Estimation of modular green roof systems installation using the method of chronometry measurements

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Abstract. Due to the experimental studies using the method of timing measurements, the temporal values of technological operations for the installation of modular landscaping systems were calculated and technological works that have a great influence on the total device construction time were determined. A comparative analysis of the complexity of the device layers of the used coating showed that the most time-consuming is the process of laying paving slabs - 45 people-hours / 100 sq.m. (80% of the total complexity of the device layers of the used coating). Technological processes and operations associated with the installation of the pavement with the use of paving slabs under pedestrian load are more labor-intensive compared to the installation of landscaping systems. The average value of the complexity of the device operating cover for pedestrian load is 56.7 people-hours / 100 sq.m., while the average value of the complexity of the device of the coating with peeling systems is 15.6 people-hours / 100 sq.m., which is 28% lower than the complexity of the device operating cover for pedestrian loading.

1. Introduction

The use of greening systems for roofing leads to an increase in the basic values of the complexity 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 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 landscaping 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.

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 regulated technological processes should be updated in the accordance to present Codes and scientific and technical bases [1]. Fast development and spreading standards, challenging research opportunities arise from process automation and BIM adaptation for existing requirements for the civil engineering [2-4]. The constructive and technological
solutions, described below will achieve maximum success in combination with investments in energy-saving measures at the stage of construction and reconstruction of real estate [5-7]. Economic calculation of the presented green roof decisions may be based on the concept of innovation for Sustainable Development Goals and environmental economic model of risk management and costs in the framework of the quality management system [8-10]. It must be noticed, that greening existing buildings strategies rely on the experimental data of the plant species capacity to withstand high pollutant environments [11-12].

2. Methodology

As an object for experimental studies, the roofing of the building at elevation was used. 13.2 m of Transmashholding Center, Russian Federation, Moscow, Skolkovo Innovation Center, planning area D2, with dimensions in the plan of 126 x 63 m (along the axes). Chronometry measurements were carried out using a stopwatch with an accuracy of up to 1 sec.

2.1. Determination of the main stages of the technology and organization of the installation processes

Before installing the roof with green spaces, organizational and preparatory measures are carried out, which in terms of content and volume correspond to SP 48.13330.2011 “Organization of construction”. Until this time, installation and related work are completed. Acts are drawn up to perform covert work in accordance with the standards of SP 70.13330.2012 “Bearing and enclosing structures” (Russian).

Before starting work on the device of the roof coating layers, the following work must be performed:
- Completed work on the device outputs of engineering networks and equipment on the roof;
- prepared the necessary mechanisms, equipment, inventory and devices;
- arranged temporary lighting of workplaces;
- a breakdown of the watersheds and removal of marks on the walls and the parapet along the perimeter of the roof;
- The materials necessary for the roof covering device were imported.

Delivery of rolled, slab and piece materials to the construction site is carried out centrally by vehicles on pallets. The vertical transportation of roll, bulk and piece materials is carried out using the Stros mine elevator; on the roof, materials are transported manually or using a material transport trolley.
When preparing work, tightly laid plants can be transported on board vehicles, they should be covered with wet straw or moss. Modules delivered to the greened object with soil and planting material should be unloaded directly to the site of acceptance and preparation of materials. Roof landscaping should be carried out depending on climatic conditions in accordance with SP 131.13330.2012 Construction Climatology (Russian).

The roof is covered starting from the pediment with the overhang towards the ridge, usually from right to left, when viewed from the ground. For the device slope-forming layer, plates of extruded polystyrene foam are used, forming a clone angle of 1.7%. Thermal insulation layer - plates made of extruded polystyrene foam. The slope of the wedge-shaped thermal insulation should be formed from the lowest mark on the roof from a funnel or parapet. When forming a slope, plates of extruded polystyrene foam with a thickness of 0.4 cm are used, which are designed for installation from above or under a wedge-shaped plate. To fasten the insulation to the supporting structure (reinforced concrete slab), a pointed screw (screw diameter - 4.8 mm) with a polyamide anchor sleeve (sleeve length - 60 mm) is used.
Layers of waterproofing (cloth waterproofing membrane) are laid freely and mechanically attached to the base along the edge of the roll in the zone of overlapping paintings or outside this zone. Mandatory additional mechanical fixation of the membrane along the perimeter of the roof. The end and lateral overlap of the rolls should be at least 120 mm, the displacement of the end face of each roll from the adjacent one should be at least 300 mm.

Adjustable supports are installed on the waterproofing (protective) layer in increments of no more than 1 m and the elements of the grating (1x1 m) are placed on the adjustable supports in an adjacent manner, in the case of a roof slope (Figure 3.5). The use of adjustable supports for the construction of operating roofing allows you to protect the waterproofing layer from repeated mechanical stresses, raise the plane of the "green" roof to a certain height and provide high accuracy horizontal orientation. Adjustable supports with a height of 17 to 1070 mm have a corrector for the slope of the roofing in the range from 0 to 5%, which is integrated into the top of the support. The support has 8 holes for screw fasteners, the supports are easily placed on a solid base, the top of the support is screwed directly into the base or into an extension sleeve (spacer) - in the case of a support height of more than 175 mm. The permissible load on each support is up to one and a half tons. If necessary, supports can be used upside down.

