these buildings are frequently visited by the general public which presents a potential for a strategically different approach in the process of refurbishment - introducing not only the functional and technological elements into a design process but also educational and demonstration ones (Miletić et al., 2022)

The main issue of concern when dealing with the public building energy renovation, is the methodology of choosing buildings for refurbishment, since in practice the funds are always limited and there is a list of “candidate” buildings. The cost-optimal method, where the buildings which achieve greatest savings through the invested means are favorized is not always a straight-forward decision tool since many other issues are in question: the urgency of the refurbishment regarding the physical state of a building, the level of pollution generated by the local heating source in the building, the conservation regime that affects the level of refurbishment, the number of building beneficiaries and the level of their comfort etc. The last issue was crucial in favorizing school and kindergarten buildings as the first ones to be refurbished, due to the poor conditions of the user comfort (windows that produce draft, leaking roofs etc.). Unfortunately, only the rare cases of building refurbishment aimed at higher levels and savings; the majority were only minimal interventions. This kind of approach, although it leads to energy savings and comfort improvement, is not adequate in terms of capturing the most of the building refurbishment process. Instead of the showcase of state-of the art building refurbishment that maximizes the energy savings and prolongs the life-span of the buildings, by true modernization and upgrade, only minor interventions were conducted and all the potentials of wider, long-term benefits were lost. In order to avoid similar mistakes in the future, which could lock the potential of full energy savings and cuts in the CO_2 emissions, a methodology for public building refurbishment is presented, taking into account not only the energy savings, but also the economic implications through cost-benefit analysis.

2.3 Methodology of building refurbishment

First, methodology was defined through a few main steps: the investigation of the existing building, the identification of the improvement measures which generate the largest savings, the formulation of the improvement packages of measures according to the project demands, the valorization of different variants, the preparation of the project documentation. These main steps can be further divided into smaller steps:

1. The acquistion and analysis of technical data about the building, based on the archive documentation and on-site investigation
2. A digital model of existing state is made, using the Rhinoceros[2] 3D modeling software. The geometry of the building is analyzed based on its thermal properties (division into different zones based on the heating regimes). This model is a base for all further calculations. All the thermal physical properties are defined – the structure of the building envelope, the parameters of the shadings, the ventilation etc. The definition of thermal properties is undergone

[2] Rhinoceros https://www.rhino3d.com/

for the climate conditions of the location, through the calculations of energy performance done in the „*KnaufTerm2 Pro*"[3] software, according to current the regulations (Rulebooks from 2011 and 2012). This software enables the performance verification of each building component, and its influence on the entire building performance, which is crucial for the formulation of the preliminary concept. Besides the calculations, the thermal properties of the building envelope are verified through the thermal imaging of the building in order to detect the greatest energy loses and possible defects.

3. The evaluation of possible measures of energy efficiency and architectural measures within the possible scope of works. The analysis and energy optimization of building physics calculations.
4. The definition of possible scenarios: the models of energy refurbishment, in order to identify the cost-optimal solution. The models are defined from the basic to complex, which include all of the proposed measures.
5. Determining the best-case scenario based on the analysis of annual energy need for heating, heat gains and losses (ventilation, lighting, users and equipment), primary energy and CO_2 emissions. The energy need for cooling is not currently being calculated for the purpose of energy performance certification, it is estimated that the measures of thermal protections (facade and roof insulation) would also affect lowering of the energy need for cooling and improving of comfort in the summer months, although the energy need for cooling is most effectively lowered by the control of solar gains (sun shading systems) and the increased ventilation.
6. The financial estimations for each model scenario are defined, and then the pay back periods are determined based on the NPV method and the actual energy costs for heating.

3. Case study: building of Palilula municipality

This case-study is dealing with the building of Palilula municipality, located in Takovska street, in Belgrade downtown. Palilula municipality is the largest city municipality, with more than 180 000 inhabitants. The municipal headquarters building was built in 1938 as the endowment of Agnija and Mihailo Srećković. After the abolition of the endowment in 1954, the building was nationalized and later turned into an administrative building. After the Second World War, an intervention was made in the form of adaptation of the attic into a useful office space, as well as the upgrades on the flat terraces of the courtyard, also in the form of the office space. It is now being fully in use for the administrative purposes.

