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## «Green roofs» - historical experience and modern requirements

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The article considers the historical experience of creating "green roofs", as well as the requirements and conditions under which such roofs are currently designed. Historical examples and existing modern world objects show the expediency of creating and using green roofs of houses in Ukraine, which will significantly enrich the "fifth facade" of buildings and improve the overall appearance of cities. The lack of regulatory framework for the design of "green roofs", as well as some types of roofing technology problems that may arise during the operation of such roofs and the consequences that they have - environmental, economic, social, and technical. Determining the design conditions and the feasibility of using "green roofs" was chosen a structural scheme of combined coverage, which has all the necessary structural elements. It has been shown that the energy efficiency of this type of coating is provided. Determination of heat transfer resistance was carried out according to all regulatory requirements of SBC B.2.6 - 31: 2006. Constructions of houses and buildings, thermal insulation of buildings. The structural component of the designed "green roof" and the sequence of arrangement of some structural layers of this type of coating are considered. The efficiency and expediency of installation of "green" coatings on residential buildings, as well as the standard service life and warranty period of maintenance-free service of this coating, subject to regulatory requirements and operating conditions

**Keywords:** energy efficiency, green roofs, green structures, landscaping, environmental improvement

## «Зелені покрівлі» - історичний досвід та сучасні вимоги

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У статті розглядається історичний досвід створення «зелених покрівель», а також вимоги та умови, за яких такі покрівлі проектуються в даний час. На історичних прикладах та існуючих сучасних світових об'єктах показано доцільність створення та використання озелених покрівель будинків в Україні, що суттєво збагатить «п'ятий фасад» будівель та покращить загальний вигляд міст. Розглянуто відсутність нормативної бази для проектування «зелених покрівель», а також деякі види проблем технології озеленення покрівель, що можуть виникати в процесі експлуатації такої покрівлі та наслідки, що вони несуть – екологічні, економічні, соціальні та технічні. Для визначення умов проектування та доцільності використання «зелених покрівель» було обрано конструктивну схему суміщеного покриття, що має всі необхідні конструктивні елементи. Було показано, що енергоефективність даного типу покриття забезпечена. Визначення опору теплопередачі велось за усіма нормативними вимогами ДБН В.2.6-31:2006 «Конструкції будинків і споруд, теплова ізоляція будівель». Розглянуто конструктивну складову запроєктованої «зеленої покрівлі» та послідовність влаштування деяких конструктивних шарів даного типу покриття. Визначено ефективність та доцільність влаштування «зелених» покриттів на житлових будинках, а також нормативний строк служби та гарантійних термін безремонтної служби даного покриття, за умов дотримання нормативних вимог та умов експлуатації

**Ключові слова:** «зелена покрівля», озеленення, покращення навколишнього середовища, «зелена конструкція», енергоефективність



## Introduction

One of the modern architects' work areas is the construction of housing, in which a person could feel protected from the negative effects of the environment. Of course, the task is complex. And yet, the more materials offered to us by nature, surrounding us in everyday life, the more comfortable we feel. Realizing this, many architects use the experience of old architects in their designs. This is reflected in the desire of more and more people to regain the lost harmony with the natural environment, to preserve and increase the orderly depleted natural systems and landscapes. One of the areas of work to bring human habitation closer to wildlife is the installation of green roofs. Green roof - a place on the structure of the building, which is partially or completely covered with vegetation and fertile soil layer with the possibility of landscaping. Nowadays, this once primitive way of building a roof is increasingly turning into high-tech roofing, gaining popularity around the world. To roof landscaping, according to the developed classification, we also include landscaping of terraces [1].

"Green roofs" can now be considered as if the fifth facade, because their beauty often attracts more attention than the main facades of buildings. They are aesthetic, attractive, improve the appearance of the area and the city as a whole, and their environmental effect is beyond doubt. In addition, they create additional places for people to rest, among flowers and trees, without leaving their home and without using transport to get closer to nature. With the help of "green structures," you can mask the shortcomings of buildings and make them more harmonious and environmentally friendly. In addition, the use of such structures helps to harmoniously fit the building into the natural environment [1].

