

PRINCIPLES OF IMPLEMENTATION OF THE VERTICAL GREENERY SYSTEM (VGS) IN ARCHITECTURE

PRINCIPI IMPLEMENTACIJE SISTEMA VERTIKALNOG OZELENJAVANJA (SVO) U ARHITEKTURI

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Abstract

The environmental problems of cities have caused an increase in energy consumption in buildings, which can be slowed by improving the buildings' energy efficiency. Energy consumption in buildings is affected by the building envelope, and integration of the greenery with the building envelope will contribute in saving energy and increasing the buildings' energy efficiency. Therefore, the vertical greenery system (VGS) has received a lot of attention in recent decades as a model whose implementation can increase the energy efficiency of buildings. Defining the basic VGS system implementation will allow engineers to systematically approach the process of VGS system implementation and help them choose the best VGS system model for a selected site or building.

Keywords: energy efficiency in buildings, implementation, principles of design, vertical greenery system (VGS)

1. INTRODUCTION / UVOD

A healthy and comfortable environment is a basic desire of all human beings. However, rapid urbanisation and industrialisation have led to many environmental problems. Environmental problems of cities, population growth, increased needs for construction services, as well as the increase in time spent inside buildings, have caused an upward trend in energy consumption (Pérez-Lombard et al., 2008). The average annual global primary energy consumption in buildings and CO₂ emissions predicted to be reached by the year of 2050 is shown in Table 1.

Architectural buildings consume 32% of total final energy, while the share of primary ener-

Table 1. Average annual global primary energy consumption in buildings and CO₂ emissions (Judkoff, 2012) / **Tabela 1.** Prosječna godišnja globalna potrošnja primarne energije u zgradama i emisija CO₂ (Judkoff, 2012)

Year	Energy consumption (EJ/year)	CO ₂ (Gt/year)
2005	122	8,8
2030	162	14
2050	215	20,5

gy consumption is 40%, which exceeds energy consumption in other major sectors: industrial

and transport. Energy consumption in the construction sector is continuously growing and will continue to do so until the facilities are designed that way to use energy more efficiently. Unless measures are taken to improve energy efficiency in the construction sector, energy demand is expected to increase by 50% by the year of 2050 (IEA, 2013).

Minimal energy consumption in buildings is influenced by many parameters, which include:

microclimate, used materials, building installations and the building envelope (Judkoff, 2012). The building envelope is a key element of a building which affects its energy balance and the quality of the indoor climate (heat, sound, air and light comfort). It is exposed to the temperature differences between outer and inner spaces, through which the building directly loses heat, so its analysis is very important. Buildings lose about 21% of energy through exterior walls and about 51% through windows (Figure 1).