[3] Knauf Insulation: http://knaufinsulation.rs

3.1 The existing state of the building

The building consists of the main volume of total 8 levels (basement, ground floor and six floors) with its main axis northeast-southwest orientation, and the courtyard volume facing south-east. The courtyard volume follows the denivelation of the terrain and has a link to the main one by a connecting staircase volume.

The building is built in a massive structural system with a load-bearing masonry walls of various thicknesses and various brick formats, so that in the composition we find walls 51 cm, 38 cm and 25 cm thick, going from the basement level to the upper floors. In the period after the Second World War, the building was upgraded with the addition of the reinforced concrete slabs above the 6th floor, above which a sloping wooden roof covered with sheet metal was constructed. The street facade is characterized by relatively reduced facade plastic in the form of vertical grooves in the zones between the window openings and stone decorative slats around the windows and terraces in the central part of the facade canvas (Figure 1), i.e. distinctive texture made of artificial stone in the ground floor area.

Figure 1. Thermal imaging and photograph of the street facade of the building of the City Municipality of Palilula. The image clearly shows heat losses in horizontal reinforced concrete elements as well as the beams over windows. No vertical reinforced concrete elements are observed

Source: Miletić et al, 2022

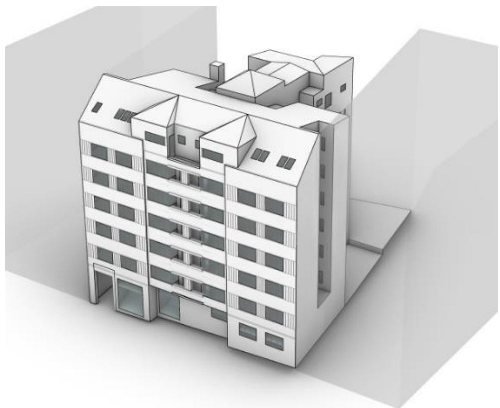
The existing windows are mostly made of PVC profiles and were installed in the early 2000s. During the exploitation, changes were made to the shape of the windows as well as their dimensions, so the current state is partially different from the original one. Still, some of the original double wooden windows with narrow sashes can be found on the parts of the facades, as well as an original segment glazed with glass blocks. Although the existing PVC windows are in a relatively good condition, they are, given their age, characterized by inadequate thermal characteristics, keeping in mind the current standards.

The building is supplied with thermal energy through a district heating system from the Public Utility Company of the Belgrade Power Plant using a hot-water radiator heating system. The radiator network is indented as not insulated within the thermal envelope of the building, with an automatic control in the technical room and without individual controls on the radiators. Cooling is performed by individual units of the "split" type of different capacities and ages (conditions) with the installation of outdoor units directly on the facade. Ventilation is natural through the window openings. The sun protection is realized by the internal curtains of the Venetian type, i.e. canvas curtains.

3.1 Improvement measures

Following the detail analysis of the existing state, a 3D model was made (*Figure 2.*), based on which the energy performance calculations were performed. Energy performance of the existing state classifies the building in **F energy grade**, with consumption of 156.73 kWh/m^{2}a. Also, the calculations of energy performance resulted in the identification of positions of the thermal envelope responsible for the greatest energy losses. Based on these information, three levels of improvements were defined, which include different packages of energy saving measures on the building thermal envelope.

