Processability of the device of exploited roofs with greening systems

Elena Korol and Natalia Shushunova

Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia
E-mail: nshushun@gmail.com

Abstract. In this research we provide the analysis of the modern green roof technological processes and operations. The traditional roofing technologies are not always suitable for operating roofs with greening systems. The use of green spaces on the coverings of buildings and structures during work is reflected in the process of forming the composition and sequence of technological processes and operations, as well as the selection of rational technological and organizational parameters. The installation of greening systems on roofing leads to an increase in the laboriousness and duration of the construction of buildings as a whole. The development and study of rational technological parameters in the construction of a multi-layer construction of roof with greening systems is aimed at reducing the additional labor costs associated with the construction of exploited roofs with greening systems.

1. Introduction
The arrangement of green spaces on roofing is a regulated technological process, the parameters of which depend on many factors, such as planning decisions, the choice of greening method (solid or modular structures), construction and technological properties of the materials used, professional and qualification skills of performers, and mechanization tools, conditions of work, etc. The use of greening systems for roofing leads to an increase in the basic values of the parameters of the laboriousness and duration of work. In order to reduce their growth, a research search is carried out and reserves are formed that take place in the variability of constructive and technological solutions and the processes directly corresponding to them. The different driving initiatives for exploited roofs with greening systems are exploring ways to cater deficiencies in existing technologies, based on their labor-laboriousness [1,2]. Challenging research opportunities arise from the process automation and BIM adaptation for the existing buildings [3,4]. Green roofs are recognized as a strategy for making the buildings more ecologically friendly and sustainable. The parameters of the energy efficiency in the buildings through the use greening systems have also been investigated [5-10].

One of the directions of improving the technology of greening roofing structures is the use of collapsible modular systems, as well as the reduction of labor-intensive technological operations of the device of a multilayer construction of a roofing base. The processability of the roofing device is one of the complex characteristics of the roofing device, which expresses the convenience of its production, maintainability and performance. The processability is the laid in the constructive-technological solutions with the appropriate assignment of the parameters of the roof parts, forms and relative position of the sections of the roofing surfaces of their elements. Technological effectiveness is based
on standardization, unification and continuity, the possibility of a new technology that embodies the achievements of science and technology allows us to achieve unique results and high consumer properties.

2. Methodology

2.1. Application the methods, based on the principles of labor and time efficiency

The study applied the methods of comparative analysis of two variants of exploited roofs with greening systems, based on the principles of labor and time savings. At the first, we consider and analyze the technological processes of the device of the under roofing part of the covering on the next variants: V1 – a variant of a roofing device with traditional greening systems; V2 - a variant of a roofing device with a modular greening system.

According to the first variant V1, the duration of the erection of the under roofing part of the coating is 20 shifts, for the second variant V2 - 18 shifts, respectively, taking into account the separation into the grips (figure 1). At the same time, the device of the under roofing design of the modular greening system is more rational both in terms of labor costs and the duration of the work, in comparison with other variants.

Figure 1. The plan for dividing the roof into grips in the axes 4-9: 1, 2, 3, 4 - grips.

The considered variants for the design of roofing with greening systems are determined by various values of the laboriousness of technological processes and operations. The under roofing device is performed on the four grips (figure 2).

Figure 2. The conventional scheme of movement of workers on the grips.
To select rational constructive solutions for the operation of roofs with greening systems, the following indicators are proposed:

1. \( K_{ml} \) – the coefficient of structural and technological variability in the laboriousness of the multilayer system of the operated roof, which shows the change in the laboriousness of the device of the selected structural and technological solution of the multilayer system of the operated roof relative to the average laboriousness of the device of the multilayer system of the operated roof for various methods, is determined according to the formula:

\[
K_{ml} = \frac{Q_{ml\ i}}{Q_{ml\ av}},
\]  

where \( Q_{ml\ i} \) – the laboriousness of the device selected structural and technological solutions of the multilayer system of the operated roof;

\( Q_{ml\ av} \) – the average laboriousness of the device of the multilayer system of the operated roof, determined for various methods of installing roof layers: \( i = 1, 2, \ldots, n \) - various methods (variants) of the device of roof layers.

When \( K_{ml} < 1 \), a reduction in the laboriousness of the device of the subroofing structure for the selected structural and technological solution is provided.

If \( K_{ml} > 1 \), the laboriousness of the device of the subroofing structure for the selected structural and technological solution increases.

2. \( K_{gr} \) – an indicator of structural and technological variability in the laboriousness of roofing greening systems, which shows the change in the laboriousness of the device of the selected structural and technological solution of greening roofing systems relative to the average laboriousness of the device of greening roofing systems for various ways of building systems greening, determined by the formula:

\[
K_{gr} = \frac{Q_{gr\ k}}{Q_{gr\ av}},
\]  

where \( Q_{gr\ k} \) – the laboriousness of the device selected structural and technological solutions for greening roofing systems;

\( Q_{gr\ av} \) – the average laboriousness of the device of greening roofing systems, determined for various ways of arranging greening systems: \( k = 1, 2, \ldots, m \) - various methods (variants) of arranging greening systems.

