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EFFECT OF SURFACE GEOMETRY AND INSOLATION ON TEMPERATURE PROFILE OF GREEN ROOF IN SAINT PETERSBURG ENVIRONMENT

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The paper addresses an issue of creating an environment favorable for the life in megacities by planting vegetation on the rooftops. It also provides information about rooftop greening practices adopted in other countries. The issues of 'green roof' building in climatic conditions of Saint Petersburg and roof vegetation impact on the urban ecosystem are examined. Vegetation composition quality- and quantity-wise has been proposed for the roof under research and a 3D model of this roof reflecting its geometric properties has been developed. A structure of roof covering and substrate qualitative composition is presented.

An effect of rooftop geometry on the substrate temperature is explored. The annual substrate temperature and moisture content in different parts of the roof have been analyzed. Results of thermal imaging monitoring and insolation modelling for different parts of green roof surface are presented.

Key words: green roofs, rooftop geometry, temperature profile, insolation.

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The rapid growth of cities and lack of green areas in the centers of megacities, aggravated by the infill construction, air and soil pollution and other urban problems in combination with a need to create environment favorable for the life of the citizens make it imperative to search for new forms of modern urban greening. One of such solutions is building the 'green roofs' which is a greening practice common for Europe and extensively developing in USA. In Toronto, Copenhagen and Tokyo roofs of multistorey buildings are now already covered by vegetation by 30-60 %. In Canada and Switzerland roof greening is compulsory and regulated by the nation-wide state laws. Annually about 10 mln.m^2 of green roofs are built in Germany and in total across Europe there are 40 mln.m^2 of green roofs. Some of the USA states have enacted laws giving builders 25 % more space for construction if they develop green roofs [10].

Besides building of green roofs help to achieve ecological effects critical for the urban environment [2]:

- lower 'heat stress' on the urban area;
- reduced load on city drainage systems;
- reduced water discharge by the cities into natural ecosystems;
- creation of 'green corridors' facilitating the movement and spread of animals and plants in the urban habitat;
- providing specific living space for animal and plant species rare for this locale;
- establishing recreational spaces on the rooftops.

Evaluation studies of plants for use on the roofs have been carried out in Europe since 1980s [3-5, 7, 8]. The general conclusion is that vegetation comprised of stonecrop varieties is most suitable for extensive green roofs in the urban areas [1].

The conducted researches present only one stage of a large-scale research project to monitor the general condition of stonecrop vegetation in climate of St. Petersburg. The primary concern at this stage is an impact of roof geometry, temperature and insolation on initial development potential of different varieties and individual species (clones) of stonecrops.

The study resolves the following tasks:

- Insolation calculations for the research object have been made.
- Temperature and moisture content of the soil layer have been analyzed.
- Practical recommendations on selection of stonecrop species and varieties for green roof vegetation in St. Petersburg environment with account of roof geometry and luminous density have been developed [9].

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The researched site was a roof of a hotel complex, located in the region of Pulkovo airport. The research object consists of two parts: horizontal roof with wavy surface and sloped roof (Fig.1). The total area of a research object 'Green Roof' is 2,000 m^2. The roof covering is a so called 'roofing pie' made of concrete foundation, waterproofing coat, drainage layer, filtering layer and topsoil.

The material for the green cover were the plants of different species belonging to *Sedoideae* subfamily of *Crassulaceae* family of *Sedum* s.str., *Hylothelephium, Aizopsis, Phedimus* genera (see the Table). The planting material selection was based on a search for species optimum for growing on the rooftops, taking into account the intraspecific polymorphism properties of stonecrops. That's why for planting on the roof we selected as many as possible genetically different plants of the same specifies. For this purpose the origin of parent plants purchased from the nursery gardens was taken into account.

Since the ultimate objective of the research is to establish the nature of interspecies relationships between different species of stonecrops, in the course of vegetation development all possible neighboring combinations with different species and clones have been implemented (Fig. 2). Location of all plants was recorded based on their species and genetic specificity in a planting diagram.

Substrate for topsoil was made of organic and mineral components and had the following approximate composition, %: peat (a mixture of lowland and upland peats) – 30; expanded clay – 50; sand – 10; compost – 5; expanded vermiculite – 5.

