Analysis of various types of loads from a multi-layer structure of green roof systems

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Abstract. For the sustainable development of green building technologies and the use of roof coverings with greening systems on buildings, it is necessary to take into account the complex of different types of loads from the multi-layer roof structure, as well as their effect on the building covering during operation processes. The introduction of new competitive technologies and methods of production of construction and installation works will ensure an increase in the operational quality of housing facilities. The article discusses the traditional technologies of roofing for operating roofs with greening systems, called «continuous» greening systems and new technologies for roofing with modular green roof systems, developed by the authors. The analysis and calculation of various types of loads for the given constructive and technological solutions of the operated roofing with greening systems is carried out.

1. Introduction

Today, more and more roofing systems have started to use greening systems. This is due to the fact that nowadays many property owners are concerned about the ecological image of their building and want to attract more tenants, clients and residents, so this problem is more urgent than ever, especially since it benefits the health of residents and looks aesthetically pleasing. Results show that the maximum roof surface UHI is reduced during the day by 1°C–3.8 °C by increasing green roof fractions from 30% to 90% [3].

However, the requirements for a green roof differ not only in the beauty of appearance, in the styles of green urbanism, but also have their own specific features when installing such coatings and taking into account various parameters in complex of technological processes. When installing greening systems on roofs, additional loads arise that must be taken into account based on local regulations and in relation to international standards and Building Codes.

Before designing a building, it is important to consider the building’s construction features, climate conditions, including wind and seismic activity, the load bearing capacity of a building, the weight of saturated plants when planted but their weight at maturity, especially where shrubs and trees are proposed, as these are likely to be significantly heavier over time. The load assessment of green roof plants is provided in the table 1 (in the relation to the international standards and Building Codes for green roof systems).
**Table 1. Green roof vegetation weight loadings.**

| Green roof vegetation type                               | Weight loading (kg/m²) |
|----------------------------------------------------------|------------------------|
| Low herbaceous (succulents and grasses)                  | 10.2                   |
| Perennials and low shrubs up to 1.5 m                    | 10.2-20.4              |
| Turf                                                     | 5.1                    |
| Shrubs up to 3 m                                         | 30.6                   |
| Small trees up to 6 m                                    | 40.8                   |
| Medium trees up to 10 m                                  | 61.2                   |
| Large trees up to 15 m                                   | 150                    |

The study of the green roof system is based on the organizational and technological solutions of modern scientists in construction, including in the field of green technologies [1-6].

2. Methodology

2.1. Determination of types of loads for various roof greening systems

When designing and arranging the operated roofing of buildings and structures, the rules of the current standards for the design of buildings and structures must be observed. When installing a roof with landscaping systems, additional loads arise on the base of the coating, which must be taken into account at the design stage. There are only few standards for predicting the general loads on the roof and weight of a green roof system, such as SP 20.13330.2016 «Loads and impacts» (Russian standard), DIN EN 1991 «Einwirkungen auf Tragwerke Teil 1-1: Wichten, Eigengewicht und Nutzlasten im Hochbau, Teil 1-3: Schneelasten, Teil 1-4: Windlasten» («Effects on structures Part 1-1: Weights, dead weight and payloads in building construction, Part 1-3: Snow loads, Part 1-4: Wind loads», German standard) and ASTM E 2397/E2397M: 2019 «Standard Practice for Determination of Dead Loads and Live Loads Associated with Vegetative (Green) Roof Systems» (American standard) [7,8,17].

Depending on the duration of the loads, there are permanent (dead load) and temporary (long-term, transient or short-term and special loads) or live load on the roofing, while the calculated value of the load is determined as the product of its standard value by the load safety factor ɣf corresponding to the considered limiting state. Climatic loads: snow, wind, temperature and ice refer to short-term loads (live loads), which are also important to consider when designing roofing systems. The special loads include, for example, loads caused by fire; climatic (snow, wind, temperature and ice) loads, the action of which can lead to an emergency design situation, which is not covered in this article.

To study the loads on the roof, it is important to use in the investigation a systematic approach and a multi-variable structure [9-16]. The following options for the construction of green roof systems were chosen:

- roof with continuous greening systems (option 1, figure 1);
- roof with modular greening systems (modules with a diameter of 0.5 m) (option 2, figure 2).

The operated continuous green roof systems have shallow substrates on two types of roof, the first roof is on shipping containers, and is designed for a dead load of 250kg /m² and live load of 100kg/m² (figure 1). The extensive green roofs are the innovative and technical solutions for environmental sustainability for the urban areas in the city [18-20].
2.2. Calculation of loads for various roof greening systems

The calculated value of the load should be determined as the multiplication of its standard value and the safety factor for the load corresponding to the considered limiting state as follows:

\[ L_c = L_n \cdot \gamma_f^* \]  

(1)

where \( L_c \) - calculated value of the load, (kPa);
\( L_n \) - normative value of the load, (kPa);
\( \gamma_f^* \) - load safety factor.

By considering the averaged values of the loads from each structural element and systematizing the data obtained, the loads on roof with continuous greening systems and the loads on the roof with modular greening systems were obtained (tables 2 and 3).

