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SUSTAINABLE RENOVATION OF BUILDING ENVELOPES

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Abstract *Sustainable building is one of the important segments of sustainable development, and includes the use of building materials that are not harmful to the environment, then ensuring durability and energy efficiency in the design and use of the building and waste management from construction to demolition of buildings. Sustainable building implies seven principles, which must be considered from design, through construction work, and use and maintenance, and eventually demolition. In the last ten years, sustainable building principles and the standard of almost zero energy consumption - Net Zero Energy Building (NZEB) have been present in the European Union (EU) and beyond, in the construction of new buildings, while in Serbia and Bosnia and Herzegovina (B&H) they are still not present. Looking at the renovation of existing buildings, depending on the type of building and location, the NZEB standard is still not present even in the EU. In this research, the sustainable renovation of building envelopes (kindergarten and residential building) is presented and analyzed according to the NZEB standard of the country in the immediate surrounding, that is in the EU (Republic of Croatia), because the values of energy consumption parameters of the mentioned standard have not yet been defined in the territory of B&H and Serbia.*

Key words: *sustainability, energy efficiency, renovation, building, envelope*

ODRŽIVA OBNOVA OMOTAČA ZGRADA

Apstrakt *Održiva gradnja je jedan od značajnih segmenata održivog razvoja, a uključuje upotrebu građevinskih materijala koji nisu štetni po životnu sredinu, zatim obezbijeđivanje trajnosti i energetske efikasnosti pri projektovanju i korištenju zgrade i upravljanje otpadom od gradnje do rušenja građevina. Održiva gradnja podrazumijeva sedam principa, o kojima se mora razmišljati od projektovanja, preko izvođenja, te korištenja i održavanja, pa eventualno na kraju i uklanjanja. Posljednih deset godina, održivi principi gradnje i standard skoro nulte potrošnje energije (NZEB) su prisutni na prostoru Evropske unije (EU) i šire, pri gradnji novih zgrada, dok u Srbiji i Bosni i Hercegovini (BiH) još uvijek nisu prisutna. Posmatrajući obnovu postojećih zgrada, u zavisnosti od tipa zgrade i lokacije, NZEB standard još uvijek nije prisutan ni u EU. U ovom istraživanju prikazana je održiva obnova omotača zgrada (vrtića i stambene zgrade), analizirana prema NZEB standardu države neposrednog okruženja, koja je u EU (Republika Hrvatska), jer vrijednosti parametara potrošnje energije navedenog standarda još nisu definisane na području BiH i Srbije.*

Ključne reči: *održivost, energetska efikasnost, obnova, zgrada, omotač*

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1. INTRODUCTION

According to the Renovation Wave Strategy, published by the European Union (EU) in October 2020 [1], only 11% of the existing building stock in the EU undergoes some level of renovation each year. However, very rarely do renovation works deal with sustainable construction principles and with that the energy efficiency that "deep" renovation belongs to. The weighted annual rate of energy renewal is low and amounts to about 1%. Across the EU, "deep" renovations that reduce energy consumption by at least 60% [2] are carried out in only 0.2% of the building stock per year, and in some regions, energy renovation rates are practically absent. At this rate, reducing CO_2 emissions from the construction sector to zero would take centuries.

The most important part of the new strategy is the key principles for the renovation of buildings until 2030 and 2050, which, among other things, promote the use of organic materials. Bosnia and Herzegovina, as well as Serbia, although they are not members of the European Union, are signatories to the Treaty on the Establishment of the Energy Community, [3], [4] which is why they are obliged to develop a Building Reconstruction Strategy. The obligation to develop the Strategy stems from the Decision of the Ministerial Council of the Energy Community from October 2015 [5] by which the Energy Community adopted the binding application of Directive 2012/27/EU on energy efficiency [6] from 2017. The strategy for the renovation of buildings in Bosnia and Herzegovina (by entities, the Strategy for the renovation of buildings in the Republic of Srpska until 2050) was presented to the public at the ENEF Symposium in November 2019 [7], but it was not officially adopted. Encouraging investment in the reconstruction of the National Construction Fund of the Republic of Serbia presented in November 2021 [8]. The strategies of B&H and Serbia are guided by cost-optimal analyzes prescribed by Regulation no. 244/2012 [9], but they do not emphasize the renewal of building envelopes with renewable and organic products and materials, but only the use of renewable energy sources.

