Problems and Solutions for Green Roofs

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Abstract. Green roofs have been the standard design in many countries for hundreds of years due to the excellent thermal insulation properties of the fertile layer. A green roof is a space created by adding additional layers of fertile soil and plants over a traditional roofing system. Green roofing should not be confused with a traditional roof garden where plants are placed in free-standing containers on an exploited roof terrace. This article discusses the main advantages of roofing landscaping, the factors that influence the choice of type of roofing depending on climatic conditions and the main types of design solutions in megacities. The authors analyse the influence of the green roof on the energy efficiency of the building in the climatic conditions of Yekaterinburg. The main disadvantages of landscaped exploited coatings are considered. Also proposed is a new technology for the construction of an operated roof without a roll coating, but using penetrating waterproofing of reinforced concrete structures. It has now been proven that a properly designed and installed green roof can replace or compensate for the green environment at ground level that a large city is deprived of as a result of urbanization. The use of green roofs gives the metropolis ecological, social, economic and aesthetic benefits.

1. Introduction

Rapid urbanization as a global challenge arose several decades ago, and the transformation of large cities into metropolises of glass and concrete has led to significant environmental degradation and lack of green areas in urban environments.

The problem of creating environmentally comfort zones in an aggressive urban environment is particularly important due to the rapid growth of urban population and the compaction of urban development.

An important direction in the development of the urban architecture is the development of a modern concept for the formation of green comfort zones. Nowadays this problem is solved by means of traditional methods, i.e., creation of parks, squares, increase in greenery of city streets. However, one of the most promising solutions in this direction is the arrangement of green surfaces on the roofs of buildings, stylobates, and underground car parks, especially near courtyard areas.

In the project "Roof Gardens" (author N.P. Titova), as early as the beginning of the XXI century, considers the possibility of significant improvement of the ecological situation in large cities through
the use of empty roof surfaces and other artificial bases for placing objects of landscape architecture [1].

V. A. Gorokhov was engaged in solving the problems of the ecological state of the modern urban environment and described the basic principles of the organization of green areas in urban development in his work "Green nature of the city" [2].

Buildings and structures with green operated roofs will stand out from the general city landscape and become not only one of the additional zones of ecological comfort, but also a genuine decoration of modern metropolises, where each square meter of free space counts (figure 1) [3-7].

![Figure 1. Greening of roofs in Moscow [8].](image1)

Russia also has experience in green roof design [9]. For example, the green courtyard of the "Stone Brook" with bridges and staircases is located on the roof of the parking lot and the shopping gallery in Yekaterinburg (Figure 2).

![Figure 2. The green courtyard of the "Stone Brook" with bridges and staircases is located on the roof of the parking lot and the shopping gallery, Yekaterinburg.](image2)

Smartly designed and installed green roof compensates for the natural environment at ground level, which is deprived of a large city due to urbanization [10]. The main advantages of operated green roofs are following:

- improvement of urban air quality (reduction of carbon dioxide concentration);
- reduction of peaks and total drainage flow volume (due to the ability of the green roofs to hold and store rainwater);
• reduction of energy consumption of the building, both in cold and summer;
• creation of habitats for animals (insects, birds);
• improvement of the aesthetic attractiveness of the building through the created environment.

2. Analysis of the green roofs' impact on buildings' energy efficiency

Green roofs are an effective tool for improving the energy efficiency of buildings in both hot and cold climate regions. In the first case, they protect the building against overheating, in the second case they become an additional layer of thermal insulation that retains heat inside the building.

Today, green roofs are sophisticated engineering systems. They include an inverted roof base (effective thermal insulation from EPPS slabs, roofing membrane). Components such as drainage layer, filtering geotextile, soil substrate with a special plant layer resistant to climatic influences are placed on top of the standard inverted structure [11].

Consider two coating options: the first is a non-exploitable inverted type of roofing, typical for a traditional residential building (Table 1), and the second is a monolithic roll-free coating with greening (Table 2).

Comparative heat engineering calculation for the climatic conditions of the city of Yekaterinburg is carried out. The required thermal resistance of the structure $R_{0}^{\text{req}}$, based on regulatory requirements for the reduced heat transfer resistance, we find by formula 1 [12]:

$$R_{0}^{\text{req}} = a \cdot GSOP + b = 0.0005 \cdot 5613.4 + 2.2 = 5.01 \frac{m^{3} \cdot \circ C}{W}$$  \hspace{1cm} (1)

where $a$ and $b$ - data ratios from [11, Table 3] for the relevant types of buildings (for coating: $a$=0,0005; $b$=2,2).

