Environmental aspects of formation of green roofs in urban areas

***Marija Stamenkovic*[a], *Goran Vuckovic*[b]**

[a] *Faculty of Civil Engineering and Architecture, Nis, Serbia,* marijastamenkovic81@gmail.com ,
[b] *Faculty of Mechanical Engineering, 14 A. Medvedeva srt, Nis, Serbia,* vucko@masfak.ni.ac.rs , ***CA***

Abstract:

The subject of this paper is to emphasize the importance of green roofs with the aim of elevating the quality of the environment in urban centers, as well as to promote them in our region. In addition to the pleasant living conditions out in the open and a nicer scenery of the city, green roofs play a significant role in air purification and noise protection, have a favorable influence on the climate, reduction and retardation of rainwater runoff, creating additional space for plants and animals, and improve the efficiency of energy use in buildings. On the bases of analyses related to the benefits of green roofs compared to conventional flat roofs, various benefits have been confirmed through numerous examples from abroad, i.e. from different climatic zones. The possibility of their implementation in our country was conceived under the provided conditions for their construction on existing buildings. Analyses emphasize the fact that the starting investments in green roofs are justified by the realized quality of the environment in the short run and by the durability of the structure in the long run.

Keywords:

Construction conditions, Efficient energy use, Environmental aspects of construction, Green roofs, Quality of the environment.

1. Introduction

It is widely known that extensive urban development does not have a favorable effect on the environment, which is primarily reflected in the degradation and reduction of green areas, as well as natural habitats. Environmental changes, brought about by anthropogenic activities, have a dominant impact on the quality of life and health of residents. The degradation in the quality of the environment is especially emphasized in densely built city centers, and is manifested as air pollution, occurrence of noise, changes of the microclimate of the cities, etc. One of the ways to improve living conditions in urban areas is the construction of green roofs.

As part of the layer of the structure, they enable the development of vegetation on flat and slanting roof surfaces up to the inclination of 58° [1]. They can be extensive, with a low and medium amount of greenery, and intensive, requiring structures with a great load-bearing capacity for the development of greater verdure and the formation of roof gardens. The type of low greenery which forms the final layer in extensive green roofs depends on the climatic conditions of the region. Plants are most frequently self-sustained since they use the natural conditions from the sun, wind and rainwater [2]. The layer condition needs to be assessed 2-3 times per year. In the event of intensive green roofs, it needs to be maintained in the form of cleaning and watering.

Natural conditions for the development and maintenance of green roofs are directly related to the environmental aspects of construction. Negative impacts which are caused by urban development, and which concern the environment, may be reduced by forming green roof surfaces which lead to air purification, noise reduction, reducing the effect of urban heat island, reduction and retardation of rainwater runoff and creating additional space for plants and animals [3]. By using the sun's power as renewable regenerative energy which is not harmful to the environment and climate, green roofs lead to the improvement of the efficiency of energy use in buildings on the basis of their thermo-insulation characteristics.

By performing a comparative analysis of green roofs and flat conventional roofs, we can visualize the benefits of building green roofs. The confirmation from the examples on constructed green roofs from abroad emphasizes the fact that there would be great benefits in our region as well. Based on this, an analysis was performed related to the conditions for their construction on existing buildings.

2. Benefits of green roofs

The environmental aspects of constructing green roofs may be researched through their benefits compared to conventional flat roofs. External noise reduction, air quality improvement, reduction of rainwater runoff and reducing the effect of urban heat island represent advantages studied in this paper.

2.1. Acoustical effects of green roofs

Noise pollution is a daily occurrence in urban areas which has an impact on the health of people and the development of natural surroundings. Green roofs may reduce the noise coming from outside in two ways: increasing the thickness of the insulation layer in the roof structure and absorbing sound waves which diffract above green roofs. The positive effects of noise reduction may be expected in the event of a dense construction of buildings with green roofs. In the event of detached buildings, there is a lower effect of noise reduction since the noise is dispersed, and a small amount of noise reaches the green roofs.

In the structure of the green roof, the vegetation layer is highly porous, which is a characteristic of sound absorbers, and enables the penetration of waves up to the substrate layer. The interaction between the sound waves and the substrate leads to the reduction of the intensity of the sound which penetrates the building. These theoretical considerations have been confirmed by numeric calculations [4] and emphasize the great potential of green roofs in the reduction of noise above them, compared to different types of flat roofs.

Through experimental research in controlled conditions, authors Renterghem and Botteldooren [4] tested sound effects of extensive green roofs in Flanders, Belgium. With an alarm gun as a sound source, at the distance of 2.5 – 25 m from the green roofs, they performed measurements of sound intensity. In all five instances, the thickness of the substrates was between 30 and 180 mm. They concluded that the lower substrate thickness and the presence of vegetation favorably influence the reduction of sounds at higher frequencies, while a greater substrate thickness is required for lower frequencies. It needs to be stressed that the frequency of sound ranging from 400 to 1250 Hz, at the sound source distance of 4.5 m, led to a reduction in sound intensity by 10 dB, which confirms the role of green roofs as sound absorbers.