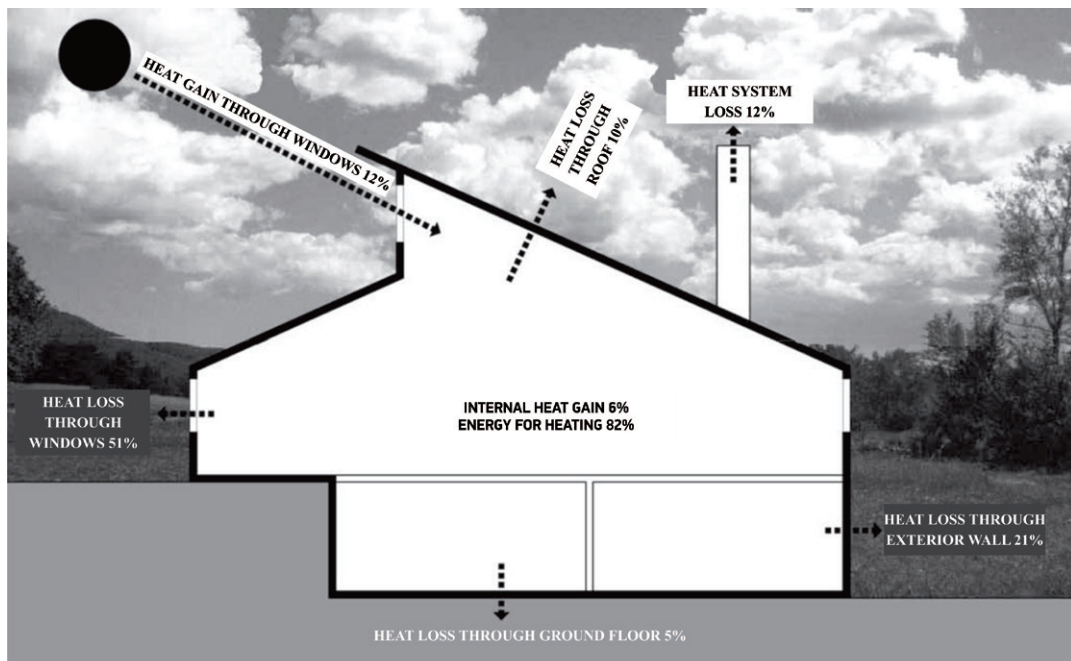


Figure 1. Energy balance of a building (Bašić et al., 2019) / **Slika 1.** Energetska bilanca zgrade (Bašić et al., 2019)

Vegetation can have a key role in the topoclimate of cities, but also in the microclimate of buildings. The integration of greenery with the building envelope is usually considered an aesthetic element and a qualitative improvement of the microclimate. However, greenery systems also affect energy savings and increase the energy efficiency of buildings (Raji et al., 2015; Schettini et al., 2016). If thermal insulation of the building envelope is properly designed, the amount of energy required to heat and cool the interior can be reduced. Namely, greenery has the ability to protect buildings from excessive

solar warming and cold air infiltration (Cameron et al., 2014; Perini et al., 2011).

Vegetation absorbs a large amount of solar radiation necessary for its growth and biological functions, such as photosynthesis, respiration, transpiration and evaporation (Ottel  & Perini, 2017; Perini & Ottel , 2012). The physiological process that occurs in plants implies that a small part of the sun's radiation is absorbed for photosynthesis and the rest is used in water evaporation, which makes the plant a mechanism for regulating the temperature. This causes vegetation to effectively block solar radiation

without any temperature increase (Sheweka & Mohamed, 2012). Vegetation can significantly reduce temperatures around the building envelope and thus reduce the amount of energy necessary for mechanical cooling of the building (Ottel  & Perini, 2017). It can also reduce cold air infiltration and convective heat loss in the building (Perini et al., 2011). Hence, vertical greenery systems protect buildings from solar radiation (Judkoff, 2012; Ottel  & Perini, 2017), while the evapotranspiration effect of plants can reduce solar radiation, showing increased levels of humidity and surface temperatures (Lu & Lin, 2015). Thus, applying certain biological systems can contribute the energy efficient architecture in many ways (Ba i  et al., 2019).

The most common places in a building that can be used to accommodate vegetation are roof greening, vertical greening, terrace planting and using indoor plants in atria especially in the design of high-rises, as shown in Figure 2.

In Bosnia and Herzegovina and countries in the region, there is an urgent need for innovative and practical improvements of the poor energy performances of a large part of the construction fund. Energy efficiency can be increased by remodeling of the existing buildings and alter-

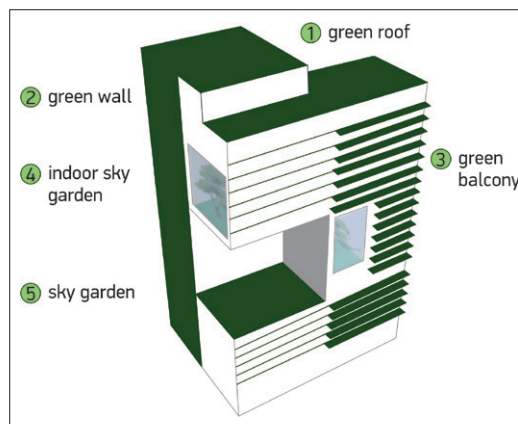


Figure 2. Figure 2. Different ways of integrating greenery systems on buildings (Raji et al., 2015) / *Slika 2.* Razli iti na ini integrisanja sistema zelenila na zgrade (Raji et al., 2015)

ing the facades and their surface characteristics (Dimitrijevi  et al., 2017). That is why this paper is based on the application of the vertical greenery system as a model whose performances can improve the energy requirements of the existing buildings in such a way that the selection of the appropriate VGS system directly affects the energy consumption, which is undeniably constantly increasing.