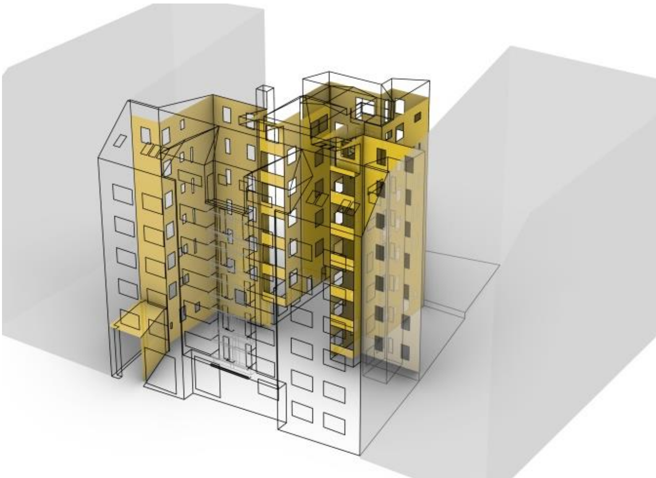
Figure 2. Illustration of the 3D model of the existing state for the purpose of energy performance calculations



The first level of improvement is modeled according to the current legislative requirement, which is the improvement of the existing energy class **for at least one grade (E energy grade)**. As illustrated in ***Figure 3***, in the case of this building, this is achieved by the following measures:

- Thermal insulation of the courtyard facade: performed by placing a thermal insulation layer of 12 cm of stone wool over the existing facade.
- Thermal insulation of the courtyard facade overhangs: performed by placing a layer of stone wool 15 cm thick and a final layer of cement mortar.

Figure 3. Illustration of the elements of the building thermal envelope upgraded in the first level of improvement



The second level of improvement is formulated with the intent of improvement of the existing energy class **for two grades (D energy grade)**, and it includes the following measures (Figure 4.):

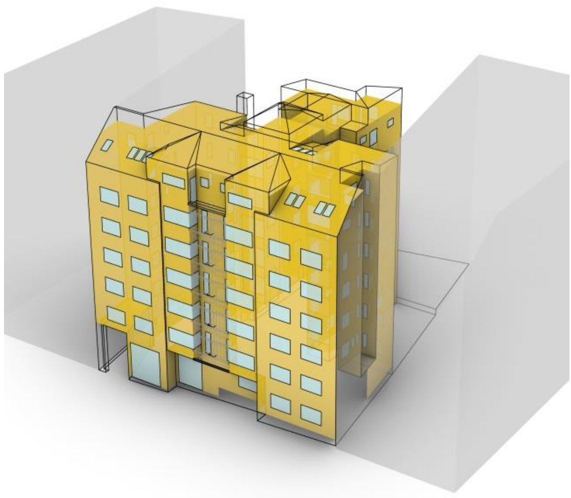
- Thermal insulation of mezzanine structures towards the attic space: performed by installing a layer of 15 cm stone wool with the addition of appropriate protective layers (steam dams, protective foils) in accordance with the requirements of building physics.
- Thermal insulation of the courtyard facade: performed by placing a thermal insulation layer of 12 cm of stone wool over the existing facade.
- Thermal insulation of the courtyard facade overhangs: performed by placing a layer of stone wool 15 cm thick and a final layer of cement mortar.
- The thermal insulation on the part of the flat roof above the first floor: performed by applying 20 cm layer of stone wool on the underside and finished with plasterboard on the appropriate substructure.

- Replacing existing PVC windows with new ones, with six-chamber PVC profiles with triple glazing filled with argon and low-emission coating. The geometrical characteristics of the newly planned windows (size and composition/division) are the same as the existing ones, but the newly planned windows are characterized by a better heat transfer coefficient of U = 1.1 W/m^2K (current legislative requirement is minimum U = 1.5 W/m^2K).

Figure 4. Illustration of the elements of the building thermal envelope upgraded in the second level of improvement

For the third level of improving the performance of the building, the aim was to reach the legislation requirement of the energy performance for the new buildings, which is **C energy grade**. This includes all of the measures defined within the second level of improvement and the additional measure of thermal insulation of the street facade, which is illustrated in ***Figure 5***. The insulation of the street facade should be performed by installing a thermal insulation layer of 12 cm of stone wool, but since the street facade is characterized by a relatively reduced facade plastic, this intervention also includes removing all layers up to the load-bearing layer of the wall and reworking the facade in accordance with the existing condition in terms of material and geometric characteristics. Work on this facade would require a long-term disruption of pedestrian traffic since the walkway in front of the building is very small. This is considered one of the most complex refurbishment measures on the building envelope, but also the one that influences the most on the perception and appearance of the building. Although this facade in not in any heritage protection regime, its stylistic features should not be lost due to refurbishment works.