## Review of the research sources and publications

In Ukraine, "green technology" in general, and roof landscaping, in particular, have not become widespread yet. This leaves a certain imprint on research in this direction. Analysis of the literature showed that the research is theoretical, analytical, and generalizing. History of the issue, types of existing green structures are considered in the works of Kraynikovets O. [8], Kildisheva S. [5], Tkachenko T. [7], Shvec V. [10], Minyailo [13] offers ways to popularize the idea of roof landscaping in Ukraine, considers the prospects of "green structures" in Poltava. However, there are no serious research developments in Ukraine.

The main directions of development of this technology in Europe and the USA are presented in the works of Wong N. [1-2], Niachou A. [3], Taylor A. [9], Akbari H. [11].

## Definition of unsolved aspects of the problem

The lack of scientific base and popularization of the introduction of "green structures" in Ukraine is due to the lack of state support and the concept of the place, role, and importance of "green structures" to solve environmental, economic, and social problems of cities. The construction of "green structures" in Ukraine is sig-

nificantly hampered by the lack of a regulatory framework. The only norm that considers certain aspects of the use of "green roofs" is [14]. It provides only one version of the scheme of "green roof" and the calculation of loads from it.

Thus, the introduction of "green structures" in the "green" domestic construction is a promising direction, as evidenced by successful examples of the long-term existence of these structures in residential, educational, and commercial institutions. But the slowdown in the construction of green structures in Ukraine is due to the lack of research and development, regulatory framework, lack of concept of the role of "green structures" in sustainable urban development, lack of state support, as well as the difficult economic and political situation.

## Problem statement

The work aims to develop a typical energy-efficient solution of "green roof" structures based on the analysis of historical experience and foreign experience.

## Basic material and results

History of the "green roofs".

The prototype of the "green roof" can be considered the first home of a prehistoric man. Our ancestors placed grass on thatched roofs to improve thermal insulation, reduce the risk of outbreaks and ensure water runoff (Figure 1). Until recently, buildings in peasant yards in the northern regions of the Slavic countries were placed very close to each other, and their roofs were covered with a layer of soil and vegetation. The history of green roofs is quite old.



Figure 1 – Houses with sod roofs in the Faroe Islands

In Scandinavia and Iceland (over 1,000 years ago), dwellings with earthen roofs were common. Grass grew on the backfill, which served as additional insulation and allowed it to retain heat. In southern Europe, by contrast, roof landscaping was used for sun protection. This technology was especially suitable for warehouses and storage of agricultural products, wine cellars. Such buildings were built, in particular, in rural Austria in the late XIX - early XX century. In Babylon, the first "metropolis" of the ancient world, there was already a problem of environmental management. One-storey dense urban buildings have almost supplanted green urban areas. Small groves, orchards, and palm alleys surrounded only areas of rich nobles. But the city looked like a green oasis due to the system of green terraces, i.e. the famous Hanging Gardens of Semiramis [8].

The famous "Gardens of Semiramis", considered the seventh wonder of the world and built around 600 BC., were nothing more than "green roofs" of Babylonian palaces. The gardens in those days were terraces. The pillars were covered with stone slabs, which housed several layers of brick, bitumen, reeds, lead, and a thick layer of earth. The lower terrace was 45 x 40 m, the upper ones were smaller. The total height of the building was about 20-22 m. On the lower terrace grew plain plants, mostly trees, and on the upper there were mountain plants. Already, in this case, we are faced with the distribution of plants in tiers according to their environmental requirements and biological needs (Fig. 2) [8].



