ENERGY CONSUMPTION FOR SPACE COOLING AND HEATING DEPENDING ON FLAT ROOF STRUCTURES RENOVATION
Case Study of the Healthcare Center Niš

by

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Since the reduction of energy consumption and efficient energy use, particularly in the building stock, is the priority for contemporary societies, the ways of how to improve the existing buildings should be examined. Flat roofs, as a part of the existing building thermal envelope, are recognized as a field of intervention for improving efficient energy use for space cooling and heating. The topic of the paper is to determine to what extent different improved roof structures affect energy consumption intended to achieve thermal comfort. Comparative analysis of four roof structures was conducted for the building of Healthcare center Niš in Serbia, one improved non-walkable flat roof structure and three green roof systems. Urbancsape extensive green roof system was used in all tested green roof models: non-walkable extensive green roof, walkable extensive green roof, and extensive and intensive green roof systems within walkable terraces. DesignBuilder software was used for energy modelling. The obtained results indicate a slight decrease in energy consumption for building models with green roofs compared to the building model with the improved non-walkable roof structure, along the cooling period, by approximately 1.5%, which is correlated with previous studies in similar conditions. On the other hand, the reduction of energy consumption over the heating period was negligible (less than 1%). Considering the results and predominant usage of commercial Urbanscape extensive green roof system in all green roof models, being characterized by small thickness (10.64 cm) and light structure, and which is predicted to be installed over the already well-insulated roof, the system's role as an additional thermal mass was confirmed.

Key words*: energy consumption, existing buildings, improved roof structure, green roof systems, comparative analysis, flat roofs, renovation*

Introduction

Energy consumption in Serbia relies mainly on non-renewable sources, which certainly does not contribute to the achievement of sustainable goals. Accomplishing and increasing efficient energy use, in accordance with both EU and national targets, should focus on reducing consumption of limited domestic fossil fuel reserves, increasing energy independence, reducing both GHG emissions and air pollutants, and ensuring the implementation of economically viable measures [1]. Since the residential building sector and the public and commercial services sector have the largest share in the final energy consumption when compared to the industrial and transport sectors [1], it is necessary to act proactively to further reduce energy consump-

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tion. In addition to the planned activities for the improvement of infrastructure in the energy sector, one of the ways to increase the energy efficiency of existing buildings (residential, public and commercial) is to improve their envelope through additional thermal insulation. This specifically refers to the buildings designed and built in the period of industrialized/partial prefabricated and industrial/full prefabricated construction, which have a significant share in the building stock. According to statistical data, 95% of residential stock was built before 1992, and it can be assumed that the situation is similar for public and commercial sectors [2].

Intensive construction, which started after World War II (and lasted until the early 1980's) had a priority to provide a basic quality of life while neglecting environmental and energy aspects. Although all relevant regulations of the period were followed, technical characteristics of building design and construction affected the increase in energy consumption in the exploitation phase. The main problems were related to:

- the inadequate connection between structural elements, which caused the appearance of thermal bridges soon after the construction,
- inadequate design and construction of waterproof layer, especially in the flat roof systems,
- insufficient thickness of façade panels, insufficient or non-existence of the thermal insulation layer and usage of inappropriate materials, and
- as well as the usage of inappropriate materials for internal partitions between heated and unheated space.

The aforementioned issues have all caused faster deterioration of structures and additional energy consumption for the purpose of achieving comfort.

The architectural appearance of buildings built in this period is characterized by compact bases and geometric volumes, which is the reason why flat roofs were commonly used.

Based on these data, and having in mind the impact of urbanization on green areas and the fact that flat roofs are unused spaces, the green roof concept has been recognized as an environmentally friendly solution to achieve sustainability of urban areas. In addition to their role in protecting the layers beneath from external influences (which also implies protecting the load-bearing structure), and their role of an additional thermal mass for energy savings [3], the implementation of green roofs could increase environmental and social benefits [4].

