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Technology used in the creation of an inverted green roof using domestic building materials

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Abstract: One way to create green areas in cities is the introduction of „green structures": green roofs and terraces, vertical gardens and facades. The success of their operation largely depends on the cost and availability of the technology used to create such structures. The technology required to create an inverted intensive green roof from local building materials included: load-bearing structures; an inclined layer of expanded clay (fraction 5-10 mm); reinforced cement-sand screed; waterproofing euroruberoid; vapour barrier (UkrSpan film); heat insulation from extruded polystyrene foam; a barrier for roots made of glass fibre (VVG 400); drainage made from expanded clay (fraction 10-20 mm); a filtering layer made from thermo-bonded geotextile; substrate and plants (steppe variety of vegetation). The long-term experimental testing of the resultant roof did not reveal any irregularities in its functioning, which indicates the correct selection and construction of the roofing layers from the locally sourced building materials and the correct selection of plant substrate and range of plants used. The technology is found to be more economical when compared to a similar German-used method.

Keywords: green structures, green roof, inversion roof, intensive roofing, domestic building materials

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Introduction

In many modern megacities, the man-made load imposed on the biosphere is at critical levels. Industrial production, transport, waste, information technology all create environmental problems, which lead to a risk of rising morbidity among the population. The policy of sustainable development is the solution to these problems in modern cities. Such a policy was adopted in Ukraine in 2015 (Decree of 5/2015). One of its components is the development and improvement of new energy-

-efficient technology. An example of such technology is „green structures”, which describes the combining of building structures with living plants: „green roofs”, „green slopes”, „green facades”, classic vertical landscaping and eco-parking. Because of the density of buildings within cities and the high cost of land (especially in central urban areas), the creation of completely green areas is impossible. In this case, „green structures” are a viable solution to the situation, since they solve environmental, economic and social problems. In many countries of Europe and America, energy-efficient „green structures” are successfully used to address problems in metropolitan areas. The introduction of these structures in Ukraine, however, is hampered by the lack of regulatory documents and availability of suitable technology in domestic building materials.

1. Object of the research

The object of the study is a 12 m high flat roof (designed and made by the author) on top of a private house. The total area of the roof is 1443.75 m^2. The area of greenery is 200 m^2. An intensive greening of the roof (expected to allow people to go on the roof) was done with a steppe variety of phytocoenosis. A layer of soil substrate was made using soil, sand, claydite, perlite, peat, clay and crushed bark. The thickness of the layer is 0.80 m (including heat insulation). To keep the soil on the roof moist, an automatic watering system was installed. In order to comply with safety, the entire roof surface was enclosed by a parapet with a height of approximately 1 m. On the the roof, in order to create pathways for walking and help with watering, special ceramic paths, which resembled wooden spits, were laid. A steppe-like landscape is the most suitable for the arid climate of the region (Fig. 1). The roof, which was made in 2006 and still exists today, consists of 11 layers (Fig. 2).

Fig. 1. Inverted green roof system with steppe phytocoenosis (made by the autor)

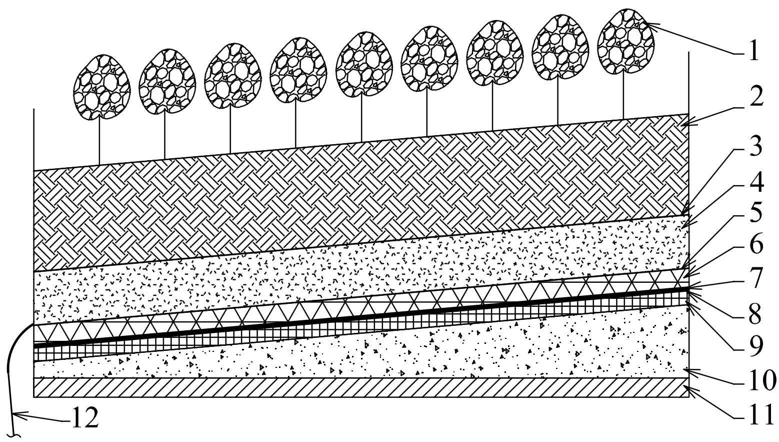

Fig. 2. Inverted green roof system made using Ukrainian materials: 1 - plants; 2 - substrate; 3 - a filtering layer made from a thermosetting geotextile; 4 - claydite drainage; 5 - the barrier for the roots made of fiberglass; 6 - extruded polystyrene foam insulation; 7 - vapour barrier (vapour-proof film UkrSpan); 8 - waterproofing euroruberoid; 9 - reinforced cement-sand screed; 10 - sloping layer of expanded clay; 11 - bearing base - reinforced concrete slab; 12 - drainage (made by the autor)

2. Materials of layers in the „green roof"

The estimated thermophysical characteristics of the building materials were adopted in accordance with Annex A (DSTU B V.2.6-189:2013).