### Table 2. The load assessment of green roof with continuous greening systems.

| Load type                          | \( \rho \) (t/m\(^3\)) | Normative value of the load, \( L_n \), (kPa) | \( \gamma_f^* \) | Calculated value of the load, \( L_c \), (kPa) |
|------------------------------------|--------------------------|----------------------------------------------|------------------|-----------------------------------------------|
| Soil, \( \delta = 0.1 \) m        | 1.2                      | 1.6                                          | 1.3              | 2.08                                          |
| Drainage profiled membrane, \( \delta = 0.008 \) m | 0.55                     | -                                            | 1.2              | -                                             |
| Insulation-mineral wool slabs, \( \delta = 0.1 \) m | 0.035                    | 0.15                                         | 1.3              | 0.195                                         |
| Geotextile - 2 layers              | 150 g/m\(^2\)           | -                                            | 1.2              | -                                             |
| Bitumen-polymer roll waterproofing - 2 layers | 1.4                      | -                                            | 1.3              | -                                             |
| Primer                             | 0.88                     | -                                            | 1.3              | -                                             |
| Reinforced cement-sand screed, \( \delta = 30 \) mm \( (\gamma = 18 \) kN/m\(^3\)) | 0.54                     | 1.3                                          | 0.7              |                                                |
| Expanded clay gravel               | 0.4                      | 0.23                                         | 1.3              | 0.3                                           |
| Base covering, \( \delta = 220 \) mm | 2.5                      | 3.4                                          | 1.1              | 3.74                                          |

**Summary:** 7.015

\*Load safety factor: a factor that takes into account, under normal operating conditions of structures, the possible deviation of loads in an unfavorable (higher or lower) direction from the standard values
Table 3. The load assessment of green roof with modular greening systems

| Load type                      | Normative value of the load, $L_{nn}$ (kPa) | $\gamma^*$ | Calculated value of the load, $L_c$ (kPa) |
|--------------------------------|---------------------------------------------|------------|------------------------------------------|
| Solar panels                   | 0.16                                        |            |                                          |
| Modules with wet soil, $\delta = 0.4$ m | 0.6                                         | 1.2        | 0.72                                     |
| Drainage grid                  | 1.5                                         | 1.2        | 1.8                                      |
| Adjusting supports Buzon       | -                                           | 1.2        | -                                        |
| Waterproofing                  | -                                           | 1.3        | -                                        |
| Base covering, $\delta = 220$ mm | 3.4                                         | 1.1        | 3.74                                     |
| Summary:                       |                                             |            | 6.26                                     |

We calculated short-term loads as snow loads on the roof in the conditions of the city of Moscow (IV snow region):

$$L_s = C_w C_t m S_e = 2 \text{ (kPa)}$$  \hspace{1cm} (2)

where

$C_w$ - the coefficient taking into account the drift of snow from the coatings of buildings under the influence of wind or other factors, taken as 1, in accordance with [8];

$C_t$ - thermal coefficient, taken as 1, in accordance with [8];

$m$ - form factor, taking into account the transition from the weight of the snow cover of the earth to the snow load on the cover, taken as 1, in accordance with [8] (the slope of the roof covering is less than 30°);

$S_e$ - the standard value of the weight of the snow cover per 1 m of the horizontal surface of the earth, taken as 2 in accordance with [8] (IV zone).

3. Results

Taking into account the basic combination of loads consisting of permanent (dead load) and long-term and short-term loads (live load), we get the following formula for calculation:

$$L = L_d + L_s$$  \hspace{1cm} (3)

where

$L$ - the total value of the roof load;

$L_d$ - calculated value of the load, $L_c$ (table 2, 3);

$L_s$ - calculated short-term snow load.

The total value of the roof loads is calculated for the options: the total load on roof with continuous greening systems ($L_1$) and the total load on the roof with modular greening systems ($L_2$):

$L_1 = 7.015 + 2 = 9.015 \text{ kPa}$;

$L_2 = 6.260 + 2 = 8.260 \text{ kPa}$.

As we can see from this calculation, the total load on the roof with modular greening systems is almost 10% less than the total load on roof with continuous greening systems. Modular greening systems are lightweight structures, therefore they are best used on green roofs.

In the CAD program "LIRA" a check was made of the cross-section of the base covering, that it can withstand the given load (figure 3).
4. Conclusions
The basic loads associated with green roof systems were considered, based on several regulatory documents. The components that are encountered in green roof system as a multi-layer structure include: base covering, waterproofing drainage grid, insulation-mineral wool slabs and plants materials. The article analyzed the regulatory documents in this area of loads and impacts on the roof, the distinctive feature was found between them. However, these regulatory documents have some features, for example, American standard «Standard practice for determination of dead loads and live loads associated with vegetative (green) roof systems» does not address live loads associated with small architectural elements as a pavement, construction activities and loads associated with snow or wind. The Russian standard for loads and impacts on the roof of the greening system has not yet been developed at the moment, but there are prerequisites for its creation. Based on the database of important tools, the value of the roof loads for modular and continuous greening systems was considered and calculated, while it turned out that the modular greening system is easier on 10% and more convenient to use and for further operation they are better suited for the green roofs and green infrastructures in urban areas.

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