The aim of this paper is to reveal to what extent green roofs contribute to the reduction of energy consumption for building heating and cooling in order to achieve thermal comfort when compared to the improved non-walkable flat roof system, and whether green roofs application on flat roofs of existing buildings is justified.

Regulations for flat roofs

In this paper, flat roofs above heated space have been considered. Related to that, national regulations in the field of thermal protection are important for determining the potential improvement of existing buildings in terms of reducing energy consumption to achieve thermal comfort, and they specifically refer to flat roofs.

At the beginning of the period of mass-produced buildings, during 1960's, thermal properties of the materials were neglected, due to the lack of regulation. As a consequence, this resulted in inadequate insulation and significant operating energy consumption. Over time, regulations have been established and improved. For a better understanding of the development of regulations in the field of thermal protection, more specifically for flat roofs, tab. 1 provides an overview of the maximum allowed values of the overall heat transfer coefficient (U-value [$\mathrm{Wm^{-2}K^{-1}}$]) for flat roofs above the heated space. Consideration of the U-values is justified by the fact that it is the first and basic element introduced in the system of thermal calculation, and that is the only parameter that can be consistently monitored from the establishment of the first regulations to contemporary tendencies.

Table 1. Overview of the maximum allowed values of the overall heat transfer coefficient (*U*-values) for flat roofs above the heated space

Regulation	Year	Designation and unit of measurement	Usage domain*	Climate zone		
				I	II	III
Regulation on minimum technical requirements in housing construction	1967	k [Wm^{-2}K^{-1}] (Kcal m^{-2}h^{-1}°C^{-1})	E	0.96 (1.12)		
Regulation on technical measures and provisions for thermal protection of buildings	1970		MV	0.69 (0.80)		
			TB	1.12 (1.30)		
Regulation on Yugoslav standards for heat in civil engineering Standard JUS U.J5.600	1980		MV	0.78	0.65	0.55
			TB	1.00	0.83	0.72
Standard JUS U.J5.600	1987		E	0.75	0.65	0.55
Standard JUS U.J5.600	1998		E	0.50	0.45	0.40
Regulation on energy efficiency in buildings	2011	$U_{\max}$ [Wm^{-2}K^{-1}]	E	0.15 new building		
				0.20 existing building		

* E – every place, MV – middle value, and TB – thermal bridge

The data shown in tab. 1 point out that with each new regulation the maximum allowed *U*-values decreased, *i.e.* that the criterion was intensified. The fact that heat losses are the greatest through the roof structure [5, 6], and bearing in mind the most stringent requirements for roof design [7], there is a reasonable justification for the research of possible improvements of flat roofs on existing buildings.

Based on the general conclusion that thermal envelopes of buildings built before 2012 (when current regulation began to be applied) did not meet up-to-date requirements of thermal protection, which is in correlation with the data that almost 98% of flat roofs are inadequately insulated [8], the question remains how to achieve energy efficiency. This is easiest to solve by renovating the existing flat roof system by increasing the thickness of thermal insulation or implementing the layer into the systems built before the first regulation (from 1967, tab. 1). The implementation of green roofs could also be one of the ways to increase the energy efficiency of buildings. In addition, these systems provide numerous environmental, social and economic benefits, and according to that, it is rather justified to consider their application as an advantage over the addition of a thermal insulation layer in the existing flat roof systems.

Renovation of existing buildings and roof structures

The fulfillment of contemporary requirements in the exploitation phase of buildings mainly refers to providing comfort to users on one side, bearing in mind that people spend approximately 70% of their time inside buildings [9], and reducing negative environmental impacts, *i.e.* efficient use of resources and energy, on the other side. This is achieved by improving existing buildings through various renovation activities that imply structural and/or functional changes. As a multidisciplinary approach to design and construction, the renovation should be conducted in a manner which allows future interventions, in terms of changing form, function, architectural appearance*, etc.*, in order to meet the needs of future generation [10]. This process, which implies repairing and replacing parts of a building, is usually divided into two categories (groups of activities): refurbishment and retrofit [10-12]. The first group of activities is conducted to improve a building in technical terms. In other words, refurbishment refers to bringing a building back to its original state, while meeting the conditions for achieving sustainability. On the other hand, retrofit refers to activities that are required to bring a building into the framework of new requirements, which is related to the implementation of new systems and technologies. The example of retrofit design strategies is shown in fig. 1.