The main characteristics of the building materials are as follows:

– Layer 10: A sloping layer of expanded clay 5-10 mm (DSTU B V.2.6-189:2013; Getun et al., 2016).
– Layer 8: A hydro-insulated layer of Euroruberoid EKO-PE-2.5, polyester-based with plastomers. A rubberite layer laid using a propane or liquid fuel burner where the surface must be thoroughly cleaned and dried before laying, and if necessary, treated with a bituminous primer. The mass is 2.5 kg/m^2. The operating temperature range is from minus 25°C to plus 90°C; flexibility on the balk is 5. Supplied from a roll of 15 m length and 1 m width (*Aquaizol*).
– Layer 7: A polypropylene vapour barrier UkrSpan 50, with thickness 0.1 mm and density 50 g/m^3. Supplied from a roll of 60 m^2 (width - 1.6 m, length - 37.5 m) or a roll of 75 m^2 (width - 1.5 m, length - 50 m).

Layer 7 is used as a vapour barrier to protect the heat insulation and other elements of the building structure against saturation of water vapour in buildings of all types. The material is laid on the inside of the heat insulation in the construction. The material has a two-layer structure: one side is smooth, the other has a rough surface for catching droplets of condensation and their subsequent evaporation. It has a stress load of 110 N/(5 cm); a vapour resistance not less than 2 m^2·h·Pa/mg;

and is waterproof up to 1000 mm H_2O. The operating temperature range is from minus 40°C to plus 80°C.

Layer 6: Heat insulation, made from extruded polystyrene foam. It is recommended that the thermal insulation layer is made of foam glass or perlite sand, foam polystyrene slabs, mineral or basalt wool. Foam glass has a service life of over 100 years, high strength and resistance to aggressive chemicals. However, it is quite expensive. Mineral wool is not recommended due to the high degree of deformation. Instead, it is suggested to use basalt wool, which is a type heat insulation made up of super-thin basalt fibres obtained by melting basalt or similar rock. It does not contain any other mineral additives, which gives it special properties such as fire safety (stone wool fibres can withstand temperatures up to 870°C without melting); heat and sound-proofing properties due to open porosity; excellent thermal insulation properties: thermal conductivity is between 0.035-0.039 W/(m·K); vapour permeability due to open porosity: approximately 0.25-0.35 mg/(m^2·h·Pa). The mineral wool density can vary widely from about 30 to 220 kg/m^3, hence, the physical and mechanical characteristics are also different. Rigid plates can withstand a distributed load of 70 kPa. Another option is foam glass, which is waterproof and non-toxic to plants and microflora of the soil. Pressed foam polystyrene slabs are also used as heat insulation materials. Extruded polystyrene foam with a density of 38-45 kg/m^3 can be used for exploiting roofs under parking and other structures with high loads (*Stalan*).

Layer 5: A root barrier made from glass fibre VVG 400 (Getun et al., 2016; *UkrBudRezerv*). Stress load of at least 78.5 N. The melted bitumen mastic is stable at temperatures of 180°C for at least 5 min. It is waterproof with a recorded stress load of 34.3 N after 24 h at relative humidity 98%. Supplied as a roll of 100 m^2 (width - 400±5 mm, length - 250 m), thickness 0.5±0.1 mm.

Layer 4: Claydite drainage, fraction 10-20 (DSTU B V.2.6-189:2013). The drainage layer is necessary for the removal of surplus atmospheric precipitation from the vegetation layer and from paths, when the amount of water exceeds the monthly norm of the rainiest period, as well as for the removal of excess water during plant irrigation. In the absence of drainage, water accumulates in the soil, which contributes to rotting or freezing of the roots of plants during cold periods. However, it should also be noted that draining water too quickly will require more frequent irrigation of plants than under normal conditions where roots have access to groundwater. The water overflow, filtered by the upper layers, will be directed by the drainage 12 to a tank for reuse for technical requirements (irrigation, flush of a lavatory, washing machine etc.) or discharged to a rainwater drainage system.

Layer 3: A filtering layer made from a thermal bonded geotextile. The geotextile is used as a filtering layer to prevent the drainage being clogged with particles of soil. Manufacturers use two methods of manufacturing the non-woven fabric:

– thermal calendering (high temperature bonding);
– a needle-punch method (the bundles of thread are stretched with a special needle through a canvas).