When \( K_{gr} < 1 \), a reduction in the laboriousness of the device for greening roofing systems for the selected structural and technological solution is provided.

If \( K_{gr} > 1 \), the laboriousness of the device for greening roofing systems for the selected structural and technological solution increases.

3. \( K_{t\ gr} \) – the coefficient of processability of the device operating cover with greening systems, which is calculated by the formula:

\[
K_{t\ gr} = \frac{Q_{gr\ k}}{Q_{ml\ i} + Q_{gr\ k}},
\]  

where \( Q_{gr\ k} \) – the laboriousness of the device constructive and technological solutions for greening roofing systems (\( k = 1 \ldots m \) possible alternatives);

\( Q_{ml\ i} \) - the laboriousness of the device constructive and technological solutions of the multilayer system of the operated roof (\( i = 1 \ldots n \) possible alternatives).

When \( K_{t\ gr} < 0.1 \), the chosen structural and technological solution for the device of the operated coating with greening systems is rational.

When \( K_{t\ gr} = 0.1 \ldots 0.2 \) - the chosen structural and technological solution of the device for the exploited coating with greening systems is acceptable.

When \( K_{t\ gr} > 0.2 \), the chosen structural and technological solution of the device for the exploited coating with greening systems is irrational.
The technological coefficient of the device of the operated coating with greening systems can be used for a rational choice of the structural and technological solution of the device of the operated coating with greening systems.

2.2. Comparative analysis of variants of exploited roofs with greening systems

Let us evaluate the processability of the device for operating roofing for the variants considered in the study for the design of roofing with greening systems: roof with a traditional greening systems (variant 1); roof with a modular greening system (variant 2). To do this, we first determine successively the processability indicators for a variant of a roofing device with traditional greening systems:

\[ K_{ml}^1 = \frac{Q_{ml\text{ k}}}{Q_{ml\text{ av}}} = \frac{71.6}{65.92} = 1.09 > 1, \text{ the laboriousness of the device of a subroofing construction of a coating with traditional greening systems increases;} \]

\[ K_{gr}^1 = \frac{Q_{gr\text{ k}}}{Q_{gr\text{ av}}} = \frac{3.42}{7.92} = 0.43 < 1, \text{ a reduction in the laboriousness of the device of greening roofing systems with traditional greening is provided.} \]

The calculation of the coefficient of processability of the roof device with traditional greening systems showed that the constructive-technological solution of the device for the exploited coating with traditional greening systems is rational:

\[ K_{t gr}^1 = \frac{Q_{gr \text{ k}}}{Q_{ml\text{ k}}+Q_{gr\text{ k}}} = 0.04 < 0.1. \]

Next, we will determine successively the processability indicators for a variant of a roofing device with a modular greening system:

\[ K_{ml}^2 = \frac{Q_{ml\text{ k}}}{Q_{ml\text{ av}}} = \frac{59.6}{65.92} = 0.9 < 1, \text{ provides a reduction in the laboriousness of the device under-roof construction of the coating with a modular greening system;} \]

\[ K_{gr}^2 = \frac{Q_{gr\text{ k}}}{Q_{gr\text{ av}}} = \frac{9.55}{7.92} = 1.2 > 1, \text{ increases the laboriousness of the device greening roofing with a modular greening system.} \]

The calculation of the coefficient of processability of a roof device with a modular greening system showed that the constructive-technological solution of the device of an operated coating with modular greening systems is acceptable:

\[ K_{t gr}^2 = \frac{Q_{gr\text{ k}}}{Q_{ml\text{ k}}+Q_{gr\text{ k}}} = 0.13; \text{ it is in the range: 0.1 ... 0.2.} \]

When installing exploited roof coverings with greening systems, additional work is required on the arrangement of greening systems, so the laboriousness of the construction of such coverings increases (figure 3).
In order to reduce the overall laboriousness when installing roofing with modular greening systems, new structural and technological solutions are applied, including the use of adjustable supports and modular structural elements. This result was achieved by reducing the laboriousness of the device of the roofing structure by 40% - the laboriousness of the device of the roofing structure with the paving slab device is 45 people-h / 100 sq.m, the laboriousness of the device of the roofing structure with modular greening systems is 35.15 person-h / 100 sq.m. At the same time, we were considering the results of other scientists in the field of assessment when designing buildings [10-15].

3. Results
These studies determined the specific labor costs of workers and machine time, and on the basis of the developed hourly schedule, the duration of the installation of modular greening systems for operating roofs. According to the results of the timing of technological processes and operations, the duration of the roofing device with a modular greening system of 10 square meters, which was 3.52 hours, was determined.