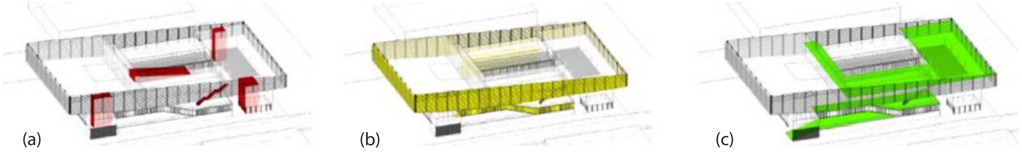

Figure 1. Retrofit design strategies [13]; (a) vertical transportation, (b) shading system, and (c) green roof

Renovation activities are an integral part of the exploitation phase of buildings. The main reason for conducting building renovation is aging and degradation of applied constructive materials and elements. Other reasons to reconsider the renovation are related to improving the aesthetic qualities of a building, increasing usable area, regulation changes, the need to improve technical systems, or changing the purpose of a building. Those activities should be examined since the share of new buildings is very small and it amounts to 1.5-2% of the building stock in developed countries [14]. Besides, 87% of all existing buildings will be in use by 2050 [15]. Demolition of existing buildings and construction of new ones, as an alternative to renovation, is not a sustainable solution, primarily due to significant financial investments, a greater consumption of raw materials and energy, and increased pollution [16].

In terms of flat roof systems, renovation is mainly conducted to ensure their functionality, whereas the majority of unused spaces could become useful areas. Renovation of flat roofs can be also divided into refurbishment and retrofit. Regarding both categories, it is primarily necessary to ensure the functionality of load-bearing structure – first, the roof slab and afterward the other elements, after which the condition of elements of the secondary (non-load-bearing) structure shall be examined. The refurbishment would refer to repairing non-functional elements, their replacement with the same or similar ones, the addition of new layers, for example, a thermal insulation layer in flat roof systems before the first regulation (from 1967, tab. 1)*, etc.* However, retrofit involves more extensive interventions. Within passive design techniques, traditional flat roofs could be transformed in a way to provide natural daylight, natural ventilation, or rainwater collection. Beside the integrated greenery within buildings (green roof systems and systems of vertical greening), renewable energy systems could be implemented, for which flat roofs become particularly significant in terms of solar and wind power exploitation. Green roofs were selected as a retrofit strategy for flat roofs due to their great potential to improve building state not only in a technical way but also to improve aesthetic quality by natural elements.

Green roofs implementation

Green roofs, as natural based systems, are a sustainable solution for retrofitting, especially in densely built urban areas. These systems could mitigate the negative effects of urbanization such as changes in the city microclimate, increased risk of flooding, noise, air pollution*, etc.*, if they are used to a large extent in an urban environment. At a building level, a number of potential benefits have also been identified. In addition to environmental benefits, the economic advantages of green roofs imply energy savings, extended life of the structure, increment in the market value of buildings*, etc.* Social benefits have great importance, and they refer to additional useful space (in case of walkable green roofs), visual experience and the image of a city, as well as improving residents' health.

The structure of a green roof generally consists of vegetation, substrate, filter, drainage and a root barrier. Depending on the set goal(s) of a green roof, the structure elements, vegetation type and materials are chosen. When it comes to energy savings, the intensive green roof type with medium and high vegetation is a better solution due to a higher thermal mass of the newly constructed roof system, unlike the extensive type which is characterized by a lesser thickness of the substrate layer and low vegetation. However, bearing in mind the potential and significance of green roofs implementation on existing buildings, extensive systems are in wider use due to their minor load on the structure. In case of an intensive type, it is necessary to verify the load-bearing capacity and strengthen the elements that do not meet the requirements.