In the existing building stock, the most important thing for long-term sustainability from the aspect of criteria related to energy exploitation is the upgrading of all envelope components and installations that affect its consumption. If we look at the content analyzes of relevant research projects in the EU and in our country, related to energy optimization in buildings, we will see that all assessments and activities are carried out in accordance with valid standards [10], [11], [12], [13].

In addition to improving energy standards, the renovation of buildings from the perspective of sustainable development should include changes to the building to the extent that it meets the needs of current and future users [14]. Architects with the necessary skills should be involved from the outset in the planning process, as they can illustrate the potential of the building as a whole and help ensure that the building's energy performance will be integrated into the overall sustainable concept. Providing goals and a pattern of key indicators are prerequisites for the concept of sustainability to come to life. In order to obtain concrete action strategies, architects need tools to identify the effects and interactive connections of social, economic and environmental measures, as well as their application in

the planning and/or construction process. Numerous tools and aids are available, such as audit lists, computer programs or assessment and certification of buildings to address sustainability issues in construction [15]. As from 2020 in the European Union (EU) the standard is that new buildings have almost zero energy consumption - NZEB (Net Zero Energy Building) [16], [9], the research is guided by the principles of sustainable renovation of buildings with an emphasis on the envelope and reaching standards of almost zero energy consumption of the building. Legislation in Bosnia and Herzegovina does not require the construction of NZEB buildings, nor does it provide incentives for their construction, although it has been mentioned since 2011 in legislative documents [17]. Sustainable construction includes the use of building materials that are not harmful to the environment, energy efficiency of buildings and waste management from construction and demolition of buildings and must ensure durability, quality of design and construction, with economic and environmental acceptability [18].

Today, sustainable construction implies seven principles, which must be considered during design and fully applied during construction, use and maintenance, Figure 1.



Figure 1. Principles of sustainable construction [19]

2. PRINCIPLES OF SUSTAINABLE RENOVATION OF KINDERGARTEN

Energy consumption also depends on the compactness of the building, i.e. the area of the envelope around the heated space and the volume of that space, the so-called shape factor. A lower shape factor value indicates that the building will consume less energy for heating. Research shows that for the design of the energy need for heating a passive building, a building that would be in energy class A+ would have to have a shape factor below the value of 0.70 [20], [21]. Analyzing the renovation of the kindergarten in Banja Luka, the Republic of Srpska, Bosnia and Herzegovina, according to the standard solution, if only the existing building will renovate, the total capacity would be for 86 children. The upgrade of the kindergarten would solve additional spaces, and the estimated total capacity would be for 120 children. The proposed concept indicates sustainable design, as it will plan to fully of use the existing and newly space. In a

sustainable solution, it is planned to demolish the parapet and maximize the opening on the south and west side, creating a direct connection with the yard of the building, which improved both the spatial and functional solution of the kindergarten, Figure 2.

The renovation of the gallery will plan so that the building on the south side has two floors and opens to the south as much as possible, and closes to the north, descending through the roof again to the level of one floor.



Figure 2. Standard kindergarten renovation (left) and sustainable kindergarten renovation (right)

The shape factor of the building, which was improved by upgrading the gallery, will plan, following the trends in the EU, and the potential of B&H itself in that building material, in wooden construction. The concept of sustainability is supported throughout all construction segments, both in the basic structure and in the envelope. Wood, as a renewable building material, is used for the new envelope of the existing part and for the upgrade of the kindergarten, Figure 3., while the renovation of buildings and the use of the existing basic structure supports the concept of sustainability, which advocates the reuse of materials and thus the reduction of waste from the removal of existing building materials.

