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PREDNOSTI UGRADNJE ZELENIH KROVOVA NA ZGRADAMA SA RAVNIM KROVOVIMA

Rezime:

U ovom radu se analiziraju različiti aspekti postavljanja zelenog krova na nekoliko tipskih zgrada u Beogradu. Razmatrani su ekstenzivni i intezivni tipovi takvih krovova. Cilj rada je bio određivanje njihovog uticaja na promenu termičkih karakteristika i nosivosti konstrukcije postojećih objekata. Na osnovu promena energetskih performansi i efekata na samu konstrukciju objekta, određena je opravdanost postavljanja zelenih krovova.

Ključne reči: zeleni krov, nosivost konstrukcije, energetska efikasnost, benefit

BENEFITS OF GREEN ROOF INSTALLATION ON BUILDINGS WITH FLAT ROOF

Summary:

In this paper, different aspects of a green roof installation are analyzed on several typical buildings in Belgrade. The analysis is performed for buildings with extensive and intensive green roofs. The goal was to determine their influence on existing buildings' structural capacity and thermal characteristics. According to the impact on the structure and its energy performance, the overall effect and justification of the installation of the green roof are determined.

Key words: green roof, structural capacity, energy efficiency, benefit

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1. INTRODUCTION

Archetypes of green roof implementation are identified through various periods in human history, and its importance for urban areas has been recognized since the middle of the 20th century [1]. In the last decades of the 20th century, green roof technology improved, and its application in the building industry has substantially increased. It was seen as a practical tool with valuable features for urban areas.

Establishing its impact and benefit in different climate zones is crucial for developing implementation strategies and appropriate city policies. In Belgrade, a new concept of the development of the city includes the installation of the green roof and greenery systems on public buildings and the development of an adequate approach for education and subsidy system for citizens. The strategic goals of the city of Belgrade can also be indirectly linked to the green roof concept through goals of preserving and increase of green areas, air quality, quality of life, green solutions, and biodiversity.

Green roofs could be classified as extensive, semi-intensive and intensive based on the vegetation, construction, and maintenance factors. An extensive green roof (EGR) represents a structure with lower substrate thickness (8-15 cm), while the intensive green roof (IGR) is usually with a growing medium layer from 20 to 40cm or even higher. According to the type of the usage, they can be inaccessible or accessible, in the form of a garden or spaces for recreation.

The impact of the application of green roofs is reflected through individual and public (social and environmental) benefits. Green roofs can mitigate the urban heat island effect up to 3 °C at large-scale implementation [2]. Relative reduction of energy needed for heating and cooling depends on the climate and thermal properties of the thermal envelope, but it can reach 20-40% [3], [4]. In these calculations, the part of the building affected by the green roof is limited to adjacent and areas relatively close to the green roof [5]. Annual water retention is also a very significant aspect from an ecological and economic point of view, as it can delay the discharge of excess water (40%-90%) [6].

The estimated life of the green roof varies from 40-55 years [7], which can be considered as a membrane longevity benefit since the usual replacement or reconstruction of the conventional roof is considered to be performed every 20 years.

Other benefits include an increase in biodiversity, positive aspects on mental health, reduced air pollution and improved acoustic insulation. All of the benefits mentioned above could be monetized in life cycle cost (LCC) analysis as presented in [7][8].

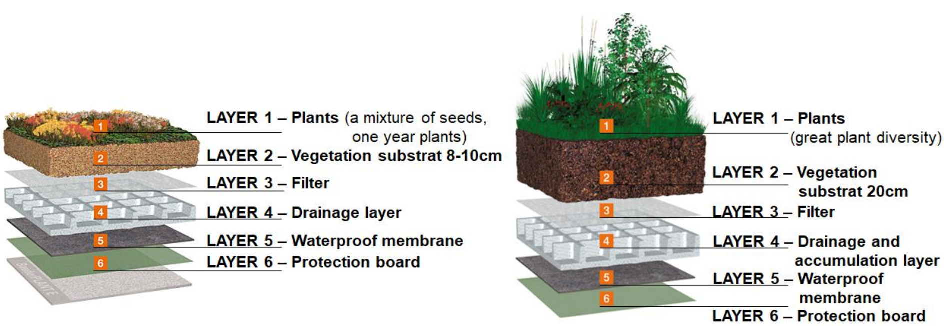

Figure 1 – Layers in extensive and intensive construction [10]

Standard layers for green roof structure include, besides substrate layer, thermal insulation, root barrier, irrigation system (inside or above), drainage layer and additional filters [9]. It is very important to provide permanent and sometimes load-distributing protection of the waterproofing layer against mechanical, thermal and chemical reactions.