Regarding the structure and the condition of applied elements of an existing flat roof, there are several cases for the establishment of a new roof system, fig. 2. In case when the layers of an existing structure meet the functionality requirements but not the requirements of thermal protection, the thickness of an additional layer of thermal insulation is calculated based on a Model A, fig. 2(a). The installation of new layers is preceded by the removal of the protective waterproofing layer. A flat roof structure modeled in this way is a *duo roof* or *plus roof* system. Repairing or replacements of elements is carried out in case when the existing roof structure does not meet the requirements of functionality. Model B is an example of a complete flat roof renovation, fig. 2(b). In case of an outdated roof structure without a thermal insulation layer that still meets the requirements of functionality, Model C is an example of renovation just by adding the necessary layers over the existing structure and thus making an inverse roof system, fig. 2(c). The examples refer to a warm flat roof structure due to their dominant application in the period of mass construction (95% of the total fund of built flat roofs) [17] and a general structure of a green roof.

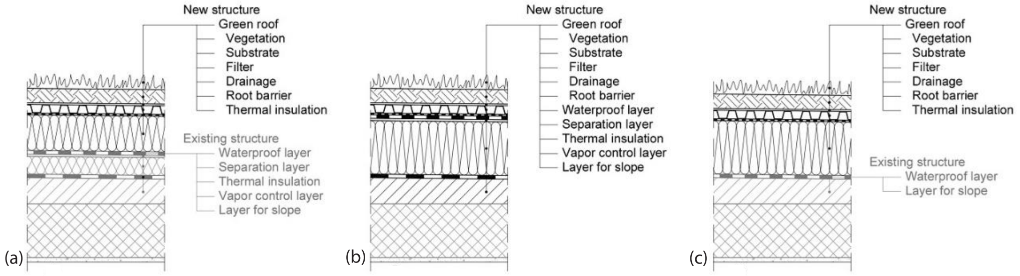

Figure 2. Conceptual models of improved flat roofs by the implementation of a green roof system

Building analysis

The building of primary health care – Healthcare center Niš, fig. 3, was chosen as a typical example for analyzing energy consumption for space cooling and heating, depending on various roof structures improved by refurbishment and retrofitting. This building is selected based on several criteria: urban conditions, *i.e.* the position of the building relative to its environment; the building age (flat roof), *i.e.* construction period or period since the last renovation; construction system and architec-

Figure 3. Healthcare center Niš

tural design of form and envelope – façades and roofs. Also, these criteria were set to determine whether the green roof concept is a suitable solution for retrofitting.

Regarding urban conditions, the Healthcare center is located in the central city zone, which is densely built area with a large share of impermeable surfaces which reduce the amount of green spaces. The age of the building reveals a typical example in terms of the materials applied, construction technologies and lifespan of flat roofs. The building has been used for 35 years, and during that time a couple of interventions on flat roofs were done. Since the previous interventions were not conducted within the existing structure, instead of which only new layers were added, it can be concluded that there is a need for renovation of flat roofs. In terms of the construction system, the building was built in the skeleton type, of which framing and prestressing IMS systems were used. The usage of skeleton systems is in line with sustainability goals. Since this construction system type was widely used, it is justified to consider the renovation of such buildings due to its characteristic of flexibility. This means that the elements of the secondary (non-load-bearing) structure are independent of the load-bearing structure, which provides many possibilities in terms of design and functional organization. In that way, a building could be adapted to future uses. In terms of its architectural design, this building is characterized by a compact basis and geometric volumes that follow the construction system. The fact that flat roofs are unused space, while the green urban areas have become scarce, indicates the possibility of green roofs to compensate, in a large share, area occupied by the building at the ground level, based on which the positive effects on the environment could be expected. Also, by the implementation of green roofs, the building would get a special architectural expression and would be recognizable in surroundings.