Figure 5. Illustration of the elements of the building thermal envelope upgraded in the second level of improvement



4. Results and discussion

When analyzing the results of the proposed improvement levels through a defined set of measures on refurbishment of the building thermal envelope, as illustrated in Table 1., it can be seen that energy savings range from **21.7%** for improvement level 1, to **51.4%** for improvement level 2 and almost **60%** for improvement level 3, compared to the existing state. Primary energy is given only as an illustration, since it is used for the calculation of CO_2 emissions. Since it depends on the energy carrier, whose improvements haven't been part of the proposed sets of measures, it remained the same in all three improvement scenarios. Thus, reductions in CO_2 emissions occur only as the result of building's thermal envelope improvements, and are significant in improvement levels 2 and 3: respectively **53.4%** and **64.3%.**

The annual heating expenses are calculated by the price list from the Public Utility Company of the Belgrade Power Plant[4] and the calculated energy need for heating. The data on the actual heat energy consumption form the building, which are often compared to the calculated energy have not been taken into account, since the variations in climatic conditions for each heating season, as well as the changing patterns of occupancy and daily routines, significantly influence the heating energy consumption and should be measured in a very precise and systematic way in order to be relevant. The research of the influence of the occupant behaviour on energy efficiency (Gram-Hanssen, 2013) show that completely identical buildings can have the heating consumption that varies with a

[4] https://beoelektrane.co.rs/cenovnici/

factor 2-3 depending on the user behaviour, while the studies confirmed that the rebound effect of energy consumption for heating after retrofit is approximately 20% (Sorrel et al.,2009).

Table 1. Energy performance, CO_2 emissions and energy costs for the existing state and defined improvement levels

CONSUMPTION	EXISTING STATE	IMP. LEVEL 1	IMP. LEVEL 2	IMP. LEVEL 3
energy class	**F**	**E**	**D**	**C**
Energy need for heating per m^2 (annually) [kWh/m^2a]	**156,73**	**122,76**	**76,12**	**64,24**
Energy need for heating [kWh]	467.005,79	365.800,02	226.808,46	191.420,83
Primary energy [kWh]	884.346,16	829.060,74	412.533,26	316.065,21
CO_2 emissions [kg CO_2]	291.834,23	273.590,04	136.135,98	104.301,52
annual heating expenses [RSD]	4.100.310,84	3.211.724,18	1.991.378,28	1.680.674,89

The expenses of the proposed refurbishment measures defined by three improvement levels are derived based on the prices of all related construction works, which have been significantly influenced by the pandemic crisis (increase in 30-40%). The list of all the related categories of construction works and their prices are given in Table 2.

Table 2. Investments related to defined improvement levels and proposed refurbishment measures, per category of construction works

prices of conducting refurbishment measures	IMP. LEVEL 1	IMP. LEVEL 2	IMP. LEVEL 3
demolition [RSD]	3.574.738,7	4.781.489,7	5.664.740,9
window replacement [RSD]	0.00	14.673.029,8	14.673.029,8
facade works [RSD]	10.425.529,4	12.681.804,2	17.981.856,1
final works [RSD]	1.880.928,4	4.075.787,3	4.362.802,6
TOTAL INVESTMENT [RSD]	15.881.196,5	36.212.111	42.682.429,4

For the purpose of the cost-benefit analysis, we need to calculate the payback period of each of the improvement scenarios. As the cost indicator net present value (NPV) is calculated. In this case, the cash flow represents year savings in energy consumption, while the discount rate and the projections of the rise of the prices in district heating systems were found in literature (Stanišić, 2017), and set to 2% and 4% respectively. Rather high payback periods were obtained for all three improvement scenarios, **of about 16 years**, which correlates to the results of similar calculations found in literature (Stanišić, 2017; Ćuković Ignjatović et al., 2015). Having this in mind, we must evaluate energy savings and reductions in CO_2 emissions when discussing the improvement scenarios.