2.2. Air quality improvement

It is a well-known fact that vegetation in urban areas has a favorable impact on the reduction of the pollution of air, which is saturated with carbon monoxide, volatile organic compounds, particles and other products of burning fossil fuels and industries that are harmful to human health [3]. Trees planted along pedestrian roads improve the quality of air, retain and process harmful compounds and produce oxygen. Forming green roofs would have a significant role in a more efficient purification of air, increasing the green area in densely built city centers.

Currie and Bass [5] performed experimental research in Toronto, Canada. Based on the digital simulation of impact of several compounds from the air on different types of green roof vegetation, they came to the conclusion that the grass of extensive green roof greatly reduces air pollution in relation to trees and bushes, while the use of bushes is the most suitable for intensive green roofs. Increasing the green roof area by 10 – 20% at the core of cities would greatly influence the improvement of the quality of the environment, as well as the health of all citizens.

Measuring air pollution [6] in Nis, Serbia, indicates that the concentration of exhaust fumes of motor vehicles does not exceed permitted levels, except in the event of carbon-monoxide (CO). Expanding green areas, which include green roofs, would lead to the reduction of pollution.

2.3. Reduction of rainwater runoff

Water circulation is a natural process which plants have a significant role in. Densely built urban areas have the possibility of increasing the area under vegetation through green roofs. Through the transpiration of plants and the evaporation of substrates, the greater portion of the rainwater quickly returns to the water circulation cycle. This leads to the reduction of rainwater runoff and decrease of the sewage system loads by approximately 700 l/m^2 of green roof water annually, as well as possible spills and floods [3]. The design and construction of green roofs on buildings which contain large roof surfaces influence the reduction of sewage network dimensions, as well as the number of drains and ducts.

Mentens et al. [7] attempted to answer whether the green roof may be a tool for resolving rainwater runoff problems in urban areas. They conducted a comparative analysis of four roof types for the region of Brussels, Belgium. According to the results shown in Figure 1, it can be concluded that non-greened roofs (trad) reach values of up to 91%, while the minimum values of 15% were measured for intensive green roofs. It needs to be stressed that the thickness of substrates for intensive green roofs exceeds 100 mm, and is lower than 100 mm in the case of extensive ones, which may also be formed on slanting roof surfaces.

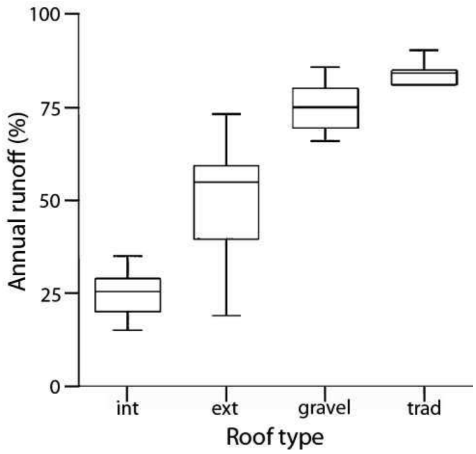

Fig. 1. Annual runoff for various roof types as a percentage of the total annual rainfall [7]

Theoretical research has shown that, for the climatic conditions prevalent in the region of Brussels, forming extensive green roofs with substrate thickness of 100 mm, occupying 10% of the total area of the roof planes, influences the reduction of rainwater runoff by 2.7% at the regional level, and by 54% in the case of individual buildings. This leads to the conclusion that green roofs may represent a successful tool for resolving rainwater runoff.

2.4. Mitigation of urban heat island

The temperature in urban areas rises with the increase of absorbing surfaces which retain the heat they accumulate during the day and emit it during the night into the surroundings, causing urban heat islands. The difference in temperature between the city centre and the suburbs during the summer months may be up to 10°C, which greatly impacts the health and quality of life of the residents. Greenery may absorb up to 80% excess heat energy through damp soil and vegetation [3]. In the events of densely built areas, green roofs may be a suitable solution for increased surfaces under vegetation. By cooling and humidifying dry and warm air, there is an improvement of the microclimate, which leads to a more suitable and healthier living environment.

Takebayashi and Moriyama [8] tested the characteristics of the green roof in relation to conventional flat roofs with different finishing. Experimental research has been conducted on the flat roof of the Kobe University building in Japan, which was separated into several sections for such purposes. Table 1 displays the solar reflection values for each type of the tested roof, which can lead to the conclusion that the green roof has the lowest value. This confirms that green roofs absorb the greatest quantity of the sun's radiation and reduce the effect of urban heat island.