**Figure 2 – Hanging Gardens of Semiramis**

The most luxurious examples of hanging gardens are known in the Renaissance. Italy was especially famous for such gardens, where in Florence in the XV century in the gardens on the roof of Villa Medici grew exotic flowers, and in Mantua a huge hanging garden was built on the roof of the palace of the Duke of Gonzaga. Cardinal Andrea del Valle in 1530 built a museum in Rome in the form of a "hanging garden", and in Verona, Count Mafarey on the roof of his palace made a beautiful garden planted with various flowers and trees [1, 3-5]. In the XVI-XVII centuries, in northern Italy on the rocks of the island of Isola Bella, surrounded by the waters of Lake Maggiore, on the terraces of the castle were built hanging gardens, which became a model of garden art of the Late Renaissance. Under the terraces, where plants from almost all over the world were collected, there was a whole gallery of underground grottoes, where you could hide from the summer heat.

Thus, in the period from the era of the Ancient World (six centuries BC) and to the XIX century. Green roofs were used to solve aesthetic and utilitarian problems. The evolution of "green roofs" took place with the development of cities and society. In Europe, the ancient roof gardens were forgotten during the Middle Ages. The second birth of green roofs dates back to the XIX century when at the World's Fair in Paris, German architect Karl Rabitz surprised the audience by presenting a house with greenery instead of the traditional roof. Since then, appeared the concept of "living roof", "operated roof" - lawns or even gardens for recreation directly on the roof of the building. Karl Rabitz formulated the idea of landscaping roofs as the most important means of improving the urban environment.

The construction of flat "green roofs" took on a particularly large scale at the end of the 19th century, and in the early XX century, in connection with the advent of reinforced concrete and thanks to the work of the most prominent architects and urban planners, among whom were the Frenchman Le Corbusier and the American FL Wright [4]. Le Corbusier made "roofs-gardens" a necessary part of the architecture, developing and implementing a large number of projects using exploited green roofs, ranging from small villas to large residential complexes. Roof landscaping from the category of privileged private closed became open to the city and its inhabitants. That is, the social component was added to the utilitarian approach.

World standards for creating "green roofs"

In Europe, the United States, and Canada, roofs have been widely planted since the early 1980s. Initially, in a number of countries, landscaping was carried out as part of national programs aimed at enhancing biodiversity. Roof landscaping is currently recognized as one of the most relevant areas of landscape design. The governments of most developed countries do their best to encourage green roofs (especially in large cities). According to experts, the generally accepted priority in the creation of garden roofs now belongs to Germany, where about 14 million green roofs appear annually. In this country, one of the prerequisites for the design of new buildings – roofs landscaping, including a significant slope. Taxes have been introduced for homeowners who do not use roofs for gardens.

In England, in 2007, the mayor of London ordered the use of landscaping in all major projects, so that the total area of green roofs is growing every year. In Copenhagen (Denmark) since 2010, each roof is subject to landscaping. Tax benefits are provided for the implementation of such projects. In Austria, roof landscaping has been paid for by the municipality since 1983.

In Switzerland, every flat roof has been landscaped since 2002 (currently more than 1,900 roofs in Basel are landscaped, which is more than 25% of the total roof area).

In France, a law was passed in 2016 that obliges commercial property owners to cover the roofs of buildings with plants or solar panels. Thus, "green roofs" will provide the necessary level of thermal insulation to reduce the amount of energy needed to heat the building in the cold season or to cool in the summer.

In Bulgaria, the design of a roof garden is necessary to meet 20% of the rate of the landscaping of the land where the building is located.

In the United States in New York alone there are more than 7.5 thousand green roofs. New York Mayor Michael Bloomberg in 2010 announced his intention to green the roofs of city skyscrapers, turning them into parks. This initiative should help solve two pressing urban problems. First, improve air quality. Second, reduce the amount of runoff into storm sewers, which is poorly handled by worn-out drainage systems in New York. Although green roofs will cost the city \$ 6.8 billion, they will save \$ 2.4 billion over the next twenty years.