By the analysis of the criteria, the justification and importance of considering the implementation of green roofs were confirmed, not only on this example, but also in a broader sense, based on general characteristics of urban areas and existing buildings with flat roofs, inherited from the period of mass construction.

Flat roofs that were considered for renovation are shown in fig. 4 ($K_1 – K_5$). Regarding the structure, roof K_1 encomasses the IMS and the skeleton framing systems. Structural decks are prestressed slabs, d = 7 cm, and reinforced concrete (RC) slabs, d = 12 cm, respectively. The part of the building with the flat roof K_2 was built in a prestressing IMS system, and the thickness of the roof slab is d = 7 cm. Roofs K_3, K_4 , and K_5 are within the part of the building built in the framing system, and RC slabs are d = 15 cm (for K_3 and K_4) and d = 12 cm (for K_5). The elements of the secondary structure, related to thermal calculation, are the same for all considered roofs, fig. 5.

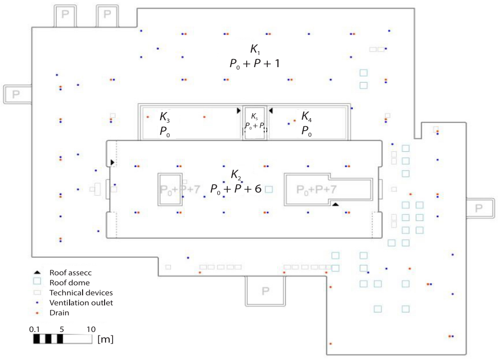

Figure 4. Roofs plane and their levels

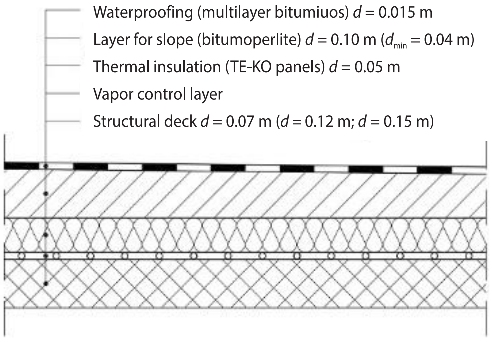

Figure 5. Existing roofs structures

Based on the hygrothermal properties of the materials used and their thicknesses, the *U*-value is calculated and amounts $U = 0.39$ W/m^{2}K (for the roof structure with slab $d = 7$ cm and the layer for a slope $d = 4$ cm). This data indicates the necessity for the roof structures renovation, according to the regulations [7].

All the other elements of the thermal envelope were not taken into consideration for renovation, so the real state, without improving existing structures, was used for further analysis, regardless of their thermal characteristics.

Based on current regulations, for this building type, in the cooling period (from April 15th to October 15th) indoor temperature should be up to 26 °C, while in the heating period (from October 15th to April 15th) minimum allowable indoor temperature is 20 °C [7].

The cooling and heating area within the building is 10691 m^2. The energy used for cooling is electricity, while natural gas is used for heating. Since the energy consumption for heating can be monitored on an annual basis, unlike the electricity consumption for cooling, the data on natural gas consumption is shown in tab. 2. These data refer to the building energy consumption before the thermal envelope improvement during 2018.