The most common barriers to green roof implementation are related to the maintenance cost and structural implications. However, by taking into account the net present value (NPV) of life cycle cost analysis, from both public and individual perspectives, the payback period is estimated from 5-14 years [11], [12], depending on the type of the green roof.

2. EFFECTS OF GREEN ROOF ON THE STRUCTURE

Comprehensive green roof guidelines for planning, construction and maintenance of the green roof are presented in [6], which is based on DIN and DIN EN standards. The waterproofing layer is critical to the successful performance of the roof as a whole, but the technical properties of all materials and layers of the green roof must comply with corresponding standards.

The main concern in the global structural response of the building with a green roof represents an increase in weight on the roof of the building. The rise of vertical loading due to the implementation of the green roof must be determined in the saturated condition (including the retained and captured water). The difference in weight between that condition and the case where the rainfall or irrigation is actively occurring, approximated by the weight of transient water in the drainage layer, is considered a live load [13]. According to [14], the saturated density of the substrate is calculated as $\gamma_s=\gamma_d+n\cdot \gamma_w$, where γ_w is the density of water and n porosity of the substrate.

Estimated permanent loading of the EGR layers above the structure (substrate layer 10cm and drainage layer 6cm) in saturated substrate conditions can vary from 1.25 to 2.43 kN/m^2 for various substrate types. [14]. The permanent loading on the flat roof without vegetation (above the structure) can be in a similar range or even higher, from 1.5 to 3 kN/m^2.

Paving slabs weigh approximately 1.6–2.2kN/m^2, and gravel 0.9–1.5kN/m^2, which in each case could be replaced with an extensive green roof with a decent thickness of substrate according to [15]. There is also a light sedum system of EGR that weighs only 0.5-0.96 kN/m^2 in the saturated state [16]. On the other hand, for the IGR, the weight of the substrate and drainage layer can have a wider range.

Green roofs are usually required to have a vegetation-free zone near the electrical and HVAC systems. They can have higher or lower percentage areas covered with vegetation, depending on design, safe access and maintenance purpose. Hence the imposed loads (people, vehicles, point loads for items) scheme can differ. The difference between EGR and IGR can be significant even in live load increase, especially for accessible green roofs for recreational purposes. The standard from the USA [17] identifies that accessible roof gardens must have minimal capacity to support 4.79 kN/m^2 live loading. In contrast, non-occupied vegetated roof decks should be designed for live loads of 0.958 kN/m^2 under saturated conditions. According to [18], the minimum imposed load for an inaccessible green roof, predicted for maintenance purposes, is 0.5kN/m^2, and for IGR (accessible), this loading is assumed to be 1.46kN/m^2.

Wind loads in roof areas can cause damage during construction (erosion problems) and after the green roof is finished. The primary consideration in wind design for green roofs [19] is the determination of wind coefficient, the height of the building, the influence of parapet walls and the security and stability of wooden plants, which must be ensured.

3. CASE STUDY FOR FOUR RESIDENTIAL BUILDINGS IN BELGRADE

In this paper, the thermal performance of residential buildings is determined for different scenarios of green roof implementation, and by investigating other implications, a corresponding LCC analysis is performed.

In table 1, information about the analyzed residential buildings is presented. Description of thermal envelope is not given, but the calculated energy needed for heating/cooling for those buildings indicates satisfactory thermal characteristics of opaque and transparent parts of the thermal envelope. Designed structures of flat roofs with no vegetation were analyzed in scenarios with EGR and IGR implementation, and the increase of loading at roof level was determined.