In Chicago, private homeowners are paid subsidies for roof landscaping. Chicago authorities have calculated that if you green all the roofs in the city, where the construction of buildings allows, it would bring to the city budget about \$ 100 million. per year due to energy savings.

In Canada, since 2009, every roof with an area of more than 2,000 m<sup>2</sup> has been subject to landscaping. In 2007, Toronto took 1st place in the list of cities in Canada with "green" roofs, when the total area of "green" roofs for the year was 83,000 square feet (7710.7 m<sup>2</sup>).

In Japan, since 2001, all roofs with an area of more than 100 m<sup>2</sup> are subject to landscaping: 20% of the roof with an area of 250 m<sup>2</sup> and 10% of the roof with an area of more than 1000 m<sup>2</sup>. "Green roofs" are also available in Taiwan and India.

In some countries of Europe, Asia, America there are associations of the landscaping of roofs, the main of which are:

- International Roofing Association (IGRA);
- Association of Roofing Landscape Architects of Germany (DDV);
- European Federation of Green Roof Associations (EFB).

In North America in 1999, the organization "Green Roofs for Healthy Cities - North America" was founded. There is even The Scandinavian Green Roof Association, which annually awards the best roof landscaping project. Every year, the International Congress of Roof Landscaping is held in different countries of the world, where development trends, the most relevant and promising areas of use, improvement of construction and design technologies, and new innovative projects are presented.

Introduction of "green structures" in Ukraine

In Ukraine, landscape and recreational planning of settlements is regulated by SBC B. 2.2-12: 2018, which has already appeared innovative means of increasing the area of landscaping: vertical gardens and parks (carpet and modular), mobile landscaping systems (mobile forms), green screens and walls, gardens of continuous flowering (work is underway on the second edition), as well as the State Sanitary Rules for Planning and Development of Settlements.

To date, there are no regulations on the introduction of "green structures" in the "green building" of Ukraine. Thus, all landscape design firms engaged in the market of Ukraine "roof landscaping" have no idea about the correctness of the design of "green structures", which leads to a gross violation of technology, safety, and reduced service life. Exceptions may be international companies (ZinCo, FlorDepot), operating in the Ukrainian market according to European standards and technologies.

Until 2000, there were virtually no examples of the introduction of "green structures" in Ukraine. Separate private "green roofs" began to appear in 2005. Over the past five years, there has been a rapid development of "green building" using "green structures". Recent projects cover not only the private construction sector. "Green constructions" began to appear in shopping

malls and offices, universities, and libraries (for example, the Ukrainian Catholic University in Lviv), as well as in residential complexes.

Existing green roofs on residential buildings are currently being approved in Ukraine as experimental housing. These include the "green roof" in Kyiv at the Royal Tower (Fig. 3) (2016) and Skyline (Fig. 4). The uniqueness of the roof on the Royal Tower is that it is intense and is located on the 32nd floor. Large woody plants up to 6 m tall are planted on the roof.



**Figure 3 – Green roof of the Royal Tower**

The Skyline has a terrace principle of landscaping. In recent years, especially popular roof landscaping of office buildings. The roof space is used as a recreational area for residents and guests of the house and is rented out for various events. Owners of some office buildings, for example, on Lobanovsky Avenue, where the "green roof" of the company "ZinCo" is located, use it for commercial purposes - for rent for various purposes.

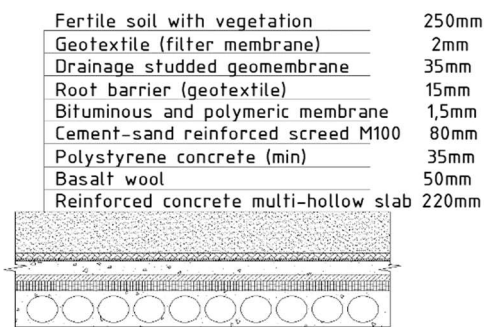


**Figure 4 – Green terraces of the Skyline house**

Among the "green structures" in business centers, there is an intensive "green roof" on Smolenskaya Street. In 2013, a project to create mini-farms on the roofs of high-rise buildings was actively discussed in Kyiv, but it never developed. However, the idea is promising, especially considering that in Kyiv there are more than 200 hectares of flat roofs that can be used as areas for small greenhouses. In addition, all roofs are usually covered with a black coating, which further retains solar heat, which can be used for greenhouses.

