Saimaa University of Applied Sciences
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GREEN ROOFS IN SAINT PETERSBURG

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ABSTRACT

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The aim of this work was to investigate Russian and foreign projects of green roofs, evaluate the possibility of building a green roof on the building Gidrokorpus and write recommendations for its installation and maintenance.

Construction of green roofs is becoming now one of the fastest growing areas of landscape architecture and is becoming increasingly popular in St. Petersburg. Considering the insufficient number of domestic works of green roofs in local climatic conditions, a number of environmental advantages of extensive green roofs with different types of vegetation in conditions of St. Petersburg was investigated. Also the possibility of building a green roof on the Gidrokorpus was evaluated and recommendations for its installation were developed.

Ekaterina Zalata was responsible for Chapter 2 (Green roofs now and in the past) and Chapter 4 (Green roof buildings in Saint Petersburg). Dmitriy Melnikov was responsible for Chapter 3 (Green roofs in construction). Chapter 5 (Construction solutions for the roof system of Gidrocorpus) was written by both Ekaterina and Dmitriy.

As the result a construction decision for the roof of Gidrocorpus was provided to the company Delta-t.

Keywords: green roof, landscaping, construction

CONTENTS

1 INTRODUCTION

A green roof is a roof of a building that is partially or completely covered with vegetation and a growing medium, planted over a waterproofing membrane. It may also include additional layers such as a root barrier, insulation, drainage and irrigation systems.

Despite of the difficulties, the demand for green roofs is growing gradually. In many European cities, green roof has become a mandatory measure. So in Copenhagen (Denmark) in 2010, every roof has to be green. In Switzerland since 2002, every flat roof has to be green (in Basel city 1930 roofs are green). In Toronto, Canada since 2009 each roof with an area greater than 2000 m^2 has to be green. In Tokyo since 2001 20% of roofs with an area greater than 250 m^2 and 10% of roofs with an area greater than 1000 m^2 have to be green. In Germany, every year there are about 14 million new green roofs. In Russia this process is not going so fast, however now in Russia there are not only corporate, but also private customers.

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2 GREEN ROOFS NOW AND IN THE PAST

2.1 History of green roofs

Green roofs date back to thousands of years. History shows the purposes of vegetated roofs were different. These purposes include the insulating qualities, and an escape from the stressful urban environment. The first evidence of roof gardens includes the mausoleums of Augustus and Hadrian. Also the Romans planted trees on top of many institutions. The ancient historian Pliny made records about trees being imported for these roof gardens. During the Renaissance, steeply terraced gardens and green roofs were spread in the city of Genoa. In Russia, hanging gardens were favored in the 17th century Kremlin, and in the 20th century, green roofs and hanging gardens were built on homes in many countries [14].

In cold climates green roofs increase internal heat conservation, and in hot climates they help to prevent the heat go in. Cold climate examples of green roofs are the longhouses of the Vikings, who layered the walls and roofs with turf to protect against the elements. Canada had several Viking and French examples of sod roofs, found in Newfoundland and Nova Scotia.

The oldest roof garden is the ziggurats of ancient Mesopotamia, built from the fourth millennium until 600 B.C.E. Located in the courtyards of temples in big cities, the ziggurats were great stepped pyramid towers of stone, built stepwise. At the landings of these stepped towers, plantings of trees and bushes on flat terraces softened the climb and offered relief from the heat of Babylon.

The most stunning example of the ancient gardens are the Gardens of Babylon (or Gardens of Semiramis) - terraced gardens, raised up about 600 B.C. Unfortunately, that gardens have not been preserved to the present day but they are rightly called one of the Wonders of the World [11].