The height of the adjustable supports is selected based on the level of the slope of the roof. Plastic modules are mounted adjacent to the surface of the grating. The grating 1x1 m is installed by links (2 installers, 2 times): starting parallel to the center of the roof fence, first lay the grating on the supports so that each element of the grating has 4 supports (the location of the supports along the corner joints), then fix the grating (Figure 2).

![Figure 2. The device of the grating on the supports for green roof covering](image)

2.2. Chronometry measurements of the technological processes of installation of the green modular roof systems

As measurements were taken, each technological process was recorded: date, names of technological processes and operations, the beginning and end of observations, their duration. Timekeeping of technological processes and operations was carried out. The time measurements (indicators) of the duration of technological operations are estimated by the stability coefficient for each time series Cs, which is calculated by the formula:

$$Cs = \frac{T_{max}}{T_{min}},$$

where $T_{max}$ is the maximum measurement value in the chronometric series, sec.; $T_{min}$ is the minimum measurement value in the chronometric series (table 1).
Table 1. The indicators of the chronometry measurements of the technology of the device of green modular roof systems (per 10 sq.m. covering)

| Technological processes and operations | Duration (in min) of technological operations for the construction of a modular roofing with greening systems as measured | Cs | Tav | SD |
|----------------------------------------|-------------------------------------------------------------------------------------------------|----|-----|----|
| 1. Installation of adjustable supports with a step of no more than 1 m: | | | | |
| 1.1. Layout of the coating for the layout of the supports (leveling) | 20 18 17 23 20 18 18 24 19 21 1,4 20 2,2 | | | |
| 1.2. Layout and gluing supports | 22 19 24 23 23 22 23 22 22 1,3 22 1,4 | | | |
| 1.3. Adjusting the angle of support | 40 46 40 45 41 38 37 38 40 38 1,1 40 1,7 | | | |
| 1.4. Fixing the clips | 14 10 15 15 14 15 14 15 15 14 1,3 14 0,8 | | | |
| The duration of technological operations, min (according to claim 1) | | | | |
| | | | | |
| 2. Installation of grating 1 x 1 m: | | | | |
| 2.1. Laying the grating on the supports | 26 27 25 26 28 24 26 27 25 26 1,1 26 1,1 | | | |
| 2.2. Fixation of grating | 17 17 20 18 18 16 16 18 17 17 1,2 17 1,8 | | | |
| The duration of technological operations, min (according to claim 2) | | | | |
| | | | | |
| 3. Installation of modules for green spaces: | | | | |
| 3.1. Installation and connection of a group of modules in the amount of 4 pcs. | 22 25 27 28 24 26 26 25 26 27 1,1 22 1,8 | | | |
3.2. Fixing a group of modules to the grating

3.3. Filling the group of modules with soil and planting material

The duration of technological operations, min (according to claim 3)  

|          | 20 | 18 | 20 | 22 | 20 | 19 | 21 | 22 | 20 | 18 | 1,2 | 20 | 1,3 |
|----------|----|----|----|----|----|----|----|----|----|----|-----|----|-----|

Total, Duration of technological operations, min (according to p.1-3.)

296 284 297 300 301 294 295 304 296 295 - - -

Total, Average duration of technological operations:

211 min = 3.52 h.

Notes regarding table 1:

Cs - stability coefficient of this time series;
Tav - the average time for a specific operation;
SD - standard deviation

3. Results and discussion

In this article, we examined the organizational and technological advantages of green roofing systems, on the other space, some experimental investigations of a green roof are aimed for the study the reduction of building energy requirements and the mitigation of Urban Heat Island, which can substantially improve the dynamic properties of traditional roof structures, especially in the case of roofs with limited dynamic performances [13-15]. Key decision factors of green roof systems were analysed in the temperate climate cities in Europe and United States [18-20].

The main results of our research are following:

1. The main stages of the technology and organization of construction processes for the installation of modular roofing with landscaping systems have been developed [16].
2. The method of timing determined the specific labor costs for the implementation of technological operations for the installation of individual elements of landscaping systems and modular system designs.
3. The vocational qualification requirements for the performers of the installation process of modular landscaping systems for operating roofing and the organization of their work in the link are determined.

Thus, according to the results of the timing of technological processes and operations, we determined: the complexity of the device of a modular roofing system with landscaping according to the measurements is 21,7 man-hours / 100 sq.m. To perform technological operations: installation of adjustable supports, installation of grating, you need to know how to mark the plane of roofs, the requirements for the quality of materials and roof coatings, ways of covering the roof with piece materials (supports, modules), therefore, according to the requirements of the tariff qualification reference book of works and occupations of workers we accept the composition of the link in the...
amount of 3 people: roofer 2 categories - 1, roofer 3 categories - 1, green construction worker 3 categories - 1.

It is important to note that the technologies of the green roof systems should be regulated by the established regulatory legal documents: green roof norms and guidelines [17].

4. Conclusions
The developed structural and technological solution of roofing with modular landscaping systems provides for the reduction of labor-intensive processes for landscaping exploited roofs at a construction site due to a collapsible design and adaptability of connecting modular elements. It should be noted that the values of the execution time of each process are determined taking into account the most optimal duration of work and the maximum combination of technological operations. At the same time, the time to complete operations when combining work is reduced by 38%. Estimation of modular green roof systems installation using the method of chronometry measurements gave the good results: during separate execution of the work 210 minutes are required, while combined operations are performed in 130 minutes.

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