Apart from certain percent weight of different substrate fractions [6], there are some other aspects concerning establishment and maintenance of green roofs in St. Petersburg attributable to climatic parameters of our region. These aspects include: a long period of stable snow cover and formation of a dense crust due to frequent winter thaws, resulting in an issue of plants nival asphyxiation; excessive air humidity throughout the year and maximum rainfall intensity in summer, favorable for weeds growth; and short growing season, creating specific plant ontogeny conditions.

At the initial research stage microclimatic parameters in different parts of the roof have been assessed. Five different zones by luminous density and wind load have been identified. Different gradations of these two factors create specific microclimatic conditions in each of five zones.

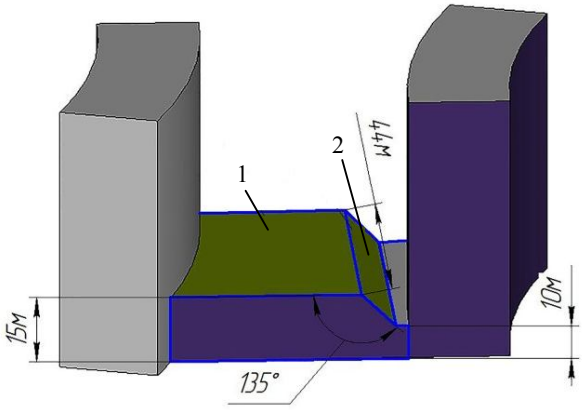
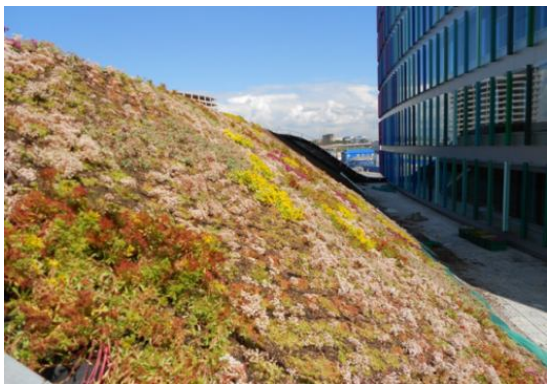


Fig. 1. Research Object Model
1 - horizontal roof with wavy surface; 2 - roof slope

Types of plants for green roof

Name	Share, %	Quantity
Sedum acre	30	15,000
Sedum album var. Coral Carpet	20	10,000
Sedum album var. Micranthum Chloroticum	10	5,000
Sedum acre var. Aureum	5	2,500
Sedum acre var. Variegata	5	2,500
Phedimus spurius	10	5,000
Sedum hexangulare	5	2,500
Aizopsis florifera	3	1,500
Aizopsis elacombiana	3	1,500
Aizopsis kamtschatica	4	2,000
Hylotelephium ewersii	5	2,500

a



b



Fig.2. Vegetation development
on sloped (*a*) and horizontal (*b*) parts of the roof

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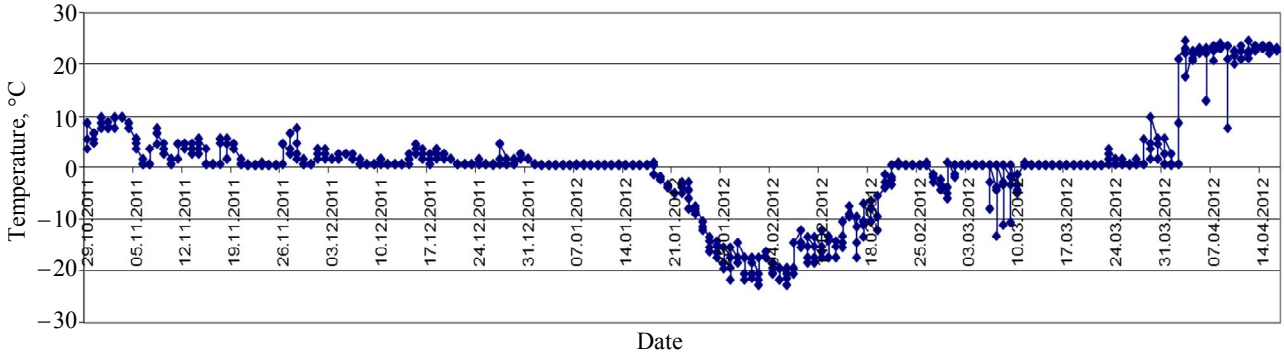


Fig. 3. Substrate temperature in one of zones in winter season

• First zone is protected from wind and sun, is exposed to light only in the early morning for two hours.