Table 1 – Buildings' energy need for heating/cooling and type of the flat roof

	Number of floors	Total Area [m^2]	Energy needed for heating [kWh/m^2 a]	Energy needed for cooling [kWh/m^2 a]	Flat roof type and top layer
1	Po+P+3	500	49.1	22.9	Gravel - inaccessible
2	Po+P+3	1800	36.11	10.85	Gravel - inaccessible
3	Po+P+7	5400	35.8	9.9	Paving - accessible
4	P+4	890	48.6	15.8	Paving - accessible

The layers representing concrete laid to fall or cement screed are present in all scenarios with similar thickness. Also, the waterproofing and thermal insulation layers are insignificant for estimating the difference in weight between flat roof layers without vegetation and green roofs. The main relative difference in the presented analysis can be observed in the top layers of the roof, where the substrate for a green roof is used in comparative analysis against gravel or paving slab as the top covering layer of the designed (existing) flat roof.

Table 2 presents the difference in loading for the green roof compared to the designed flat roof. EGR is assumed with variable substrate thickness from 8 (inaccessible) to 15cm (accessible), where the density of the substrate also ranges from 550 to 1200kg/m^3 in dry conditions and 1300 to 2000kg/m^3 in saturated conditions, respectively. For IGR, the thickness is assumed to be between 20 and 40 cm and with the same substrate density as EGR. In Table 2, the weight of the concrete layers, insulation (and filter layers) and covering layers are taken into calculation separately and with a different range as well, accounting for all buildings in the analysis.

Table 2 – Relative increase of permanent loading for different types and thickness of the green roof

	Top layers		Total permanent loading		Relative increase		Relative increase	
	min [kN/m^2]	max [kN/m^2]	min [kN/m^2]	max [kN/m^2]	min [kN/m^2]	max [kN/m^2]	min [%]	max [%]
Existing	1	1.5	2.05	3.65				
EGR-dry	0.6	1.68	1.65	3.83	-0.4	0.18	-19.5	4.9
IGR-dry	2.64	5.28	3.91	7.48	1.86	3.83	90.7	104.9
EGR-sat.	1.2	2.4	2.27	4.6	**0.22**	**0.95**	10.7	26.0
IGR-sat.	3.84	7.68	5.11	9.88	**3.06**	**6.23**	149.3	170.7

As it was proposed in [18], not all roof areas could be covered with green roofs, so it is assumed that only 80% of the roof area is covered with vegetation. Distributed live loading difference is only significant for IGR (4.8kN/m^2) in comparing to EGR and existing flat roof structure (inaccessible type has 1kN/m^2 and accessible type 2kN/m^2).

Following the local difference in loading on the roof, global structural implications can be assumed. It can be seen from Table 2 that no significant difference in loading level is observed in the comparison between EGR and existing designed flat roof construction if the maximum and minimum values are compared. The relative maximum increase of permanent weight at the roof level could be up to 8%, 14%, 20% and 21% in the scenarios with EGR for building 1, 2, 3 and 4, respectively. If IGR is constructed instead of the adopted structure of a flat roof, the maximum permanent weight at the roof level could be increased to 112%. 120%, 138 and 140%, in the scenarios for building 1, 2, 3 and 4, respectively.

The difference in NPV in LCC analysis is calculated based on the cost and individual benefits of such projects. Since the flat roof structure of the analyzed buildings has adequate thermal properties, as it is the requirement for all parts of the thermal envelope according to the Rulebook on Energy Efficiency of Buildings from 2011, no significant difference in calculated energy needs is observed in the conventional procedure for determination of thermal properties of green roof. For the existing buildings, besides concrete structure and exterior top layers of gravel, the most contributing part for thermal resistance is provided for buildings 1, 2,3 and 4 as 20-30 cm thickness layer expanded polystyrene. Calculating heat transfer coefficient U[W/m^{2}K] for a green roof system requires modelling in software [20] that will take into account special features provided by vegetation. Therefore, the Ecoroof model (EnergyPlus) is used to simulate and evaluate the thermal and energy performance of a building which leads to a more realistic reduction in energy consumption, especially for cooling.

The profitability of proposed IGR and EGR installation projects is based on the probabilistic approach for the life cycle profit analysis. The total cost in the LCC analysis represents the difference in installation cost between the existing flat roof structure and green roof structure with additional maintenance costs. On the other hand, the benefits include savings obtained by reduction of the annual energy need for heating and cooling of the building and membrane longevity in the case of green roof installation.