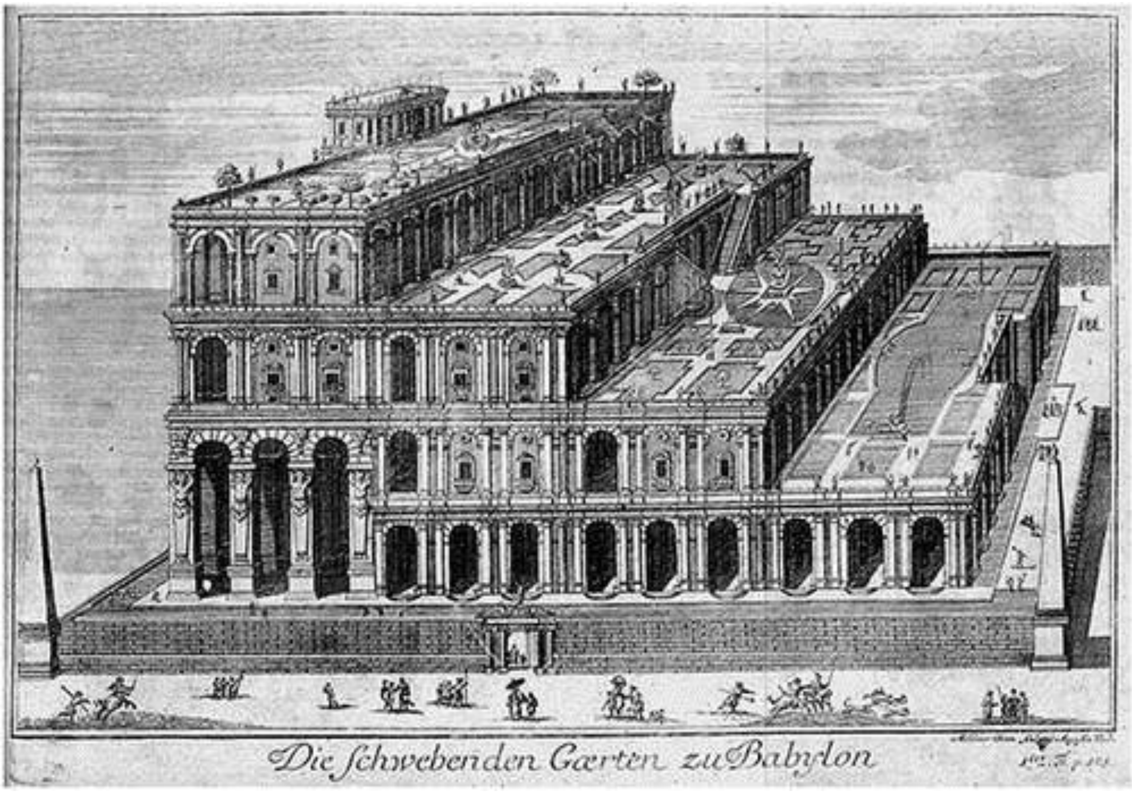

Fig. 2.1 The Gardens of Babylon (http://o-p-i.ru/promyshlennoe-proektirovanie/14-staticheskie-stranitsy/proektirovanie/stati-i-publikatsii/961-zelenye-krovli-chast-ii-istoriya-poyavleniya.html)

The palace was created stepwise, the total number of steps is unknown but there were at least four. Each step was built on pillars, stone slabs were filled with tar. After that hundreds of tons of fertile soil were poured on the extensive terrace. Bushes and trees, with great caution brought directly from Media, were landed in that soil. The Hanging Gardens required thousands of liters of water for irrigation. In the interior columns pipes were hidden inside the pillars, water was delivered with the help of a system of blocks and buckets rising from the Euphrates River to the upper terrace. People perceived a wonderful structure is a real miracle - in the middle of the desert there was a beautiful green oasis, which was clearly visible from the Mesopotamia Valley [11].

The first information about flower beds and gardens on the roofs in Russia belongs to the 17th century. Hanging garden of Metropolitan Jonah was arranged in the Kremlin of Rostov the Great. The garden was located on the second floor between the buildings of the palace and was supported by the arch. Massive ceilings were covered with lead sheets to make ceilings waterproof. Such gardens were arranged in the boyars' estates and the estates of the higher clergy. For the beauty and originality they were called the Red Gardens [11].

Due to the complexity and high cost these gardens were not widespread in Russia and were concentrated in the Moscow Kremlin. There were two large and several small hanging gardens on roofs and terraces [11].

Upper Waterfront garden was created in the 17th century on the Reserve yard. It had a U shape in plan and was placed from the riverside. It consisted of five consecutive flower compositions. The terrace was surrounded by a special wall with frequent apertures, through which it was possible to admire the panorama of the valley of the Moskva River. According to some reports in the far western corner of the garden, a small pool with fountains was arranged. The garden was supplied with water by means of a special mechanism, which Christopher Galloway created in 1633 and placed it in the tower near the garden. According to the historian Ivan Zabelin the garden was 62 fathoms in length and 8 yards in width (2600 m^2) [11].