2. CLASSIFICATION OF VGS / KLASIFIKACIJA SVO

The application of the VGS system represents a modern concept of architectural design, which is based on the improvement of the environment and the energy performance of buildings. As a unique design element, the VGS system provides environmental, economic and social benefits to the community. Due to the application of the VGS system, engineers are confronted with many different principles of system classification, which primarily depend on the authors of the work. Accordingly, the term vertical greenery system will be used in this paper, which encompasses any method of placing plants on a vertical surface (i. e. facade wall), regardless of the way of growth of the plant medium (Tong, 2013). The definition of VGS encompasses different types of vertical greening, depending on

the mechanism of growth of the plant medium, the construction of the system as well as the benefits achieved by individual systems.

Defining the subtypes of the VGS system according to the classification scheme (Figure 3) was made on the basis of the characteristic substructure of the VGS system and the way the vegetation layer is supported, thus dividing the VGS system into green facades and living wall system.

In the scientific literature, the green facade system is often defined as a two-dimensional system that involves the installation of a substructure in the form of a wire or net and grid system in front of the facade wall as a necessary supporting structure for climbing plants. The sub-

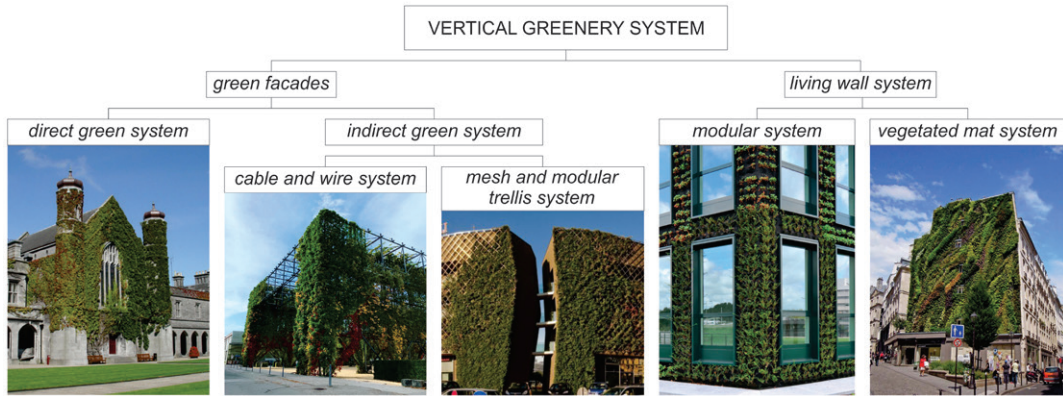


Figure 3. The VGS system classification (Authors according to Čekić, 2019) / **Slika 3.** Klasifikacija SVO (Autori prema Čekić, 2019)

system of green facades for plant media uses only creeping and climbing plants and, depending on the proximity and method of planting according to the wall surface, is divided into direct and indirect greening system (Villanova, 2013).

Direct greening system includes the planting of climbers, most often ivy species, directly along the facade wall without any construction to support the vegetation layer. The direct greening system is the oldest VGS system in which climbers grow directly against the wall, using their 'air root system' to lean on the wall surface, where the strong rooting effect often causes damage to the wall structure (GRHC, 2008; Villanova, 2013).

Unlike direct greening, the indirect greening system involves the application of a substructure, which does not allow plants to directly touch the wall surface, thus preventing its potential damage. The indirect green system supports the use of cable and wire systems and mesh and modular trellis systems, often combined with boxes/pots as necessary supporting structures that provide greater and faster coverage of facade surfaces (GRHC, 2008; Villanova, 2013).