Thermal bonded geotextile has many advantages, due to which it is becoming increasingly popular. For example: manufacturing is less labour-intensive; the raw material is enriched with special admixtures that increase light and moisture resistance; increased mechanical strength; resistance to various chemicals (*Aquaizol*).

Layer 2: Substrate. As a soil, a substrate is used. It is much lighter than usual earth-based soils, this significantly reduces the load on the foundations of the roof. Reducing the weight of the green roof is particularly relevant for intensive roofs. The acidity of the substrate is important for plants, and is determined on a scale: strongly acidic soils - pH below 4; medium acidic (pH 4.1-4.5); slightly acidic (pH 4.6-5.2); neutral (pH 6.7-7.4); alkaline (more than 7.5). Avoiding fertilizers reacting with the alkalinity is necessary to eliminate the negative impact on the structural elements of the roof. In order to decontaminate the soil before laying it on the roof, it is recommended to heat the soil to a temperature of ≈ 100°C. The main component of the substrate is soil. So-called plant soil is made by removing the upper layer of soil to the depth, where the root system of plants begin to occur. The soil must be cleaned of foreign impurities and plant root residues and have a density of at least 5-20 kg/cm^2 (density is defined as resistance to compression). In addition, the fertility of the soil is very important: the content of humus cannot be less than 4%, per 20 g of substrate. There should be at least 6 mg of easily hydrolysable nitrogen, accessible to the plants, and no less than 10 mg of phosphorus hydroxide (P_2O_5) and potassium oxide (K_2O). The fertility of substratum is determined in laboratory tests. Improvement in soil fertility is achieved through the supplementation of mineral and organic fertilizers. The mechanical composition is improved by additives (sand, peat). Expanded clay, vermiculite, perlite, and peat can also be used as for the substrate. In the study, we used a substrate based on soil, sand, claydite, perlite, peat, clay and crushed bark. The thickness of the layer was 0.80 m (including compression).

3. Economic efficiency of the roof's domestic building materials

Calculation of the cost of the roof produced from domestic materials and materials from a German company ZinCo showed a significant difference (Tables 1-2). The German system of the company ZinCo „The Garden on the Roof" (Fig. 3) is considered analogous to the domestic system of roof-landscaping.

This is a multifunctional design of landscaped roofing with a high level of water accumulation. It is possible to arrange a lawn and perennial plants or, with a higher level of substrate, even trees.

It is possible to combine other roof system uses, such as walking paths, road surfaces, ponds and playgrounds. When using the „Garden on the roof" system, it is recommended that the maximum amount of precipitation should be utilized in order to reduce the cost of watering.

Table 1. Cost of square meter of green roof construction using Ukrainian materials

Layer	Material	Developer	Unit	Cost of the unit $	Number of units	Total cost $/m^2
10	Clay 5 cm, 5-10 mm fraction	Plant of Clay Gravel, Kyiv	m^3	33.85	0.05	1.70
9	Cement, 50 mm	Cement.ua, Kyiv	t	71.31	0.025	1.79
	Sand	Drimbud, Kyiv	t	1.93	0.075	0.15
	Reinforcement Ø8	Trimet, Kyiv	m	0.38	20	7.60
8	Ruberit Eko-PE-2.5	Akvaizol, Kharkiv	m^2	1,35	1	1.35
7	UkrSpan 50	UkrSpan, Brovary	m^2	0.15	1	0.15
6	Ekobord 50	Ekobord, Kharkiv	1.2×0.6 = = 0.72 m^2	3.53	2.78	9.82
5	Glass fibre VVG 400	Skloalians, Konstiantynivka	m^2	0.04	1	0.04
4	Clay 10 cm, 20-40 mm fraction	Plant of Clay Gravel, Kyiv	m^3	34.62	0.1	3.47
3	Thermal bonded geotextile	Akvaizol, Kharkiv	m^2	0.58	1	0.58
Σ	–	–	–	–	–	26.65

Table 2. Cost of square meter of green roof construction by ZinCo (*ZinCo*)

Layer	Name	Material	Price of 1 m^2	
			€/m^2	$/m^2
3	Thermally strengthened filter sheet of SF	Polypropylene	2.24	2.61
4	Drainage and water retention element Floradrain FD 40	Thermoformed recycled polyolefin	24.57	28.61
5	Fibre mat ISM 50	Polyester/polypropylene, bottom sided fiber impregnation using acrylic compounds	12.55	14.61
6	Protection and anti-slip mat Elastosave ES 30	Recycled rubber	14.85	17.29
7	Bearing base, which includes:	Concrete or other material	Not included	
	Water barrier membrane	EPDM	7.74	9.00
	Heat insulation Ekobord 50	Expanded polystyrene	8.44	9.82
Σ	–	–	70.39	81.94

The drainage element Floradrain® FD gives a water resistance up to 40 mm H_2O, and saturates the plants with water through capillaries and diffusion. Drainage element Floradrain® FD can be used as a foundation for road surfaces, thus not breaking the waterproofing layer.