In April 1683 in Moscow a Lower waterfront garden was created, it was constructed on an artificial basis and was smaller in size (1500 m^2). The garden was located on the slopes of a Kremlin hill. There were ponds, painted pavilions, greenhouses for vegetables and flowers in the territory of the Lower waterfront garden. Ponds were used not only as a decorative function, but also for fish farming [11].

Upper Waterfront garden was destroyed in 1771 during the site clearance for the construction of a new Kremlin Palace [11].

Figure 2.2 Upper Waterfront garden (http://o-p-i.ru/promyshlennoe-proektirovanie/14-staticheskie-stranitsy/proektirovanie/stati-i-publikatsii/961-zelenye-krovli-chast-ii-istoriya-poyavleniya.html)

Two hanging gardens created in the era of Imperial Russia have survived till nowadays. They are the Hanging Garden of the Small Hermitage in Saint Petersburg and the Hanging Garden in Tsarskoye Selo (Leningrad region).

Hanging Garden of the Small Hermitage in Saint Petersburg was created in the period from 1764 to 1769. It is located on the second floor, above the premises of the former stables and arena, and occupies the space between passages that connect the North and South halls of the Small Hermitage. The garden is surrounded from all sides of the palace by walls and resembles an open-air gallery [11].

Closed in all sides by high walls the garden has its own microclimate: closeness of Neva river softens the temperature drops, and garden orientation (north to south) ensures maximum sunlight during the daylight hours. Under the garden there were engineering communications which provided additional heating. As a result, the vegetation period started earlier, and the autumn leaf fall was later than in other gardens of St. Petersburg [11].

Figure 2.3 The Hanging Garden of the Small Hermitage (http://o-p-i.ru/promyshlennoe-proektirovanie/14-staticheskie-stranitsy/proektirovanie/stati-i-publikatsii/961-zelenye-krovli-chast-ii-istoriya-poyavleniya.html)

In 2004 the Hanging Garden of the Small Hermitage was closed for an engineering and technical reconstruction which included the complete replacement of the waterproofing layer and the drainage system. Modern reconstruction lasted a long time and ended only in late 2011. All plants are blooming trees and shrubs and are chosen so that the garden is effectively blooming in different colors from spring to autumn due to the continuous change of flowering and fruiting [11].

The Hanging Garden was also created in the suburban royal residence Tsarskoye Selo. The garden was built on the second floor of Catherine's Palace so that the Empress could get in the garden through one of her private rooms.
For waterproofing, lead sheets of the best quality were laid on vaults and a thick layer of soil was poured on then. Apple trees, lilac, jasmine and rose were growing there; tulips, peonies and daffodils were planted around bushes. Blossoming lasted continuously all the warm season [11].

Figure 2.4 The Hanging Garden of the Small Hermitage nowadays (http://o-p-i.ru/promyshlennoe-proektirovanie/14-staticheskie-stranitsy/proektirovanie/stati-i-publikatsii/961-zelenye-krovli-chast-ii-istoriya-poyavleniya.html)

At the end of the 19th century in Russia gardens decorated the roofs of many merchant houses (http://o-p-i.ru/promyshlennoe-proektirovanie/14-staticheskie-stranitsy/proektirovanie/stati-i-publikatsii/961-zelenye-krovli-chast-ii-istoriya-poyavleniya.html).

At this time in Russia flat roofs were used more as a viewing platform.

In USA "linear" gardens and boulevards on artificial grounds extending along the roads and highways and separating pedestrian and vehicular traffic became a reality in many cities [11].

Having carefully studied the European experience and the possibility of new building materials, in the late 1950s in Oakland, one of the largest gardens with an area of 12000 m^2 on the roof of the Kaiser-center five-storey garage was built. The author of the project is a landscape architect Theodor Osmundson [11].