Designing a "green roof"

When developing the project of construction of a multi-storey residential building, a constructive solution of the "green roof" was applied according to this scheme (Fig. 5).

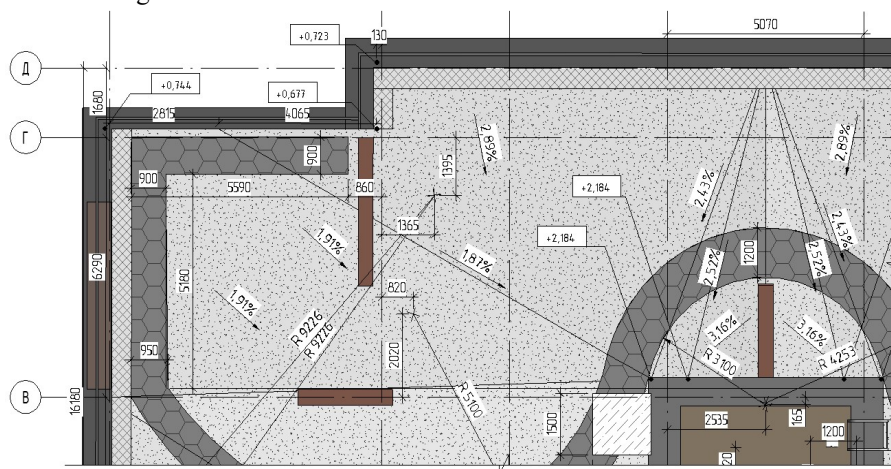


**Figure 5 - Constructive scheme of coverage**

In accordance with the calculated values and conditions defined in SBC B.2.6 - 31: 2006 [15], performing the thermal calculation of the combined coating, we obtain the heat transfer resistance of this structure. The normalized value will be equal to  $R_{qmin}=6.0 m^2 \cdot K/W$ , and accordingly calculated  $R=6.82 m^2 \cdot K/W$ , in such a way  $R_{\Sigma} \geq R_{qmin}$  that it will fully provide the conditions we need.

After these calculations, you can start designing a "green roof" for a multi-storey residential building. Taking into account all design features, according to SBC [15], aesthetic and recreational conditions that can be created on this type of roof, after the design we get a fundamentally individual and structurally provided "green roof".

The designed "green roof" (Fig. 6) has extensive landscaping, does not require special care. Almost around the perimeter of the roof is a green "fence" of boxwood.



**Figure 6 – Fragment of the designed "green roof"**

### Conclusions

Currently, scientific and technical development of "green structures" are carried out in the following areas:

- increase of energy efficiency of the building (improvement of heat-protective properties of buildings, passive cooling);
- reducing the amount of rainwater runoff by absorbing water "green roofs";
- improvement of the environment (reduction of thermal and chemical pollution of the atmosphere by eliminating "thermal islands", biological conversion of greenhouse gases into safe compounds);

– improving the aesthetic properties of buildings and the psycho-emotional state of man;

- applied use of "green structures" (for recreational purposes, doing business, growing medicinal and agricultural plants, grazing animals), etc.

The paper proposes to use "green" roofs and facades to solve the problems of cities related to urbanization.

The project proposal of the "green" roof was created and the energy efficiency of the proposed solution was proved by thermal calculation.

"Green" roofs are a dynamic system, the economic and environmental effect of which is very significant but not implemented in Ukraine.

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