The degree-days of the heating period are determined by the formula 2 [12]:

$$GSOP = (t_{\text{int}} + t_{hp}) \cdot z_{hp} = (-20 - (-5.4)) \cdot 221 = 5613.4 \circ C \cdot \text{day}$$  \hspace{1cm} (2)

The values for the length of heating period $z_{hp}$ and the average air temperature $t_{hp}$ are taken according to [13, Table 1].

| №  | Material                                      | Thickness $\sigma$, mm | Thermal Conductivity Coefficient $\lambda$, W/m°C | Thermal resistance $R$, m$^{2}$$\circ$C/W |
|----|-----------------------------------------------|------------------------|-----------------------------------------------|----------------------------------------|
| 1  | Ballast (washed gravel)                       | -                      | -                                             | -                                      |
| 2  | Geotextile (heat treated)                     | -                      | -                                             | -                                      |
|    | Extrusion polystyrene foam Techniconic         | -                      | -                                             | -                                      |
| 3  | CARBON PROF $t=100+100=200$ mm                 | 200                    | 0.032                                         | 6.25                                   |
| 4  | Geotextile (needle punched)                    | -                      | -                                             | -                                      |
| 5  | Waterproofing Technoelast EPP (2 layers)      | 10                     | 0.17                                          | 0.06                                   |
| 6  | Reinforced cement-sand screed (on a slope, $t_{\text{min}}=50$ mm) | 50                     | 0.76                                          | 0.07                                   |
| 7  | Monolithic reinforced concrete plate B25, F75, W4 | 200                    | 1.92                                          | 0.10                                   |
|    | Total thermal resistance of coating №1        |                        |                                               | 6.48                                   |

Table 1. Non-exploitable inverted type of roofing.
Resistance to heat transfer with successive uniform layers is determined as the sum of the thermal resistances of the individual layers (formulas 3 and 4), which is typical for first coating:

\[ R_{1}^{\text{con}} = \frac{1}{a_{\text{int}}} + \delta_1 \frac{1}{\lambda_1} + \delta_2 \frac{1}{\lambda_2} + \ldots + \frac{1}{a_{\text{ext}}} = \frac{1}{8.7} + 6.48 + \frac{1}{23} = 6.63 \frac{m^2\cdot\text{C}}{W} \]  \hspace{1cm} (3)

Taking into account the heterogeneity of the structure:

\[ R_{1}^{\text{act}} = R_{1}^{\text{con}} \cdot r = 6.63 \cdot 0.92 = 6.09 \frac{m^2\cdot\text{C}}{W} > R_{0}^{\text{reg}} = 5.01 \frac{m^2\cdot\text{C}}{W} \]  \hspace{1cm} (4)

### Table 2. Monolithic roll-free coating with greening.

| №   | Material                          | Thickness \( \sigma \), mm | Thermal Conductivity Coefficient \( \lambda \), W/m°C | Thermal resistance \( R \), m\(^2\cdot\text{C}/W \) |
|-----|----------------------------------|-----------------------------|---------------------------------------------------|----------------------------------|
| 1   | Soil with greenery               | 200                         | 1.05                                              | 0.19                             |
| 2   | Profile membrane Planter         | 8.5                         | -                                                 | -                                |
| 3   | Geotextile (heat treated) Extrusion polystyrene foam | -                  | -                                                 | -                                |
| 4   | Technicol CARBON PROF \( t = 100+100=200\)mm | 200                         | 0.032                                             | 6.25                             |
| 5   | Geotextile (needle punched) Waterproofing Technoelast GRIN | -                  | -                                                 | -                                |
| 6   | Waterproofing Technoelast EPP \( 1 \) layer | 10                           | 0.17                                              | 0.06                             |
| 7   | Reinforced cement-sand screed \( t_{\text{min}}=50 \) mm | 50                           | 0.76                                              | 0.07                             |
| 8   | Monolithic reinforced concrete plate B25, F75, W4 | 200                         | 1.92                                              | 0.10                             |

Total thermal resistance of coating № 2: 6.67 m\(^2\cdot\text{C}/W\)

Resistance to heat transfer for the second coating is calculated by formulas 5 and 6.

\[ R_{2}^{\text{con}} = \frac{1}{a_{\text{int}}} + \delta_1 \frac{1}{\lambda_1} + \delta_2 \frac{1}{\lambda_2} + \ldots + \frac{1}{a_{\text{ext}}} = \frac{1}{8.7} + 6.67 + \frac{1}{23} = 6.83 \frac{m^2\cdot\text{C}}{W} \]  \hspace{1cm} (5)

Taking into account the heterogeneity of the structure:

\[ R_{2}^{\text{act}} = R_{2}^{\text{con}} \cdot r = 6.83 \cdot 0.92 = 6.28 \frac{m^2\cdot\text{C}}{W} > R_{0}^{\text{reg}} = 5.01 \frac{m^2\cdot\text{C}}{W} \]  \hspace{1cm} (6)

Difference of reduced heat transfer resistances:

\[ \Delta R = 0.19 \frac{m^2\cdot\text{C}}{W} \]  \hspace{1cm} (7)

\[ R_{1}^{\text{con}} = 6.09 \frac{m^2\cdot\text{C}}{W} < R_{2}^{\text{act}} = 6.28 \frac{m^2\cdot\text{C}}{W} \]  \hspace{1cm} (8)
Figure 3. The graph of the dependence of the weight of the roof on the thickness of the vegetation layer and insulation, with a constant thermal resistance of the enclosing structure $5.2 \text{ m}^2\cdot\text{K}/\text{W}$ (Coating 2).