The basic principle embodied in this project is the relief of loads on the building structure. Paving and all facilities in the garden were made of lightweight concrete, decorative stones and boulders were made of pumice. Each tree was placed so that the weight of it was transmitted directly to the column (equipped with an internal drain) without downloading weight to the slab. Lightweight vegetable mix was used, pulverized shale replaced sand, and the height of this layer was reduced due to the fact that the selected plants were with shallow root system. Water in a decorative pond was in continuous motion. Coming out of the pool it was filtered and re-entered the pond through the same hole. Also it helped to moisturize the air [11].

Due to the success of this garden in the United States a massive new construction began including the roofs of private buildings, dormitories and museums [11].

1960s were a turning point in the construction and landscaping of gardens on rooftops. Construction began to acquire mass character, thanks to the emergence of new synthetic materials and natural soil substitute [11].

2.2 Use of green roofs today

Despite of the difficulties, the demand for green roofs is growing gradually. In many European cities, green roof has become a mandatory measure. So in Copenhagen (Denmark) in 2010, every roof has to be green. In Switzerland since 2002, every flat roof has to be green (in Basel city 1930 roofs are green). In Toronto, Canada since 2009 each roof with an area greater than 2000 m^2 has to be green. In Tokyo since 2001 20% of roofs with an area greater than 250 m^2 and 10% of roofs with an area greater than 1000 m^2 have to be green. In Germany, every year there are about 14 million new green roofs. In Russia this process is not going so fast, however now in Russia there are not only corporate, but also private customers [12].

Below there are some of the most interesting green roof projects.

1. Roof Garden on a condominium, Phuket, Thailand

This condominium is located near Patong Beach, one of the most popular tourist destinations in southern Thailand.

The roof garden is a reflection of the nature of Phuket Island and has a swimming pool. The garden is also located on the terrace of the seventh floor, with 180-degree sea views.

Author of the project: Shma Company Limited

Client & Developer: Sansiri PCL

Implementation: 2015

Figures 2.5 - 2.9 Roof Garden on a condominium, Phuket, Thailand (http://www.ecosoil.ru/useful/luchshie-sady-na-kryshah/)

2. Roof gardens in Kensington, London, UK

Roof gardens in Kensington are one of the most unusual sights of London. The complex includes three gardens: Spanish, English for members of the club and the garden of "Babylon" restaurant with a total area of 0.6 hectares.

The beginning of the construction was 1936. Two years later, the gardens were opened to the public. In 1987, the gardens were closed for renovation until 1992. This project is an excellent example of the use of roof gardens in the city.

This is confirmed by numerous awards in professional competitions in the hotel and restaurant sectors and in the landscape.
Author: landscape architect Ralph Hancock.
Owner since 1981: Virgin Limited Edition.

Figures 2.10 - 2.12 Roof gardens in Kensington, London, UK (http://www.ecosoil.ru/useful/luchshie-sady-na-kryshah/)

3. Multi-storey car parkings in Singapore

In 2008, the Bureau of Landscape “Nature Landscapes Pte Ltd” implemented the project of the green roof of the two multi-storey car parkings in Singapore. In cooperation with experts of green roofs, landscape architects created two parks on the roof, which became a popular destination for city dwellers.

Figures 1.13 - 1.16 Multi-storey car parkings in Singapore (http://www.ecosoil.ru/useful/luchshie-sady-na-kryshah/)

4. Public Gardens of Congress Hall in Montreal, Canada

The grand prize of the Canadian Society of Landscape Architects.

The park is located on the roof of the parking building of the Congress, on the edge of Chinatown and Old Montreal. The park is accessible for everyone, here you can relax, go out for a coffee break or just contemplate the beauty of the plants what many office workers do. It was hard work for a landscape architect, especially in the selection of plants, due to the limited volume of soil.

The park is very colorful in spring and autumn.

Author: Claude Cormier


Figures 2.17 - 2.19 Public Gardens of Congress Hall in Montreal, Canada (http://www.ecosoil.ru/useful/luchshie-sady-na-kryshah/)

2.3 Green roofs in Russia

In Russia green roofs appear only in the largest cities such as Moscow, St. Petersburg, Yekaterinburg, Kaliningrad, Tver, Voronezh and several others.
Green roofs are also used in the construction of international level facilities for the Sochi Olympics 2014 and the FIFA World Cup 2018. The real estate market increasingly feels the need to design eco-roofs in residential buildings, as the economic effect of their implementation in development projects may exceed the cost of maintenance more than a third.