Table 2. Data on natural gas consumption for building heating

Year	Natural gas consumption annul [kWh]	Natural gas consumption per unit area [kWhm^{-2}]
2017	897549.98	83.95
2016	863550.00	80.77
2015	1131830.00	105.87

Modelling of new roof structures

The improvement of existing flat roofs by refurbishment and retrofit has been considered. Taking into account the fact that the roof structures do not meet the requirements of functionality (in terms of leaking that affect structural stability of the building), as well as the requirements for thermal protection (specifically requirement for *U*-value), the renovation

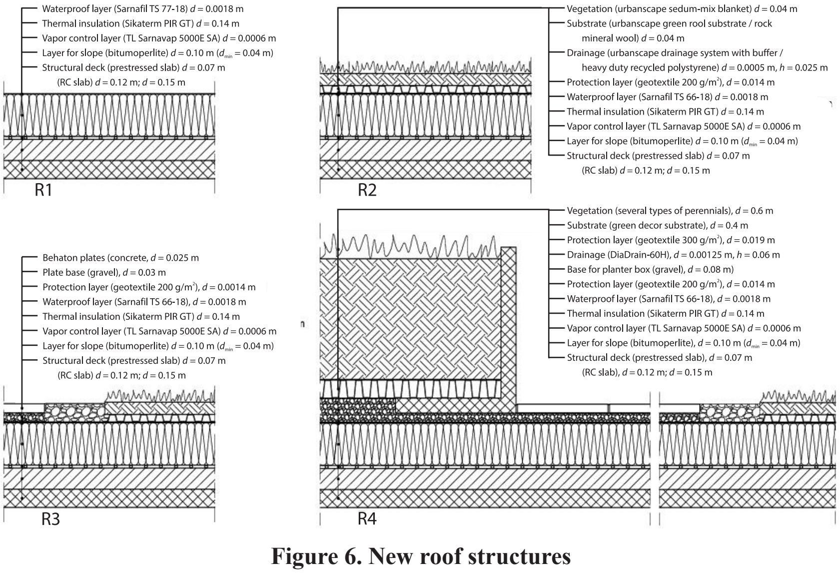

Figure 6. New roof structures

based on Model B (a complete flat roof renovation), fig. 2, is recommended. One new roof structure was defined by the application of refurbishment (R1) and three models of green roofs within the retrofit strategy (R2, R3, and R4). The improved roof structures relevant to energy modelling are shown in fig. 6.

Primarily, the improved roof structure by the refurbishment (R1) was modeled. The selection of contemporary materials for the structural elements was made. They were dimensioned based on the hygrothermal properties to meet the requirements of thermal protection. The calculated U-value, U = 0.160 W/m^{2}K, is in accordance with the regulations ($U_{\max}$ = 0.20 W/m^{2}K for existing buildings).

By the application of the retrofit strategy, new roof structures were modeled in a way that all the elements beneath the waterproof layer were the same as in the refurbishment model. This was done to provide a possibility to consider the application of green roofs on already refurbished flat roofs. In systems with green roofs, a different waterproof layer (suitable for their implementation above) has been used. The roof structure R2 is a non-walkable roof, for which, the application of the Urbanscape green roof system has been proposed. This commercial extensive system is suitable to apply due to easy and fast installation that does not require expert engagement, relatively low cost, low level of maintenance, and confirmation of successful implementations in our region. Based on conducted research [18-21] referring to energy modelling of buildings with green roofs, by using the DesignBuilder software, the characteristics of the vegetation layer, which consists of a mixture of sedum plants, is determined (leaf area index 2.5, reflectivity 0.22, absorptivity 0.60, transmissibility 0.18, emissivity 0.90, and minimum stomatal resistance 96.7 s/m). The calculated U-value, U = 0.133 W/m^{2}K, indicates the fact that this green roof system has higher level of thermal insulation in comparison to the refurbishment model (R1).

The roof R3 is a green roof within walkable terraces. The Urbanscape system has also been applied for this structure. Since it was determined that U-value for the roof structure R2 is within the allowed values, the U-value for walkable parts of the roofs was calculated, and it amounts U = 0.159 W/m^{2}K, which is also in accordance with the regulation.