Based on the results obtained (figure 3), we can conclude that the most optimal type of roof greening in the climatic conditions of Yekaterinburg is the extensive type with a soil substrate thickness of 150-200 mm.

This technology combines: improving the thermal performance of the roof, protecting the building from overheating in the summer with a relatively small weighting of the roof – 100-150 kg/m².

3. Features of the arrangement of green operated coatings

In contrast to the usual flat roof, which is calculated only on the impact of climatic loads, the exploited one is exposed to increased mechanical loads arising from crowding, traffic, loads from the own weight of materials used to create functional space.

The additional load of the green surface depends on the nomenclature of plants used, the weight of the soil and gravel layer in the wet state, the weight of the additional road surface, the weight of the necessary equipment, etc. (Figure 4) [14].

Figure 4. Schematic structure of the "green roof" [15].
There are two main types of green roofing systems: extensive and intensive. They differ mainly in the choice of plants used, the thickness of the plant environment, as well as cost.

**Extensive green roofing systems** characterized by:
- low weight (plant layer 0,10-0,20 m, wet weight 100-250 kg/m²);
- low variety of used plants (plants with high resistance to climatic influences);
- minimum roof maintenance.

**Intensive green roofing systems** characterized by:
- high weight (plant layer 0,20-0,60 m, wet weight 250-950 kg/m²);
- high variety of used plants;
- high requirements for roof maintenance (need to use special drainage and irrigation systems).

Traditional green operated roofs are characterized by extremely low repairability, so the choice of components, and especially the arrangement of the waterproofing layer must be approached with great responsibility.

If the waterproofing layer of the used roofing starts to leak over time, it will be necessary to remove the roof structure above it. Therefore, both the bearing elements and the waterproofing materials of the green roofing must meet the highest requirements for strength and durability.

4. **Roll-free type of roofing**

The waterproofing layer protects the structural elements of the roof from the harmful effects of external climatic factors, such as moisture, frost, ultraviolet, etc. Most often the service life of the whole building depends on the reliability of the waterproofing layer.

Traditionally, roll-fed or coated materials are used for waterproofing concrete structures. They protect the concrete from moisture, but work separately from the main structure. During operation, such materials peel off the base, break down and fully stop working, resulting in leaks [16].

To address the problems of durability and quality of roof coverings, EPK "Dokros" patented a new type of roof "Reinforced Concrete roll-free roofing» (Figure 5).

![Figure 5. Simplified scheme of a roll-free roofing system.](image-url)
The roof structure consists of monolithic reinforced concrete slabs (plates) separated by expansion joints depending on the size of the covering. The structural parameters of the covering slabs (section height, reinforcement, concrete class) are selected based on the working conditions and estimated load on the roof [17].

The necessary properties of the concrete in terms of density and waterproofing are ensured by selecting the appropriate additives from the "Penetron" system for the initial waterproofing, which eliminates the need of using traditional roofing materials with short service life.

It is enough to waterproof only the concrete slab using the special additive for concrete "Penetron Admix", which will ensure a high level of waterproofing of the structure already at the construction stage [18]. Waterproofing of concreting joints, as well as places of entry of communications, is carried out with materials of the "Penebar" system.

The main advantages of a roll-free type reinforced concrete roof:

- increasing the reliability and durability of the roofing structure (the service life of the initial waterproofing is equal to the service life of reinforced concrete up to 100 years);
- reduction of labor costs for roofing (exclusion of secondary waterproofing);
- weight reduction of roofing by 10-15 kg/m².

In addition, the components of the "Penetron" system make it possible to repair the roof from the inside of the room, which significantly reduces the complexity, and most importantly, the cost of repair work, especially on green operated roofs (Figure 6) [19].

![Figure 6](image)

**Figure 6.** Elimination of pressure leaks and sealing cracks in a monolithic reinforced concrete roof from inside the room.

This roof will serve as a reliable basis for the setup of a green operated roofs, both on the high-rise part of the building, and above the parking lot or stylobate of any architectural form.

5. **Conclusion**

The implementation of operated green roofs can solve many problems, including reduction of the number of grey, unremarkable roofs of existing buildings, as well as solving the problem of the lack of urban spaces for creating zones of environmental comfort.
However, an important engineering task is to increase the reliability and durability of green operated roofs, due to the expensive maintenance and repair of traditional roofing systems using roll-fed waterproofing materials.

One of the solutions to this problem is using green operated roof coating based on a roll-free monolithic coating, which not only simplifies the installation of the coating, but also reduces the cost of its operation. In addition, the absence of a fragile waterproofing layer significantly expands the possibilities in the choice of systems and technologies for the operated roof setup.

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