For a complete analysis and final results, we must take into consideration all the factors from the external environment, which have been fulfilled according to the authors. The significance of green roofs has also been confirmed from this structural aspect.

Table 1. Solar reflectance of each surface [8]

Observation Surface	Bare soil	Green	Concrete	Highly reflective gray paint	Highly reflective white paint
Solar reflectance	0.17	0.15	0.37	0.36	0.74

3. Using solar energy for achieving efficient energy use

Exposure to the sun is significant for green roof maintenance. At the same time, the utilization of regenerative energy improves the efficient energy use of buildings. Green roofs play a great role in the regulation of internal temperature to make it stable, and act as passive air cooling systems during the summer and heat isolators during the winter.

The energy savings of the building with a green roof for cooling the air inside during the summer and maintaining a pleasant temperature during the winter depends on the characteristics of layers of the roof structure. Substrates and vegetation possess thermo-insulation properties in the green roof structure, and they are dependent on the thickness of the substrates and the type of greenery. Based on research [9], the extensive green roof has proven to be a better thermo-insulator compared to the intensive one, which has greater substrate thickness. Low undergrowth, as a homogenous layer of the extensive green roof, reduces the flow of temperature during the summer and heat loss during the winter, unlike the combination of the low, medium and high-level greenery in intensive roofs, which might lead to losses in certain instances.

The smaller requirement for cooling internal air in summer is reflected in the movement and reduction of extreme heat value flows, which can be seen in Figure 2. Research conducted by Lui and Minor [10] relate to the impact of the roof system on the heat flow. The characteristics of the green and conventional flat roof were compared on a public building in Toronto, Canada.

Heat enters the building through the conventional roof (R) shortly after sunrise, around 6 am, reaching maximum intensity of 15 W/m^2, and decreases before sundown, around 6 pm, when it is converted into heat loss during the night. The green roof (S) reduces the heat flow, both the gains and the losses, through the roof system, and the limit values are lower than 2.5 W/m^2, noting that heat loss occurs until noon, when they are converted into heat gain, i.e. heating the interior.

It has been proven that the energy savings for cooling a building through the use of green roofs range from 6 to 49% [11].

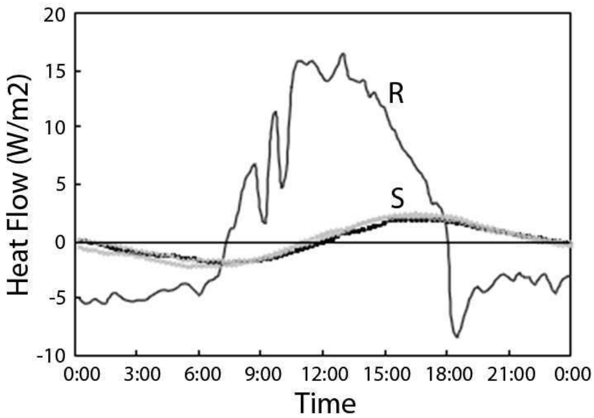

Fig. 2. Heat flow profile through conventional flat roof (R) and green roof (S) on a tipical summer day [10]

4. Conditions for constructing green roofs on existing buildings

In order to utilize all the advantages of green roofs in densely built urban areas, we have to conduct an analysis of the conditions under which green roofs can be constructed on existing buildings in the most favorable manner.

The economic factor, i.e. the price of executing the green roof, is significantly higher compared to the price of the conventional flat roof. For example, 1 m^2 of the extensive green roof has the price of \$10 – \$20, while the intensive one is \$20 – \$40, compared to the comparative roof with the price of \$4 – \$8.5 [1]. The mentioned data represents an approximate ratio since the actual price depends on many factors, such as the species and type of greenery, the composition and thickness of the substrate, drainage layer type, type of materials for other layers of the roof structure etc. The high price of green roofs in the construction phase of the building is justified by the longevity of the roof structure, protected from external influences by the layer of substrates and vegetation. It is estimated that the roofs with the green roof system last twice longer than the conventional flat roof [12]. The most favorable moment for building green roofs on existing buildings is during the renovation of the building, since it has been estimated that the roof system has a life span of 15 - 20 years [9].

The load-bearing capacity of the existing roof structure influences the choice of the type of the green roof to be constructed. The most frequent structures are extensive green roofs whose construction mostly does not require additional supports to the structure, because their weight is lower (72.6 – 169.4 kg/m^2) compared to intensive ones (290 – 967.7 kg/m^2) [13]. The full load must account for the weight of the green roof soaked in rainwater.