Living wall system is characterised as a three-dimensional system, which involves placing the vegetation layer in previously prepared panels and modules of various shapes with substrate and insulation layer of synthetic membranes, which are directly fixed to the vertical surface. The pronounced thermal insulation properties

of living wall system, as well as the possibility of applying the widest range of plant species which, in combination of colours and shapes, create attractive design solutions, ensure the acceptability of the system in the field of urban renewal and improvement of energy efficiency of buildings. The process of maintaining a living wall system is more demanding than maintaining any other VGS system, primarily because of the irrigation system installed as an integral part of the panel, but also because of frequent replacements of plant material due to changing seasons. The market keeps track of the wide use of the living wall subsystems, forming different shapes as well as entire panel structures which develop characteristic subsystem types by improving and developing fertilisation and irrigation systems, depending on site requirements. Depending on the form and the installation of the vegetation layer, the living wall system is divided into two basic types: the modular system, which consists of vertical panels in which plant species are planted, and the vegetated mat system, which most commonly appears in the form of a pocket system (GRHC, 2008). Different variations of individual types are present on the market, which primarily arise as a result of applied research and technological development of the VGS system itself.

Depending on the type, the VGS system has various characteristics which affect the environmental, social and economic benefits. The clas-

sification of the VGS system is primarily done according to the aspect of system review, i. e. according to the technical arrangement of the

application of the system in relation to the vegetation mechanism of growth and the structure of the system itself.

3. PRINCIPLES OF VGS IMPLEMENTATION / PRINCIPI IMPLEMENTACIJE SVO

The vertical greenery system is not enough present in the very technical application, primarily due to insufficient knowledge and market presence. That is why defining the application principle greatly contributes to its successful implementation. When choosing an adequate system for implementation, all aspects of the system should be taken into account. Particular attention should be paid to the design and maintenance process of the system, as well as to all other factors that directly affect the choice of the system.

The basic principle of VGS system implementation is based on a detailed analysis of the location where VGS system implementation is planned. Primarily, urban analysis is used to define the narrower and broader locations and from which directly results the analysis of microclimatic conditions. Microclimatic conditions are a very important element in planning the application of a VGS system, since the certain types' need for increased insolation along with the strong airflow can cause permanent damage to the system. That is why this analysis should be conducted according to the correct microclimate inputs.

The analysis of the characteristic features of the building is an architectural analysis of the building itself, on which the installation of the VGS system is planned. This analysis is conducted independently and it defines the constructive and design parameters, which directly influence the selection of the appropriate type model of the VGS system. It is exactly on the elements of this analysis that a further analysis of the planning structure is carried out. It can be said that, depending on the parameters defined by the analysis of the characteristic features of the building, further analyses and even the design of the VGS system are carried out. The design of the system is developed on the basis of the concept and conceptual design, which is the result of previous architectural analyses. The design defines in detail the choice of substructure, plant material, method of installation, as well as all other requirements that the system must satisfy in order to be successfully implemented. According to the chosen system design, a planned maintenance system is performed as well as the cost-benefit analysis for the intended model at a specific location (Figure 4).

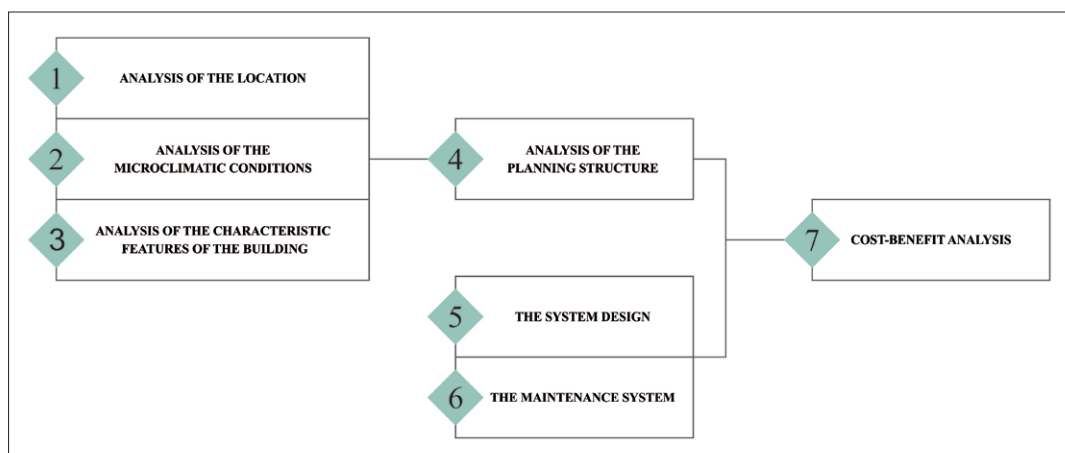


Figure 4. Principles of VGS implementation (Čekić, 2019) / Slika 4. Principi implementacije SVO (Čekić, 2019)