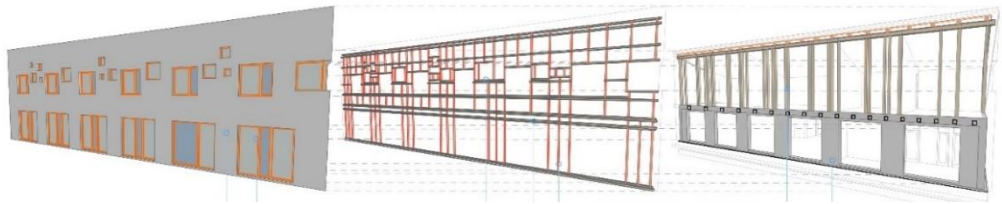
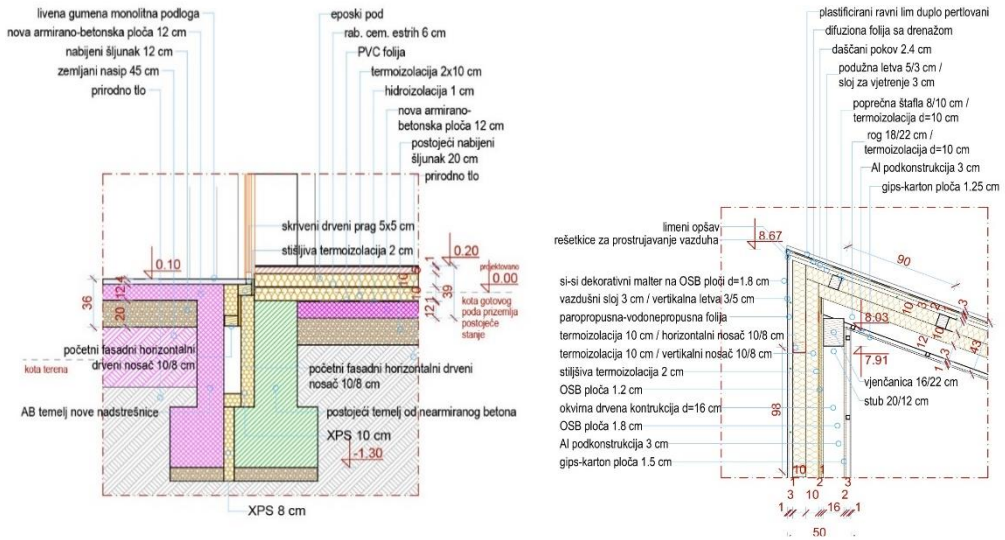


Figure 3. Diagram of sustainable shell renewal according to TES (Timber Energy System) principles

Properly designed and executed technical details on the building envelope will solve the durability of the building. On the south side of the building, the wall at the base of the building is thermally insulated. The designed new wooden canopy for protection from the sun is separated from the existing kindergarten building. Excavation for the foundations of the canopy created an opportunity to intervene on the thermal insulation of the existing foundation, which are today's principles of proper foundation insulation in new buildings, Figure 4.

The development of the envelope in a sustainable solution was guided by a cross wooden substructure filled with thermal insulation, which was installed alternately, to reduce thermal bridges to a minimum. The complete load-bearing

structure is wooden. Transverse wooden beams are attached to the massive wooden rafters on the upper side and thermal insulation is installed between them, as well as between the rafters, thus reducing the thermal bridges that



appear over the wooden rafters in the roof structure, Figure 4.

Figure 4. Details - improvement of the existing foundation and new foundation for the canopy (left), connection of the facade wall and the roof of the upgraded gallery (right)

Standard renovation, without upgrading, while respecting the improvement of the envelope to the prescribed U-value (U_{max}) cannot reach the energy need for heating prescribed by the regulations, i.e. energy class C, neither residential buildings, nor educational institutions, because the permitted class is not even prescribed for kindergartens [22]. The sustainable solution envisages the construction of a wooden substructure with insulation from expanded polystyrene (λ=0.034 W/mK) with a thickness of 30 cm and a final layer of silicate-silicone precious mortar, then windows with wooden frames and three-layer thermal insulating glass with low-E coating and filled with argon (U_w=0.90 W/m^{2}K). The floor is waterproofed with 20 cm of extruded polystyrene (λ=0.035 W/mK), over which protection from PVC foil is placed, followed by cement screed and the final layer - epoxy floor. Since the roof structure is above the heated gallery space, it was planned and implemented to install a layer of mineral wool (λ=0.034 W/mK) with a thickness of d=35 cm on the roof structure. Properly resolved thermal bridges and sealing with the help of RAL window installation, estimates the expected air flow reduced to the volume of heated air, at a pressure difference between the internal and external air of 50 Pa at 1.00 h-1.