The position of the building with respect to other neighboring buildings, as well as its orientation, influences the selection of the vegetation type. Getter et al. [14] considered the formation of green roofs on buildings shaded by neighboring structures, as well as the non-favorable orientation of the roofs for developing vegetation, by researching various types of plants which are able to survive under such conditions.

Based on the fulfilled conditions for constructing green roofs on existing buildings, whole building blocks with a top vegetation layer can be constructed. Ethelred Estate in London, England, represents one example of such a block [9]. 4000 m^2 of roof surfaces have been made green in the goal of improving the quality of the environment in the densely built urban tissue.

4. Conclusion

The violation of the natural surroundings and the degradation of the quality of the environment in urban centers may be reduced by building green roofs. By increasing the green surface, many benefits are gained, some of which have been described in the paper, and which concern the environmental aspects of construction.

The significance of the green roof as a sound absorber is supported by the fact that the extensive green roof can reduce the intensity of the sound by as much as 10 dB. Research supports that grass or bushes, as a vegetation layer of green roofs, influence the reduction of air pollution better, compared to high amounts of greenery. Intensive green roofs greatly retain the rainwater runoff and only 15% is drained from the surface of the roof. The efficiency of extensive roofs from which at least 20% of water is drained, at the substrate thickness of 100 mm, should also not be overlooked. In this manner, the water retained at the surface of the roof is returned to the natural water circulation process. Heat retention, which goes up to 80% in the summer period, leads to the reduction of temperature in urban areas and the effect of urban heat island. The green roof system layers reduce the flow of heat inside the building, which reduces the need for cooling, and thus achieves the building's efficiency in terms of energy use.

A brief overview of the environmental aspects in construction, with considerations to the advantages of the green roofs compared to conventional flat roofs, may lead to their application in our region. Although every researched case is special, they may form the basis for anticipating results by making simulations of climatic conditions of a certain region. This paper represents a sort of promotion of green roofs for our country.

References

[1] Zivanovic M. Why green and how roofs in urban areas can be planted. Portal of onstruction industry. Serbia. [internet] 2009. Available at: http://www.gradjevinarstvo.rs/TekstDetaljiURL/Zeleni_krovovi_-_za%C5%A1to_i_kako_ozeleneti_krovove_u_urbanim_sredinama.aspx?ban=820&tekstid=739 [accessed 24.10.2010].

[2] Liptan T, Strecker E. EcoRoofs (Greeroofs) – A more Sustainable Infrastructure. Portland Oregon, USA: Bureau of Environmental Srevices; 2003.

[3] Sesilja D, Milankovic T. Green roofs as method of ecoremediation of urban ecosystems. International conference Degraded Areas & Ecoremediation; 2010 May; Belgrade, Serbia. Faculty of Applied Ecology Futura: 415-25.

[4] Van Renterghem T, Botteldooren D. In-situ measurements of sound propagating over extensive green roofs. Building and Environment 2011:46:729-38.

[5] Currie B. A, Bass B. Estimates of air pollution mitigation with green plants and green roofs using the UFORE model. Urban Ecosystem 2008:11:409-22.

[6] Petrovic M, Trajkovic S. Air pollution as the cause of urban stress. A case study: Nemanjica Boulevard, Nis, Serbia. Facta Universitatis 2010:8(4):403-12.

[7] Mentens J, Raes D, Hermy M. Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century? Landscape and Urban Planning 2006:77:217-26.

[8] Takebayashi H, Moriyama M. Surface heat budget on green roof and high reflection roof for mitigation of urban heat island. Building and Environment 2007:42:2971-979.

[9] Castleton H. F, Stovin V, Beck S. B. M, Davison J. B. Green roofs: building energy saving and the potential for retrofit. Energy and Buildings 2010:42:1582-591.

[10] Lui K, Minor J. Performance Evaluation of an Extensive Green Roof. Greening Rooftops for Sustainable Communities; 2005 May; Washington, D.S., USA. p.1-11.

[11] Santamouris M, Pavlou C, Doukas P, Mihalakakou G, Synnefa A, Hatzibiros A, Patargias P. Investigating and analysis the energy and environmental performance of an experimental green roof system installed in a nursery school building in Athens, Greece. Energy 2007:32:1781-788.

[12] van Wyk L. Green Roofs. The Green Building Handbook. 2010. Available at: http://researchspace.csir.co.za/dspace/bitstream/10204/4458/1/Van%20Wyk1_2010.pdf [accessed 23.10.2010].

[13] Peck S. W, Callaghan C, Kuhn M. E, Bass B. Greenbacks from green roofs: Forging a new industry in Canada. Canada Mortgage and Housing Corporation; 1999; Ottava, Canada.

[14] Getter K. L, Bradley Rowe D, Cregg B. M. Solar radiation intensity influences extensive green roof plant communities. Urban Forestry & Urban Greening 2009:8(4):269-81.