3.1. Analysis of the location / Analiza lokacije

The proper selection of plants is necessary for the sustainability and longevity of the system and the very selection must be adapted to local climatic conditions for easier adaptation, but also for proper maintenance and eventual replacing of the plant medium. A long-term system maintenance plan is required in order to provide a healthy and comfortable environment system, where plant fertilisation, irrigation and annual maintenance must be monitored. Maintenance work as well as the very implementation of the system must be performed by experts, ensuring the correct technical implementation, which depends on the geographical area in which the system is applied.

When choosing the right VGS system, an important role is played by construction costs, i.e. the costs of the system implementation, which vary depending on the type of the system and the choice of the plant medium. The initial costs of installation and system maintenance are often very high, so when choosing the right system, it is necessary to get familiar with the cost range and the potential benefits of the system, as well as all the possible models of financial subsidies, if there are any. The capital expenses require a more detailed analysis using the economic studies and analyses. Based on all that, the very implementation of an appropriate VGS system is accepted as a profitable investment.

The analysis should take into account the location and size of the building onto which the VGS system is installed, as well as its storeys and the purpose of the surrounding buildings. When positioning a VGS system, it is also necessary to analyse the impact of roads whose frequency may make the system vulnerable due to increased CO₂ emissions. Due to all this, it is suggested to use the plant species which are more resistant to pollution. The location analysis implies an appreciation of the proximity and purpose of the surrounding buildings, which are adjacent to the potential installation of the VGS system. It is necessary to pay particular attention to objects that have a detrimental effect on the system itself, such as cooling towers and machines with a ventilation system (Peng, 2014).

When choosing the appropriate position of the VGS system, it is also necessary to take into account the strategic position of the chosen site, which enables the creation of attractive public space, necessary visibility and accessibility of the space to its visitors. In order to successfully integrate the VGS system into urban space, the very design element should take advantage of its visual elements in order to create a unit which does not disturb the vision of the location.

3.2. The analysis of the microclimatic conditions / Analiza mikrolokacije

The analysis of the local microclimatic conditions includes the analysis of solar radiation of the wall surfaces onto which the installation of the VGS system is planned, the temperature and humidity of the air, as well as the wind effects. Microclimatic conditions directly affect the selection of plant species and their fertilisation and irrigation. The relationship between the building with the VGS system and its surrounding buildings is important when analysing contextual conditions, since nearby buildings often create shade. Therefore, the selection of the plants that tolerate cooler and shady spaces is necessary for such surfaces.

The solar radiation analysis involves observing the level of sun radiation of the wall surfaces according to the seasons and the amount of solar radiation that the wall surfaces receive. The cold winter period is characterised by a much shorter time from sunrise in the southeast to sunset in the southwest, reducing the level of solar radiation of the wall surfaces facing north, as well as the surfaces facing east, while the highest level of sun radiation is on the south and southeast wall surfaces respectively. In the summer months, the sun rises in the northeast and sets in the northwest, providing the highest level of reflective and diffuse radiation. With this, east and west wall surfaces get the strongest sun radiation, while the north and southeast ones receive the least solar radiation during the same period. The installation position of the system, which allows the application of many plant species, is in the west, south and southeast side, as these wall surfaces receive higher solar radia-

tion than others. Wall surfaces exposed to direct sunlight require careful selection of the plant species, as plant drying often occurs due to increasing climate changes. The very position of such wall surfaces requires a special care during the high-temperature period (Tzortis & Sophocleuous, 2018).