Fan convectors are installed in all rooms where children and employees stay. During the heating period, two air-water heat pumps are used as a heat source. Heat pumps have the possibility of cooling. The heating capacity of each heat pump at an outside temperature of -20°C is 16 kW, and the cooling capacity is

13.1 kW. One heat pump has an integrated hot water boiler with a volume of 230 liters in which an electric hot water heater is installed.

The ventilation of the children's rooms is achieved through four recuperative ventilation systems with a capacity of 900 m³/h, recovery rate of 75% with a pressure drop of 170 Pa, which are installed in the attic space. The amount of air is selected according to the number of people in these spaces (for 25 people up to 900 m³/h). The ventilation system has its own control and the ability to work up to an outside temperature of -15 °C. The technical system of the kindergarten was supplemented with photovoltaic panels, in order to meet the requirement for the production of energy from renewable sources. A canopy was designed on the southern side of the kindergarten, which serves to improve protection from the summer sun, and which also served as a support for photovoltaic panels. The total area of the panels is 47 m^2. Efficient built-in 60x60 cm LED lighting designed for children's rooms. In the communication zones, i.e. the corridors, overhead LED lighting was designed, circular in shape with a lamp radius of 22 cm. The systems were expanded with a presence control system, which significantly reduced the amount of energy needed for lighting. Presence sensors were selected in all toilets and rooms in accordance with the useful floor area.

2.1. Contributions from the sustainable renovation of kindergartens

Comparing the classic/standard renovation of the kindergarten with a sustainable solution, in order to reach the NZEB standard at the same time, it is necessary to improve the shape factor of the building, from the existing 0.79 to 0.68, as well as to have lower U-value for the envelope than are valid prescribed by the Rulebook. According to the sustainable solution, the building met the prescribed U-value and the coefficient of transmission loss per unit area of the heated part of the building. The annual energy need for heating per unit of useful area of the heated part of the building $Q''_{H,nd}$ amounts to 27.93 kWh/m^2a, which according to the Rulebook on conducting energy inspections of buildings and issuing energy certificates of the Republic of Srpska [23] reaches the permitted energy class B for buildings intended for education and culture, as well as for all other offered categories of buildings.

The calculated annual produced electricity from RES at the location of the building is $EEL_{,RES}$ = 6984.42 kWh/a. The system consists of 28 monocrystalline silicon panels with non-ventilating modules. The dimensions of one panel are 1640x992x35mm. The projected production of energy from renewable sources is 45.41% and the consumption of primary energy per unit of useful area of the heated part of the building is E_{prim} = 41.30 kWh/m^2a. Taking into account the energy analysis, the required energy for heating in the case of a standard renovation would amount to about 92 kWh/m^2a [24], and in the case of a sustainable renovation about 28 kWh/m^2a, while the delivered energy in the case of a standard renovation would amount to E_{del} = 14942.37 kWh/a, and for sustainable renewal E_{del} = 9204.57 kWh/a.

In the countries of the former Yugoslavia that are now in the European Union (the Republic of Croatia and the Republic of Slovenia), in which NZEB is

prescribed, the maximum allowed value of annual primary energy per unit of useful area of the heated part of the building is 50 - 100 kWh/m^{2}a, depending on the type of building and that it is a new building or renovation/major reconstruction. There are still no prescribed NZEB values in B&H, but the concept of an improved kindergarten solution with primary energy consumption per unit of useful area of the heated part of the building of E_{prim} = 41.30 kWh/m^{2}a would be able to reach even lower than the stated conditions of NZEB in these countries of the EU. If we look at the gross area of the existing kindergarten building, which is 465.59 m^2, and the sustainable solution is 814.10 m^2, we will get that the price per unit of gross area is 30% lower for the sustainable solution.

In addition, the sustainability of the concept of a sustainable kindergarten is that the number of users would also increase, by 34 children, which is an increase in capacity by 28%, as would the difference in receiving financial resources from the users. Analyzing the cost of children's stay, by expanding the capacity of users, the difference between standard and sustainable renewal of the initial investment would pay off in three years.