The improvement level 1, which is defined by the insulation of courtyard facade, brings to only 6% in CO_2 emissions reductions and 21.7% in energy savings. Rather high investment is related to a complexity of the construction works which are related to the proposed refurbishment measure: all the “hidden“ expenses include scaffolding, the removal of existing facade layer, dismantling and re-mounting of the exterior split system units, as well as all the linings, gutters etc.

The improvement level 2, which besides the refurbishment of the courtyard facade also includes the insulation of overhangs and slabs towards attic space, as well as a large group of works on window replacement, cuts down CO_2 emissions and energy consumption in half. This illustrates the influence of the transparent parts of the thermal envelope on energy performance, because the window replacement lowers the thermal loses not only through transmission loses but also through lowering the infiltration and ventilation loses. Also, the transparent parts of the thermal envelope mostly influence the comfort in summer months and energy need for cooling. Thus, their characteristics need to be carefully studied, since the balance between enabling solar heat gains in winter and transient periods and preventing overheating in summer months plays the crucial role in moderate climates. Having this in mind, we might question the decision to skip this measure in the first improvement level. Reasoning behind this decision lies again in the “hidden“ works that follow the window replacement, if done properly. Lining on the window sills also needs to be replaced and refurbished, and this requires scaffolding, so it would be the best if these works are combined with the works on the facade refurbishment which also demand it. Generally, with complex facades, it is very hard to split these two measures, and the most favorable situation is to do these two sets of refurbishment measures as part of one package.

The difference in investments between the improvement levels 2 and 3 is minor in comparison to almost 10% increase in both cuts in CO_2 emissions and energy savings. Since the payback periods of both investments are the same, it is reasonable to choose the model which makes the most of the direct benefits of the refurbishment. Also, the most ambitious refurbishment scenario affects all the issues in the thermal envelope of the building, not leaving any of its parts unimproved. This mostly relates to the issue of the refurbishment of the main, street facade. Since this is a municipal administrative building, it should set an example of the adequate treatment of buildings in the refurbishment process. It should be showcased on this building type, that small additional efforts and investments in keeping the valuable architectural features should be encouraged.

5. Conclusion

Improving the energy efficiency can bring a whole range of positive effects in the economy and in society. However, the energy efficiency programs are often evaluated only on the basis of the energy savings achieved. The result of such an assessment is that the overall value of improvement in the field of energy efficiency is significantly underestimated. The improvement in the field of energy efficiency can produce significant positive effects at the macro level, from economic, through social and environmental.

The implementation of energy efficiency projects in public buildings is the right way for countries with rather low level of energy efficiency, such as Serbia, to achieve a number of benefits for the society. The results of this work indicate that the renovation of buildings leads to a significant reduction in CO_2 emissions, as well as to significant economic savings, as the most obvious direct benefits. The most obvious indirect benefits are lowering of air pollution and redirecting the money used for energy bills to different fields. This is especially important when we speak of public buildings because the money saved belong to all citizens. But also, a series of other indirect benefits are linked to the refurbishment of buildings, of which some can be traced and valorized through money savings, like increase in jobs that are created in the refurbishment process or cuts in the medical expenses of illnesses linked to pollution. However, these are often hard to trace on the level of a single building refurbishment, but they should be kept in mind.

An adequate management of benefits proves the responsibility towards taxpayers, whose funds are used to implement a large number of energy efficiency projects in public buildings in Serbia. The focus of this paper was on the short-term effects of renovation of public buildings. It is possible to imagine that some effects would have more long-term consequences. The long-term effects of such renovations could be an interesting topic for future research.