• Second zone is protected from eastern and northern winds and is exposed to light throughout the day.

• Third zone is protected from eastern and northern winds and is exposed to light only in the second half of the day.

• Fourth zone is exposed to wind blowing through in a direction from north to south, protected from eastern and western winds and exposed to light throughout the day.

• Fifth zone is exposed to wind blowing through in a direction from north to south, protected from eastern and western winds and exposed to light only in the second half of the day.

To monitor the temperature conditions and moisture content in the substrate the temperature and humidity loggers DS1923-F5 have been used, which are self-contained devices (i.e, do not require additional power supply or data transmission lines for operation), designed to measure and record temperature and relative humidity values with subsequent PC processing of the readings. Loggers were put into the substrate in different zones; temperature and humidity were monitored throughout the year.

Analysis of readings (Fig.3) reveals a clear correlation between a substrate temperature and microclimatic conditions largely influenced by a wind load. In winter most of snow cover was blown away from the horizontal part of the roof exposing some of its parts. While at the same time only little snow was blown away from the sloped part and as evidenced by the loggers' readings in winter the substrate temperature on a slope is higher.

As shown by the analysis of substrate moisture content, humidity on the slope is higher than on the horizontal part, which can be explained by a shorter period of insolation on the sloped part. Insolation calculations for the researched surface have been pursued based on a model built in Revit and with account of object's geographical location. Insolation period was assumed to be of the same duration as vegetation period (from May 1 to October 1).

The calculations illustrate that the sloped surface receives direct sunlight for two and half hours from 12.00 pm to 2.30 pm (Fig. 4) while horizontal surface is exposed to sunlight from 11.00 am to 4.00 pm (Fig.5).

Temperature of green roof top layer has been measures by means of thermal imager (Fig.6), which allowed in addition to temperature monitoring identify areas of heat loss (Fig.7).

The conducted research and analysis of results have shown that surface geometry has a minor direct impact on the temperature conditions of the green roof. But when combined with other factors, such as spatial location, proximity of adjacent buildings, wind load, insolation period, it leads to occurrence of separate zones with their own microclimate, which in its turn substantially alters a temperature profile of the substrate and the green roof in general.

The results obtained allowed to determine external impact factors and range varieties and species by their growing intensity:

• *Sedum hexangulare > var. Micrantum Chloroticum > Sedum acre > Sedum album var. Coral Carpet, Sedum acre var. Variegata, Sedum acre var. Aureum.*

• *Phedimus spurius > Aizopsis kamtschatica, Aizopsis ellacombiana > Hylotelephium ewersii, Aizopsis florifera.*

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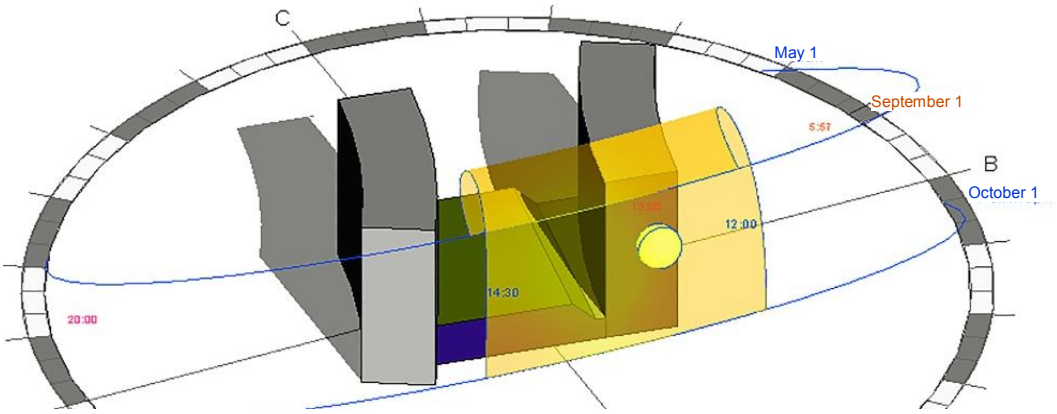