3. SUSTAINABLE RENOVATION OF A RESIDENTIAL BUILDING

The existing residential building shown in, Figure 5, is an example of a free-standing building (MFH-multy family house) that was built in 1964 and is a typical example of the construction period from 1961-1980. It is estimated that B&H has about 5,215 such buildings with 103,141 residential units, while Serbia has 17,265 buildings with 223,910 apartments [11], [12]. The original structural system of the building was a massive brick construction with only horizontal reinforced concrete cerclages, and after the earthquake in 1969, vertical reinforced concrete cerclages and reinforced concrete walls were added to the building. This building does not have thermal insulation on the envelope and has wooden windows - joined sashes with two single panes. The building is compact, rectangular in shape without structural protection from solar radiation such as a canopy, balcony or loggia, with a building shape factor of 0.40. Through a detailed energy audit, the calculated value of the energy need for heating the existing selected sample corresponds to the average value specified for typical buildings in the Typologies of B&H and Serbia, an average of about 164 kWh/m^2 [11], [12].

By applying cost-optimal measures related to "deep" renovation of the sample envelope, it is possible to reduce the value of the required energy for heating below 40 kWh/m^2. By applying "deep" renovation to buildings of this type and period, B&H could save 430,658 MWh/a, and Serbia 2,778,105 MWh/a [25].

The sustainable renovation of the building, and with it the building envelope, was carried out from the conceptual design to the details, with an energy analysis and a preliminary estimate and recalculation of the works, in order to determine the energy savings and the economic profitability of the investment. It was concluded that in addition to the renovation of the envelope, for the sustainability of the concept, it is necessary to upgrade the building with new residential units and the addition of new technical systems for the production of electricity and thermal energy, consumable hot water, and the use of rainwater. The sustainable

renovation project, as with the kindergarten, was guided by the TES modular system, which defined five modules for the entire facade envelope (facade panels made of wooden substructure filled with thermal insulation with a wooden window frame) with energy characteristics defined by a cost-optimal analysis in B&H, then adding ramps and elevators, adding balcony modules and establishing energy-efficient technical systems, Figures 5 and 6.

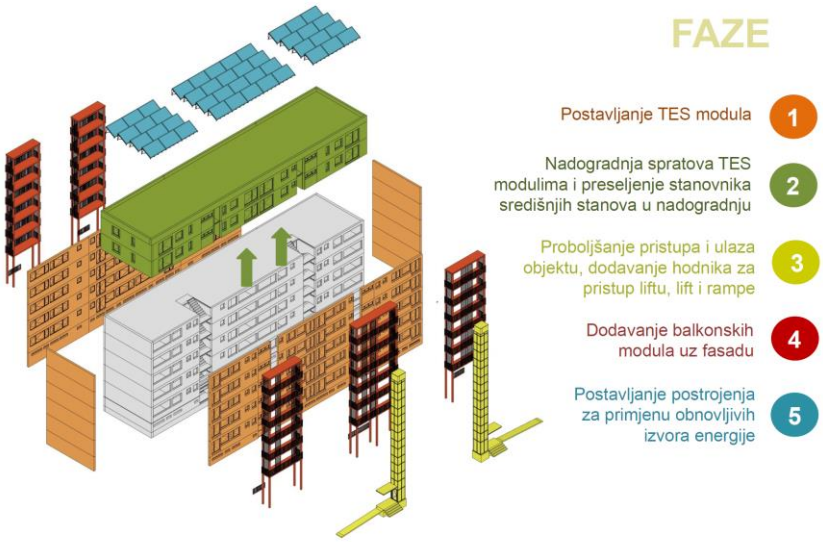


Figure 5. Diagram of sustainable renovation of a residential building

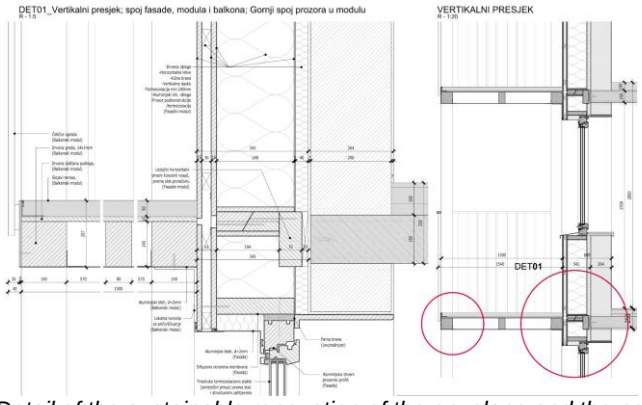


Figure 6. Detail of the sustainable renovation of the envelope and the new balcony