The roof model R4 encompasses extensive and intensive green roof systems within walkable terraces. The U-values for the extensive, Urbanscape, system and walkable parts of the roofs, with behaton plates, are the same as in previous roof models, due to the same structures. The proposed intensive green roof is a non-commercial system. The substrate mixture and thickness have been determined based on selected perennial plants. Bearing in mind that in the research so far, the emphasis has not been on specific plant species, the required characteristics of plants for energy modelling have been determined based on the analysis of scientific papers [18, 19, 21] (leaf area index 5.0, reflectivity 0.22, absorptivity 0.60, transmissibility 0.18, emissivity 0.95, and minimum stomatal resistance 180 s/m). The calculated U-value, U = 0.117 W/m^{2}K, indicates the highest level of thermal insulation of the intensive green roof in relation to the previously analyzed structures.

The thermophysical characteristics for elements of roof structures were obtained from regulations, manufacturers and conducted studies.

When the design of renovated flat roofs by retrofitting is in question, the criterion was to provide the largest green area possible. The designed solutions (planes and views) of roofs, which correspond to roof models R2, R3, and R4, are shown in fig. 7.

The total area of roofs that are considered for the research is 3640 m^2. In the design of roofs related to the roof model R2, the share of greenery is 91% (3300 m^2). Regarding the designed solutions based on roof models R3 and R4, the share of greenery and walkable

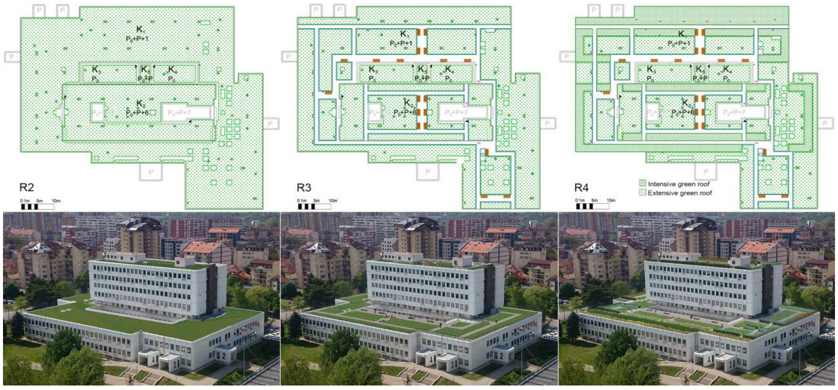

Figure 7. Roofs planes and views of the building with implemented green roofs

parts are the same in both cases. Green areas occupy approximately 70% of total roof areas (2551 m^2). Considering the application of different green roof typologies in the model R4, the ratio of areas under the extensive and intensive systems is approximately 60% : 40% (1602 m^2 and 977 m^2, respectively).

The roof systems designed in this way were used for the building energy simulation to obtain results for energy consumption for cooling and heating.

Results and discussion

DesignBuilder software was used for obtaining the results of energy consumption for the building cooling and heating. Four building models with different roof structures have been defined. The structures of façades, ground floors and inner partitions corresponded to the real building state. New layers (primarily thermal insulation) within some elements of the thermal envelope that were added in 2018 have been considered. Bearing in mind the complexity of the building in terms of the type and architectural design, the thermal zones were formed in a simplified manner. It is significant to mention that all the parameters related to the thermal envelope, except for the roof structures, were the same in all models, as well as the parameters that were selected in line with the building type for energy modelling. The results of electricity consumption for cooling and natural gas consumption for heating are shown in tab. 3.