Fig. 4. Insolation period of sloped roof

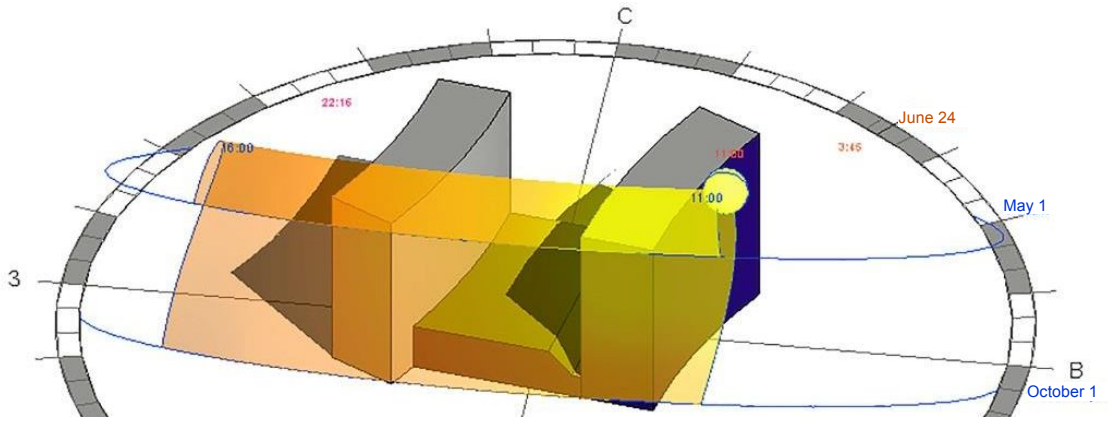
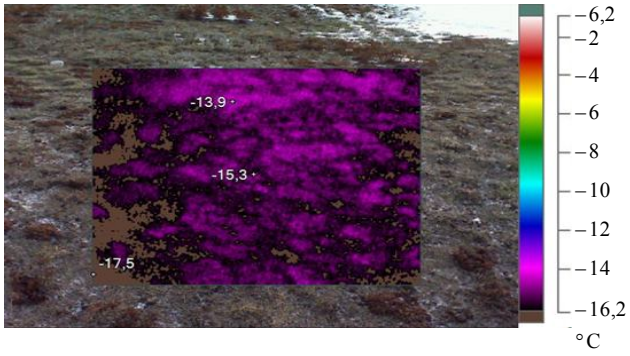


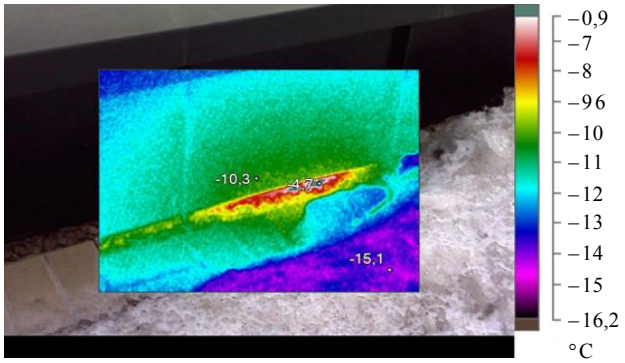
Fig. 5. Insolation period of horizontal roof



Main image markers

Name	Temperature	Emission coefficient	Back-ground
Central point	-15,3°C	0,80	-10,0°C
Hot	-13,9°C	0,80	-10,0°C
Cold	-17,5°C	0,80	-10,0°C

Fig. 6. Temperature profile of horizontal roof



Main image markers

Name	Temperature	Emission coefficient	Back-ground
Central point	-10,3°C	0,80	-10,0°C
Hot	-4,7°C	0,80	-10,0°C
Cold	-15,1°C	0,80	-10,0°C

Fig.7. Identified heat loss area

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Based on research results practical recommendations have been developed for establishing stonecrop coverings with required adornment and growth properties in climatic conditions of Saint Petersburg.

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