The results of the economic analysis are determined for three different scenarios: installation of inaccessible EGR, accessible semi-intensive green roof (SIGR) and IGR. As is expected, energy saving varies in a small range (similar for all buildings) depending mainly on the type of the green roof. Saving from reduced energy need for cooling is estimated in the range of 0.04-0.20 EUR/m^2 of roof area for all buildings in analysis. On the other, a reduction in the energy need for heating can lead to savings in the range of 0.1 – 0.4 EUR/m^2 of roof area.

Based on the presented input data, computed life cycle NPV for all IGR and SIGR is negative, and for EGR, the value can be positive for buildings 3 and 4. Minimum and maximum NPV at the end of life cycle of EGR installation is calculated as -26 EUR/m^2 and -4 EUR/m^2, -33 EUR/m^2 and -1 EUR/m^2, -26 EUR/m^2 and +4 EUR/m^2, -42 EUR/m^2 and +10 EUR/m^2 for buildings 1,2,3 and 4 respectively. On the other hand, minimum and maximum NPV at the end of life cycle of SIGR installation is calculated as -92 EUR/m^2 and -16 EUR/m^2, -90 EUR/m^2 and -20 EUR/m^2, -90 EUR/m^2 and -13 EUR/m^2, -88 EUR/m^2 and -6 EUR/m^2 for buildings 1,2,3 and 4 respectively. Minimum and maximum NPV at the end of life cycle of IGR installation is calculated as -227 EUR/m^2 and -98 EUR/m^2, -234 EUR/m^2 and -107EUR/m^2 , -230 EUR/m^2 and -101 EUR/m^2, -225 EUR/$m^2$and -95 EUR/m^2 for buildings 1,2,3 and 4 respectively. In sensitivity analysis, it is concluded that the most influential parameters for the outcome of the analysis are maintenance and installation costs. A usual individual benefit that can be accounted for is a property value increase that can be in the range relatively close to the installation cost. For example, it is estimated that installation of EGR and IGR will lead to an increase of property value 2-5% and 10-20%, respectively [11], or in the range from 20-80EUR/m^2 for EGR and 45-180EUR/m^2 for IGR [21]. In this case of accounting the property value increase as a benefit, and especially energy savings, a distinction must be made between residential units below the roof and other residential units.

Furthermore, the public (social and environmental) benefits predicted in [11] include aesthetics benefit, reduction of infrastructure improvement and flood risk, mitigation of urban heat island effect, habitat creation, improvement of air quality and carbon reduction. However, the cost of air pollution (during the production of material) and landfill costs must also be taken into account. It is estimated in [11] that at the end of the lifecycle, the most probable NPV, accounting for the social benefit only, would be 20EUR/m^2 and 60EUR/m^2 for EGR and IGR, respectively.

In a study performed in the USA [22], a comparison between economic preferences between white, black and green roofs concluded in favour of white roofs, but if the local environment is a primary interest, green roofs would be preferred option.

4. CONCLUSION

In the presented paper, two general aspects of a green roof installation are discussed. Evaluation of their influence on the increase of loading in roof level and benefits for existing buildings is aimed to provide the basis of profitability analysis of the proposed projects. It is important to indicate that the presented analysis was associated with the potential modification of flat roofs in new buildings in Belgrade, where the limit of the loading is not the restricted (analysis could be performed in design stage), and with the existing flat roof configuration that have satisfactory thermal properties.

Various benefits of a green roof installation on a flat roof are indicated, but the realistic economic analysis included only individual (private) benefits. Although a diverse green roof system can be designed, in the presented analysis, it is estimated that 80% of the roof is under vegetation of EGR or IGR. Based on the design of four typical residential buildings in Belgrade, the difference in permanent loading is estimated in the cases of green roof installation. The increase of weight on the roof level can be generally associated with corresponding scenarios in LCC analysis.

Current private benefits from the installation of a green roof are limited to energy savings and membrane longevity benefits. This resulted in negative NPV for nearly all scenarios of EGR, SIGR and IGR models of flat roofs. It is also important to indicate that significant individual benefit – property value increase is not taken into account in the analysis, and the presented literature review indicated its substantial influence on project profitability. Since its wider implementation could have various public benefits, evaluated results could therefore be used to estimate the level of the potential subsidy or tax reduction for the green roof implementation to be more affordable for investors.

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