Table 3. Energy consumption of building models with improved roofs

	R1	R2	R3	R4
Electricity consumption				
Annual [kWh]	141698.25	139499.51	139521.66	139456.98
Annual per unit area [kWhm^{-2}]	13.25	13.05	13.05	13.04
Natural gas consumption				
Annual [kWh]	812954.31	810274.12	810325.12	806626.34
Annual per unit area [kWhm^{-2}]	76.04	75.79	75.80	75.45

With regard to the applied renovation strategies, the obtained results indicate the reduction of energy consumption for building models in which roof systems were improved by retrofitting compared to the building model with roof improved by refurbishment. It can be seen that, by implementing the green roof systems (*i.e.* retrofitting), electricity consumption for cooling was reduced by 1.55% (R2), 1.54% (R3). and by 1,58 % (R4) when compared to the building model with roof structure R1 (*i.e.* improved by refurbishment). Based on previous research [22], it can be confirmed that the obtained results are within the expected values. The study on the green roof potential for energy savings conducted in a Mediterranean climate, which is more convenient than the climate zone in Serbia, showed that energy consumption was reduced by up to 2% in the case when green roofs were installed on insulated buildings, whereas these reductions ranged 37-48% in the case of uninsulated buildings [22]. In terms of natural gas consumption used for heating, less energy savings were achieved by implementing green roofs. The energy consumption was reduced by 0.33% (R2), 0.32% (R3), and by 0.78% (R4) in comparison to the building model with the roof structure R1. These results are in accordance with the research results so far which have indicated the slight reduction of energy consumption or the inefficiency of green roof systems in a heating period [23].

A comparison of energy consumption of the existing building and new building models is not relevant to learn the full potential of green roof energy savings, although the obtained results indicate the reduction of energy consumption for heating period. Firstly, green roof systems were predicted to be installed over already well-insulated roofs, then, the building models for energy simulation were simplified in terms of thermal zones, and finally, there is a difference between the structures of thermal envelopes of the existing building and new building models. In addition, the selected extensive green roof system is characterized by low level of thermal insulation and the proposed architectural design of roofs is not the only solution. However, a comparison of the results of the energy consumption of new building models can be considered relevant due to previously analyzed criteria used for their modelling.

Although the building model related to the roofs structure R4 displays the greatest energy savings, by implementing newly added load, the load-bearing capacity requirements have not been fulfilled (in contrast to loads of the other structures – R2 and R3), so there is a need to strengthen some structural elements. This indicates the need for great financial investments for the intensive green roof system implementation. However, this building model was analyzed in the case when the intensive green roof systems could be applied to some of the existing buildings, without any interventions on the load-bearing structure.

Conclusions

The general problem of the existing building stock, particularly buildings constructed in the period of mass production, related to functionality and performance of thermal envelopes, indicates the necessity of its renovation. Construction technologies and applied construction systems affected the large share of flat roofs, therefore, they are recognized as a field of intervention. Renovation strategies – refurbishment and retrofit – for the flat roofs improvement have been proposed. The building of Healthcare Center Niš was selected as a typical example for analysis of energy savings for space cooling and heating, depending on different improved roof structures. Four building models were defined: one building with refurbished flat roofs and three models with green roofs within a retrofit strategy. Three models of retrofit were offered to make green roofs competitive to roofs refurbishment, which is, otherwise, necessary to conduct. By refurbishment, the existing roof structures were improved in technical terms, while the improvement by retrofit, specifically by green roof concept, brought a number of potential benefits in terms of achieving sustainability.

Regarding the results obtained for energy consumption in the case of all building models, the implementation of green roofs indicates better building energy performance, but the question is whether the energy savings justify their investment costs. The reasons why retrofitting by green roofs is preferred over the refurbishment are related to the following facts. Firstly, the selected extensive green roof has low thermal mass and the application of other systems could improve roof thermal performance to a larger extent. Secondly, the life expectancy of a flat roof becomes twice or three times longer when implementing a green roof system. Thirdly, there is a possibility to reduce the thickness of the thermal insulation layer, due to thermal characteristics of green roofs, and in that way to reduce the investment cost of the roof structure beneath the green roof system. Finally, green roofs provide a number of environmental, social and also economic benefits which could compensate for their high investment costs. To sum up, even a slight reduction in energy consumption of building models with green roofs, with the aim to achieve thermal comfort, compared to the building with refurbished roofs, justified their very application.

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