To select rational structural solutions for the device of operated roofs with greening systems, the following indicators are proposed: Kml – the coefficient of structural and technological variability in the laboriousness of the multilayer system of the operated roof, Kgr – the indicator of structural and technological variability in the laboriousness of greening roofing systems, Ktgr is the coefficient of the processability of the device of the operated coating with greening systems.

Recommendations and prospects for the further development of the research topic: studies of the parameters of technological processes for erecting roofing with modular greening systems in various climatic conditions, adaptation of new building materials and structural solutions to form the regulatory and technological base for the organizational and technological design of buildings with exploited roofs, taking into account the assessment of the experimental extensive green roof data [16-21].

4. Conclusions
The developed structural and technological solution of exploited roofs with modular greening systems provides for the reduction of labor-intensive processes for greening exploited roofs at a construction site due to a collapsible design and the processability of the roofing modular elements. At the same time, indicators of the duration of each process were identified the rational duration of the work and their maximum combination: the duration of the work is reduced by 38% (from 210 to 130 minutes to cover 10 sq. m), provided that the work is combined. The need to develop new greening systems for exploited roofs as a result of this approach was highlighted.
References

[1] Mansoo M, Mariun N 2017 *Ecological Engineering* 99 pp 209-221
[2] Sugak E 2013 Man and work, vol 10, pp 48-51
[3] Cepurnaite J, Ustinovicius L, Vainsoras M 2017 *Proc. Eng.* Vol 208 pp 8-13
[4] Volkov A, Sukneva L 2014 *Proc. Eng.* Vol 91 pp 377-380
[5] Eleftheriadis S, Mumpovic D, Greening P 2017 *Renew. Sust. Energ. Rev.* Vol 67 pp 811-825
[6] O'Dwyer E, Pan I, Acha S 2019 *Appl. En.* Vol 237 pp 581-597
[7] Li M, Yang J 2014 *Resour. Conserv. Rec.* Vol 93 pp 85–98
[8] Beazley S, Heffernan E, McCarthy T 2017 *En. Procedia* Vol 121 pp 57-64
[9] Bruno R and Arcuri N et al. 2015 The Passive House in Mediterranean Area: Parametric Analysis and Dynamic Simulation of the Thermal Behaviour of an Innovative Prototype. *Energy Procedia* Vol. 82, pp. 533-539 DOI: 10.1016/j.egypro.2015.11.866
[10] Palomo E 1999 *Energ. Buildings* 29 259-81 DOI: 10.1016/S0378-7788(98)00061-9
[11] Korol O 2015 *Constr. Mater.* Vol 6 pp 3-15
[12] Pérez-lombaard L, Ortiz J and Pout C 2007 *Energ. Buildings* 40 DOI: 10.1016/j.enbuild.2007.03.007
[13] Poddaeva O, Dunichkin I, Gribach J 2018 *Web of Conferences* 64 03013 https://doi.org/10.1051/shsconf/20196403013
[14] Santos R, Costa A, Silvestre J, Pyl L 2019 *Aut. in Const.* 103 pp 127-149
[15] Soust-Verdaguer B, Llatas C, García-Martínez A 2017 *Energ. Buildings* vol 136 pp 110-120
[16] Mousazadeh H, Keyhani A, Javadi A, Mobli H, Abrinia K, Sharifi A 2009 A review of principle and sun-tracking methods for maximizing solar systems output. *Renewable and Sustainable Energy Reviews* vol 13 pp 1800–1818
[17] Bruno R, Bevilaquca P, Longo L, Arcuri N 2015 Small Size Single-axis PV Trackers: Control Strategies and System Layout for Energy Optimization *Energ. Procedia* vol 82 pp 737-743
[18] Bevilaquca P, Mazzeo D, Bruno R and Arcuri N 2016 *Energy and Buildings* vol 122 pp 63-79. DOI: 10.1016/j.enbuild.2016.03.062
[19] Bevilaquca P, Mazzeo D, and Arcuri N 2018 Thermal inertia assessment of an experimental extensive green roof in summer conditions. *Building and Environment* vol 131 pp 264-276. DOI: 10.1016/j.buildenv.2017.11.033
[20] Bevilaquca P, Mazzeo D, Bruno R and Arcuri N 2017 Surface temperature analysis of an extensive green roof for the mitigation of urban heat island in southern mediterranean climate. *Energy and Buildings*.Vol 150 pp 318-327. https://doi.org/10.1016/j.enbuild.2017.05.081
[21] Carbone M, Garofalo G, Nigro G et al. 2015 Green Roofs in the Mediterranean Area: Interaction between Native Plant Species and Sub-Surface Runoff. *Applied Mechanics and Materials*, vol 737 pp 749-753. DOI: 10.4028/www.scientific.net/AMM.737.749