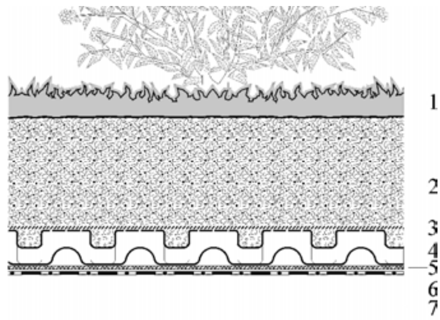

Fig. 3. Inverted green roof system by ZinCo (Germany):
layers: 1- plants; 2 - substrate; 3 - thermally strengthened filter sheet of SF; 4 - drainage and water retention element Floradrain FD 40; 5 - fibre mat ISM 50; 6 - protection and anti-slip mat Elastosave ES 30;7 - bearing base with water barrier and heat insulation (ZinCo, official site: http://www.zinco-usa.com)

This quote does not include the cost of heat insulation and waterproofing, because ZinCo does not produce these components. Therefore, components from third-party manufacturers are taken into account. The cost of protecting the roof from the roots of the plants by WSB 100-PO is quite large. Therefore, the company recommends the use of an EPDM membrane waterproofing system. Consequently, the cost of 1 m^2 of roof will increase by the cost of this membrane. The calculation does not include the cost of plants and substrate because they are the same in both cases.

It is clear from the calculations that the total cost of the roof using Ukrainian materials is \$26.60. The roof made from German materials is \$81.94, which is \$55.34 or 3.08 times more than the Ukrainian materials.

A roof of 200 m^2 made from Ukrainian materials costs \$5330. The same roof made from German materials costs \$16388.

In this study, we considered only the investment. In addition, using domestic materials decreases pollution of the environment due to the elimination of fuel used during the transportation of foreign materials.

Conclusions

Long-term field studies of the inverted intensive green roof have not revealed any abnormalities in the functioning of the roof, which testifies to the accurate selection of roofing layers and domestic materials, suitability of the technology for laying the layers; the correct selection of vegetation substrate and assortment of plants.

It is clear from the calculations that the total cost of the roof made from Ukrainian materials is \$26.60. The roof made from German materials costs \$81.94, which is \$55.34 or 3.08 times more expensive than the Ukrainian materials. A roof measuring 200 m^2 made of Ukrainian materials costs \$5330. The same roof made of German materials costs \$16388.

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Doskonalenie technologii tworzenia zielonego dachu inwersyjnego z wykorzystaniem krajowych materiałów budowlanych

Streszczenie: Jednym ze sposobów tworzenia zieleni w miastach jest wprowadzenie „zielonych struktur”: zielonych dachów i tarasów, pionowego ogrodnictwa, bloków elewacyjnych. Sukces ich działania w dużej mierze zależy od ekonomiki i dostępności technologii budowania. Udoskonalono technologię tworzenia intensywnego inwersyjnego zielonego dachu z krajowych materiałów budowlanych: konstrukcje nośne; nachylona warstwa glinki ekspandowanej (frakcja 5-10 mm); wzmocniony jastrych cementowo-piaskowy; hydroizolacja euroruberoid; paroizolacja (film UkrSpan); izolacja cieplna z ekstrudowanej pianki polistyrenowej; bariera dla korzeni z włókna szklanego (VVG 400); drenaż z keramzytu (frakcja 10-20 mm); warstwa filtrująca z termospajanej geowłókniny; podłoże; rośliny (stepowy rodzaj roślinności). Długoterminowe badania eksperymentalne uzyskanego dachu nie wykazały żadnych nieprawidłowości w jego funkcjonowaniu, co wskazuje na prawidłowy dobór i ułożenie pokrycia dachowego z rodzimych materiałów budowlanych; prawidłowość wyboru podłoża roślinnego i zasięgu roślin. Technologia tworzenia zielonego dachu z wykorzystaniem krajowych materiałów budowlanych jest bardziej ekonomiczna w porównaniu z podobną niemiecką.

Słowa kluczowe: zielone konstrukcje, zielony dach, dach inwersyjny, intensywne pokrycia dachowe, krajowe materiały budowlane