References

Botzler S., Dahmen, J. (2017) *Evaluation and specification of wider benefits of deep renovation measures.* Technical report. DOI: 10.13140/RG.2.2.28608.23043

Bull, R., Chang, N., Fleming, P. (2012) The use of building energy certificates to reduce energy consumption in European public buildings. *Energy and Buildings*, 50. DOI:10.1016/j.enbuild.2012.03.032

COM (2019) 640 final. *The European Green Deal*. Brussels, 11.12.2019

COM (2020) 662 final. *A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives* (SWD (2020) 550 final); Communication from The Commission to The European Parliament, The Council, The European Economic and Social Committee and The Committee of The Regions, Brussels, 14.10.2020.

EC, Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the Energy Performance of Buildings. Official Journal of European Communities 04.01.2003, L1/65-71.

EC, Directive 2009/28/EC of the European parliament and of the Council of 23 April 2009 on the Promotion of the use of energy from renewable sources and amending and subsequently repealing Directive 2001/77/EC and 2003/77/EC, Official Journal of the European Union 5.06.2009, L 140/16.

EC, Directive 2010/31/EC of the European Parliament and of the Council of 19 May 2010 on the Energy Performance of Buildings (recast), Official Journal of the European Union 18.06.2010, L 153, 13-35.

EC, Directive 2012/27/EU of the European parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC, Official Journal of the European Union 14.11.2012, L 315/1.

Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast) (Text with EEA relevance.), Official Journal of the European Union 21.12.2018, L 328/82.

EC, Directive (EU) 2023/2413 of the European parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652, Official Journal of the European Union 31.10.2023, Series L.

Gram-Hanssen, K. (2013) Efficient technologies or user behaviour, which is the more important when reducing households' energy consumption? *Energy Efficiency*, Vol. 6, DOI 10.1007/s12053-012-9184-4

Herring H. (1999) Does energy efficiency save energy? The debate and its consequences. *Applied energy,* 63, pp.209-226.

Ignjatović, D., Zeković B., Ćuković Ignjatović, N., Đukanović, Lj., Radivojević, A., Rajčić, A. (2021) Methodology for Residential Building Stock Refurbishment Planning—Development of Local Building Typologies. *Sustainability*, *13*(8), DOI: 10.3390/su13084262

Ionescu, C., Baracu, T., Vlad, G., Necula H., Badea, A. (2015) The historical evolution of the energy efficient buildings. *Renewable and Sustainable Energy Reviews*. DOI: 10.1016/j.rser.2015.04.062

Jovanović Popović, M., Ignjatović, D., Radivojević, A., Rajčić, A., Đukanović, Lj., Ćuković Ignjatović, N., Nedić, M. (2013) *Nacionalna tipologija stambenih zgrada Srbije/National typology of residential buildings in Serbia*. Belgrade: Faculty of Architecture University of Belgrade&GIZ.

Jovanović Popović M.; Ignjatović D.; Rajčić A.; Đukanović Lj.; Ćuković Ignjatović N.; Nedić M.; Zeković B.; Živković B.; Sretenović A.; Kotur D.; Đurišić Ž. (2018a) *Zgrade školskih i predškolskih ustanova – metodološki okvir formiranja tipologije i poboljšanja energetske efikasnosti/ School and Kindergarten Buildings – A methodological framework for the formation of typology and the improvement of energy efficiency*. Belgrade: Faculty of Architecture University of Belgrade & GIZ. Available at: http://eeplatforma.arh.bg.ac.rs/en/publications/school-and-kindergarten-buildings-%E2%80%93-a-methodological-framework-for-the-formation-of-typology-and-the-improvement-of-energy-efficiency (last accessed 31.01.2024.)