3.1 Contributions from the sustainable renovation of a residential building

Differences in the energy need for heating applying standard (respecting the current rulebook) or sustainable renovation do not exist, because that parameter still determines the energy class of the building in both B&H and Serbia and depends on the height of reaching the U-values on the envelope, while the price indicates that the TES system would in 30 % more expensive than the standard

application of contact facade. With the use of solar panels of 320 m^2, 52746 kWh/a would be achieved, which would amount to 36.1% of the electricity demand. By installing 80 m^2 of solar collectors, 43,572 kWh/a would be achieved, which is 67.8% of the hot water needs. It is possible to collect 411,320 l of rainwater from the roof, which would account for 39.1% of gray water consumption. Due to the current price of electricity on the B&H market, the investment return period for solar panels and solar collectors is estimated at 11 years. Also, due to the price of water, the investment of a rainwater collector is not profitable either, whose investment return period is 15 years. Cost-effectiveness of the renovation of the entire envelope, which was carried out according to the Rulebook of the minimum requirements for energy characteristics in buildings [23], with the cheapest facade system (contact EPS facade), installation of EPS under the mezzanine ceiling above the unheated basement space and above the mezzanine ceiling which is below the unheated ceiling and PVC windows is a total of 6-8 years. Replacing only windows is not an adequate renovation, because by not installing thermal insulation on the envelope, it is impossible to properly install windows and thermal bridges appear, and even that individual renovation, window replacement, has a return on investment period of 14-17 years. By setting up the TES system, the investment return period will be 9-11 years. According to the research in the territory of Bosnia and Herzegovina, every renovation of the envelope is profitable, because the estimated service life of the envelope of buildings is 30 years, while technical systems have 15 years [26]. Sustainable building renovation is not only about improving the envelope and introducing new energy-efficient technical systems, but also about providing the tenants with an accessible, healthy and comfortable living space, so this building, in addition to all of the above, also received an elevator and ramps and landscaping of the outdoor space, which was the only it is possible to realize everything by upgrading the new apartments in the building, Figure 7.



Figure 7. Sustainable renovation of the envelope of residential buildings (left) and landscaping in front of the building (right)

By upgrading two floors (expanding the building by 40%) and introducing all the mentioned technical systems and improving the envelope, with this sustainable solution it was obtained that the price of using the building before and after all the mentioned measures was reduced by 35%.

4. CONCLUSION

Each building and its environment as well as the users of that building are unique and a detailed review must be carried out in order to plan an adequate sustainable renovation. Sustainable renovation of the envelope implies the application of the TES system, as it enables the use of renewable building materials such as wood. Wood is primarily used for the substructure, in which various thermal insulation materials that exist on the market can be installed. In addition, the final layer of the building envelope can be made of renewable materials. The contributions of a sustainable approach to the renovation of buildings are multiple, because in addition to ensuring the comfort of the users and by reducing the cost of capitalization, it extends the life of the building. Sometimes it is impossible to achieve lower consumption by improving the envelope, because it is necessary to change the form factor of the building, which requires upgrades or changes in the thermal zones of the space. Energy analyzes of the sustainable renovation of kindergartens and residential buildings indicate that with the calculated share of energy from renewable sources of about 45%, it is possible to reach a higher percentage than in the NZEB standards, which are prescribed in Croatia, which is 30% share of energy from renewable sources sources in the total primary energy of the building. The economic analysis of the sustainable renovation of the kindergarten, which took into account the retention of only the basic structure of the existing building, indicates that by increasing the gross area by about 40%, the cost of construction works and works on mechanical and electrical installations per m^2 of the gross area of the kindergarten is obtained by 30%. By increasing the usable area of the kindergarten, the number of users is also increased, which in this analysis is an increase of 28% for the NZEB renovation solution. The sustainable renovation of the residential building showed that by increasing the gross area by 40%, the cost of using the building is reduced by 30-35%.

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