It is necessary to take into account both quantity and frequency of precipitation. The increase of temperature differences, as well as the creation of heat islands, can disrupt the plants of the VGS system and cause permanent damage. The importance of microclimatic conditions is one of the key factors that dictates the choice of plant species, as well as the possible implementation of the system and its sustainability in relation to the temperature changes to which it is exposed. Frequent and sudden temperature differences do not have a favourable effect on the VGS system. That is why it is necessary to anticipate the critical points for the system and try to remove or reduce their influence as much as possible during the technological implementation.

The influence of the climate environment is of great importance for the selection of the appropriate type of VGS system, as well as for plant medium whose stability and adaptation to the microclimate conditions of the selected location is the basis for the successful growth of the planned system.

3.3. The analysis of the characteristic features of the building / Analiza karakterističnih osobina zgrade

Before the very installation of the VGS system, it is necessary to analyse the current condition of the building onto which its installation is planned. The analysis includes the examination of the structural and design parameters of the building, as well as the eventual damage. This analysis ensures the choice of an appropriate method and type of system that will meet the installation possibilities with the characteristic substructure (Tzortis & Sophocleuous, 2018).

It is necessary to take into account the materialisation of the building and the quality of its wall surfaces in order to mend the eventual damage

prior to the system installation, as well as the orientation of the facade surface and evaluation of the characteristic high elements of the building, which affect the very position and method of the VGS installation. The installation of the VGS system must not impair the existing condition of the building, its stability and structural assembly. Customer safety requirements must also be taken into consideration. Particular attention should be paid to the fire requirements that certainly change due to this installation.

3.4. The analysis of the planning structure / Analiza strukture planiranja

When designing a planning structure scheme, it is necessary to take into account the technological solution, develop the irrigation and maintenance system of the VGS system and to elaborate the details of the installation, as well as any additional attaching of the VGS elements on the structural assembly of the building. By selecting the substructure, it is necessary to define the material from which it is derived and to develop the scheme of laying modules and boxes with plant material on the intended surface.

The analysis involves getting familiar with the basic characteristics and requirements of the selected system and methods of maintenance, in order to ensure the healthy and comfortable system, as well as the selection of the appropriate substrates and fertilisers necessary for the plant species. When choosing the right VGS system, static analyses of the system are required, as well as the calculation of the additional load on the structure (snow, plants, wind, safety of the load-bearing structure). All predicted system loads must be shown in the analysis (Loh, 2008).

3.5. The system design / Dizajn sistema

The selection of plant species is one of the most important factors, which directly influences the design of the VGS system. The proper selection of plants is based on the selection of local species, depending on the geographical region – all in order to make the adaptation to climatic conditions easier and to apply the known method of maintenance and eventual replacement of individual plants due to drying.

The choice of plants depends on the position of the sun and wind, hardness of the surface, but also the visual context and the very design concept. It is necessary to set the realistic expectation regarding the presumed visual attractiveness of the system and the very growth of the plant medium, since some systems take up to ten years to reach the full coverage of the wall surface.

The combination of the widest selection of plant species is made possible by the application of the living wall system. Depending on the season, certain plant species can bloom and change the leaf colour. Their rhythm of different visual patterns provides an element of variety and visual attractiveness of the wall. When combining the plant species with various visual characteristics, the ability of some plant species to absorb the solar energy as well as the efficiency in reducing air temperature should not be ruled out (Prihatmanti & Taib, 2017).

The realisation of ecological benefits in the form of the air temperature reduction is a characteristic of plant species with red leaves, while plants with darker leaves are the best when it comes to solar energy absorption. When choosing the plant species, it is necessary to pay attention to the leaf density and leaf area index (LAI), where the use of leaves with multiple layers is a better choice because it increases the efficiency in reducing solar energy, whereby only one layer of leaf can absorb 50% of visible infrared radiation, reflect 30% and transmute 20% (Giordano et al., 2016).

The combination of plant species according to the leaf area index can greatly improve microclimatic conditions. So, for example, plant species with small leaves (e.g. Lanceolate, Spatulae, Linera) significantly lower the air temperature, increase the relative humidity and absorb chemical pollutants from the air, while the broadleaf plants (Conlata Elliptical) only reduce the temperature. The best combination is the combination of various colours and shapes, since the appearance of the VGS system is more vivid, satisfying even the most complex design requirements and providing better thermal comfort (Tzortis & Sophocleuous, 2018).