Jovanović Popović, M., Đukanović, Lj., Nedić, M. (2018b) Energy refurbishment of public buildings under cultural heritage protection in Serbia: Constraints and potentials. Thermal Science**,** 22. DOI: 10.2298/TSCI170601226J

Lević, B., Đukanović, Lj., Radivojević, A., Dimitrijević, B. (2023) Potentials for a complex and integrated refurbishment of post-war housing stock of Serbia. Energy Efficiency, 16:93. DOI: 10.1007/s12053-023-10171-z

Mihić, M., Vučković, A., Vučković, M. (2012) Benefits management in energy efficiency projects in Serbian public buildings. *Management*. DOI: 10.7595/management.fon.2012.0003

Miletić, N., Ignjatović, D., Zeković, B., Ćuković Ignjatović, N. (2022) Energy efficient refurbishment of municipal public buildings in Belgrade, Serbia. In: Maksimović S. & Kosić-Jeremić S. (Eds.), *Proceedings of international conference on Contemporary Theory and Practice in Construction XV (STEPGRAD2022), Banja Luka, June 16-17, 2022.* (pp. 160-169). Banja Luka: University of Banja Luka Faculty of Architecture, Civil Engineering and Geodesy. DOI: 10.7251/STP2215160M

Ministry of Construction, Transport and Infrastructure of Republic of Serbia (2009) Law on planning and construction. The Official Gazette of Republic of Serbia No. 72/2009.

Ministry of Construction, Transport and Infrastructure of Republic of Serbia (2011) Rulebook on energy efficiency in buildings. The Official Gazette of Republic of Serbia No. 61/2011.

Ministry of Construction, Transport and Infrastructure of Republic of Serbia (2012) Rulebook on conditions, content and method of issuing energy performance certificates. The Official Gazette of Republic of Serbia No. 69/2012.

Ministry of Construction, Transport and Infrastructure of Republic of Serbia (2022) Long term building renovation strategy Republic of Serbia until 2050 (LTRS). The Official Gazette of Republic of Serbia No. 27/2022.

Ministry of Energy, Development and Environmental Protection (2013) Draft of the Energy Development Strategy of the Republic of Serbia for the period up to 2025, with projections to 2030. Available at: http://energetskiportal.rs/dokumenta/Strategije/Nacrt%20strategije%20razvoja%20energetike%20Republike%20Srbije%20za%20period%20do%202025.%20godine%20sa%20projekcijama%20do%202030.%20godine.pdf (last accessed 31.01.2024.)

Ministry of Energy and Mining of Republic of Serbia (2013) Law on efficient use of energy. The Official Gazette of Republic of Serbia No. 25/2013.

Ministry of Energy, Development and Environmental Protection (2013) National Renewable Energy Action Plan. Available at: https://climate-laws.org/document/national-renewable-energy-action-plan_424b (last accessed 31.01.2024.)

Ministry of Mining and Energy (2021) Law on energy efficiency and rational use of electric energy. The Official Gazette of Republic of Serbia No. 40/2021

Ministry of Mining and Energy (2022) Rulebook on conditions for distribution and use of resources for application of measures for improvement of energy efficiency. The Official Gazette of Republic of Serbia No. 12/2022.

Mlecnik E. (2012) Defining nearly zero-energy housing in Belgium and the Netherlands. Energy Efficiency. DOI: 10.1007/s12053-011-9138-2

Pucar M. (2019) Nauka i praksa, stanje i perspektive razvoja gradova u svetlu klimatskih promena u Srbiji. In: Stojkov B.&Pantić M. (Eds), *Gradovi Srbije u Budućnosti*. (pp.109-114) Beograd: Akademija inženjerskih nauka Srbije i Akademska misao.

Petrović Bećirović, S., Vasić, M. (2013) Methodology and results of Serbian Energy-Efficiency Refurbishment Project. Energy and Buildings 62, DOI: 10.1016/j.enbuild.2013.03.027

Santamouris, M., Vasilakopoulou, K. (2021) Present and future energy consumption of buildings: Challenges and opportunities towards decarbonization. e-Prime - Advances in Electrical Engineering, Electronics and Energy 1, 100002.