3.6. The maintenance system / Sistem održavanja

The maintenance system includes the planned layout of the maintenance system according to the required seasonal work, depending on the selected plant species (Peng et al., 2014). The maintenance system requires monitoring of the entire life cycle of the VGS system, a timely response in order to prevent any damage that may cause the system failure, as well as the expertise of the staff and necessary knowledge of the operation and maintenance of the entire system. Cyclic maintenance is adapted to shorter time intervals and includes the control of irrigation systems, stability of the substructure and work such as pruning, autumnal leaf removal etc. If the system becomes damaged at any point, a reactive maintenance is planned. This includes evaluating and repairing the damage, as well as the control of its proper functionality. If the damage is large, it presents a real danger to the system.

3.7. The cost-benefit analysis / Analiza troškova i dobiti

The cost-benefit analysis includes the review of the initial costs of the VGS system installation, based on the design requirements and the design of the selected system, and the costs of maintaining and removing the selected VGS type for a period of fifty years, as well as the comparison to the potential benefits of reducing energy for heating and cooling buildings, and increasing the value of the building. In the analysis, not all benefits are measurable at a given moment, as is the case with the realisation of social benefits (Tzortis & Sophocleuous, 2018; Loh, 2008).

The vertical greening system is not sufficiently present in the very technical application in Bosnia and Herzegovina and its surrounding countries. This is due to insufficient knowledge and presence of the system in the market, so the very assessment of the economic feasibility is unclear for engineers and investors who decide to apply this type of facade. By defining the technological system requirements as the degree of achieved benefits through adequate maintenance system, technical and economical indicators are formed based on which a detailed cost-benefit analysis is performed.

4. CONCLUSION / ZAKLJUČAK

Defining the basic principles of the VGS system implementation will allow engineers to systematically approach the process of the VGS system implementation and help them select the best VGS system model for the selected location and building. The importance which the VGS system achieves as an environmentally friendly model for the process of improving insulation performance is great. The basis of energy efficiency is exactly the reduction of energy consumption and CO₂ emission. Thus, the application of this facade model allows the reduction of pollution and provides a sustainable approach to engineering. The frequent application of the VGS system in the last decade has required a clear definition of conditions and standards which must be met in order to successfully install the VGS system.

According to the above mentioned principles of implementation, there are some clearly defined segments, which must be covered in the process

of planning, for which a detailed analysis is necessary to be performed. It is exactly on the basis of location analysis, microclimate conditions analysis and architectural analysis that a plan for implementing the appropriate type model is being worked out. By defining the concept and design of the system itself, it is possible to specify the maintenance system, i. e. the costs of the system itself, which are indisputably an important factor in the planning process.

The application of VGS systems in the field of energy efficiency represents a significant step forward in terms of ecology and in relation to the choice of current models and facades. It is exactly according to the needs that this field requires that it is necessary to define the basic principles of the VGS system in the process of its concrete application in practice. These principles would provide engineers with the necessary basic framework for practical action.

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Saetak

Ekoloki problemi gradova uzrokovali su rast potronje energije u zgradarstvu, koji se moe usporiti poboljanjem energetske efikasnosti zgrada. Na potronju energije u zgradama utie i omota zgrade, a integracija zelenila sa omotaem zgrade doprinjee utedi energije i poveanju njene energetske efikasnosti. Stoga, sistem vertikalnog ozelenjavanja (SVO) posljednjih decenija uzima veliku panju, kao model ija implementacija moe poveati energetska efikasnost zgrada. Definisanje osnovnih principa implementacije SVO sistema omoguie inenjerima sistematian pristup procesu implementacije SVO sistema i pomoi e im da odaberu najbolji model SVO sistema za odabranu lokaciju i zgradu.

Ključne rijei: dizajn SVO sistema, energetska efikasnost zgrada, implementacija, sistem vertikalnog ozelenjavanja