Radivojević, A.(2003). Experiences and trends in the development of standards in the field of thermal protection in Serbia and in the world. In J. Popović (Ed.), *Energy optimization of buildings in the context of sustainable architecture. Volume 1 - Analysis of the construction stock structure*. Belgrade: Faculty of Architecture, University of Belgrade. pp. 99–123

Sorrel, S., Dimitropoulos, J., Sommerville, M. (2009) Empirical estimates of the direct rebound effect: a review. *Energy Policy*, Vol. 37. DOI: 10.1016/j.enpol.2008.11.026

Stanišić N. (2017) *Makroekonomske koristi od unapređenja energetske efikasnosti u stambenim zgradama u Srbiji*. Beograd: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

WHO (2019) Health impact of ambient air pollution in Serbia A CALL TO ACTION. Denmark: WHO Regional Office for Europe.

WCED (1987) *Our Common Future*. Oxford: Oxford University Press.

Đukanović, Lj., Ignjatović, D., Ćuković-Ignjatović, N., Rajčić, A., Lukić, N., Zeković, B. (2022) Energy refurbishment of Serbian school building stock – A typology tool methodology development. *Sustainability*, 14, 4074. DOI: 10.3390/su14074074

Ćuković Ignjatović, N., Ignjatović, D., Zeković B. (2020) Improving energy efficiency of kindergartens in Serbia: Challenges and Potentials. *Thermal Science 24/6A,* DOI: 10.2298/TSCI200323273C

Ćuković Ignjatović, N., Ignjatović, D., Stanković, B. (2016) Possibilities for energy rehabilitation of typical single family house in Belgrade—Case study. Energy and Buildings, Vol. 115 DOI*: 10.1016/j.enbuild.2015.08.010*

COST-BENEFIT ANALIZA ENERGETSKOG RENOVIRANJA ZGRADE – STUDIJA SLUČAJA JAVNE OPŠTINSKE ZGRADE

Apstrakt: Za postizanje tranzicije ka klimatski neutralnoj, čistijoj i zdravijoj životnoj sredini, moramo se pozabaviti pitanjima koja najviše doprinose klimatskim promenama i zagađenju, preko prekomerne potrošnje fosilnih goriva i neefikasnog korišćenja drugih resursa. Izgradnja i eksploatacija zgrada je svakako jedno od ovih pitanja, uz procenu da zgrade troše oko 40% ukupne energije (EU). Jedna od strategija koja se smatra najefikasnijom u povećanju resursa i energetske efikasnosti građevinskog sektora je renoviranje starih zgrada koje više ne ispunjavaju kriterijume za postizanje adekvatnog komfora uz minimalnu potrošnju energije. Njihovo renoviranje, nasuprot njihovom rušenju i izgradnji novih, donosi brojne koristi za životnu sredinu, a takođe pokreće tranzicije čitavih gradova i zajednica ka otpornijem i boljem okruženju. Nedavne politike (Direktive o energetskoj efikasnosti, EU Green Deal, Nova evropska inicijativa Bauhaus) takođe naglašavaju važnost renoviranja zgrada i postavljaju ciljeve za ambiciozne stope renoviranja za ceo fond zgrada. Istovremeno, ističu važnost renoviranja javnih zgrada, zbog pozitivnih implikacija koje ono ima u smislu izložbene i obrazovne svrhe. Ovaj rad predstavlja studiju slučaja opcija obnove za karakterističnu opštinsku zgradu, kroz analizu troškova i koristi (cost-benefit) različitih scenarija renoviranja.

Ključne reči: Energetska efikasnost, renoviranje zgrada, cost-benefit analiza.

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Ignjatović Dušan, PhD, Professor, University of Belgrade – Faculty of Architecture, is with an over thirty years of experience in architectural design and practice, research and education. Over thirty realized buildings and interiors in Serbia and abroad, more than 40 conceptual projects and a large number of award-winning competitions works. Specialized in the field of sustainable architecture and building refurbishment, holds a 300 and 381 licenses, LEED GA license, and ITC Thermographer Level 1 license. Co-author of several monographs, author of numerous chapters in monographs and works published in scientific journals, proceedings of international conferences and professional studies.

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