Meanwhile, we can not ignore the factors that slow the development of this idea in Russia and they are not only related to economic conditions [8].

One of the arguments against is the fact that due to the climatic conditions in Russia, the roof can not withstand the cold season testing, and large temperature differences during the year negatively affect the waterproofing membrane and destroy it. But practice shows that due to fast development of construction technologies roofs are successfully exploited, for example, in the Scandinavian countries. Of course, in countries with severe winter the installation and maintenance of a green roof is more expensive. If the air temperature becomes below zero, a layer of soil and water in the drainage system becomes frozen. To avoid this, they use a heated drainage system. However this brings a significant rise in the cost of construction and maintenance of green roofs [8].

Other reasons are the following: an additional load on the supporting structures of the building, technical complexity of the design, the high cost of green roofs, the need for regular maintenance - in a time of flowering and in winter. However in compliance with national standards for construction the project can be carried out correctly and without any problems. The bearing capacity in case of an extensive green roof with saturated soil saturated should not exceed 70 kg/m^2 of surface, and with intensive green roof - no more than 300 kg/m^2.

Another reason for the failure of green roofs in Russia is unfortunately the poor quality of construction and installation works. Installation of such a roofing system requires specialized knowledge and experience. The maintenance programme brings additional complexity and cost, because the plants require constant care. Opinions against are sometimes caused by lack of knowledge and information, by little experience in this area of domestic architects and design engineers, contractors, operators, and sometimes even customers themselves. However it is much more important that green roofs are able to bind dust, humidify the air, revive the architectural look of cities, protect the roof covering, increase the heat and fire resistance of the building and create a habitat for beneficial insects and birds [8].

2.4 Cons of green roofs

Beyond their attractive visual nature, green roofs offer many undisputable benefits, both ecological and economical, provided they are built with the right system.

Improve the microclimate

Green roofs cool and humidify the surrounding air. Thus they contribute to improving the microclimate in urban centres. This cooling effect significantly increases the performance of air-conditioning systems, reducing carbon emissions [10].

Bind Dust and Toxic Particles

Green roof vegetation helps to filter out dust and smog particles. Nitrates and other harmful materials are absorbed by the plants out of the air and rainfall and bound within the substrate [10].

Increase Rainwater Retention

A green roof can reduce water run-off by 50–90%; any water flows from the roof with a delay. Outlets, pipes and drains can be reduced in capacity, thereby saving construction costs. Sewer costs can be reduced in some areas [10].

Improve Noise Protection

Planted areas are natural sound insulators and absorb more sound than hard surfaces. Green roofs reduce reflective sound by up to 3 dB and improve sound insulation by up to 8 dB. This is very effective for buildings near airports, noisy nightclubs and factories [10].

Reduce of Energy Costs

A green roof has the ability to buffer temperature extremes and improve the buildings’ energy performance [10].

Protect the Waterproofing

A green roof protects the waterproofing from climate extremes, UV exposure and mechanical damage. This greatly increases the life expectancy of the waterproofing and results in reduced maintenance and replacement costs [10].

Offer a Natural Habitat

Landscaped roofs compensate for green spaces, which are lost to building development. They provide natural habitats for wildlife and bring nature back into the cities [10].

Provide Additional Space

Green roofs offer additional space for numerous uses. Whether you want a relaxing garden, a playground or a golf course, it all can be achieved as part of the existing footprint [10].

Environmental benefits

Many supporters of the use of green roofs consider them as a way of returning to nature. The natural space of land on which the building stands becomes impermeable and the natural flora and fauna disappears. Proponents of green roofs regard them as a natural oasis in an urban area. Although not all habitats can be recreated on the roof, some types of habitats, such as grassy lawns and moss carpets on green roofs can be created.

In Switzerland the number of spiders and beetles on green roofs were investigated. These studies showed that the green roofs which vary by type and planting density contain a large variety of species of spiders, beetles and birds. In his studies, Brenneisen compared habitats of green roofs with natural habitats found on the ground level and containing such vegetation as green roofs (Brenneisen 2003). He found that those species of beetles and spiders did not differ significantly. This shows that green roofs can adequately recreate natural habitat. A research carried out in Switzerland also confirmed the presence of many bird species that were there in search of food and for reproduction on green roofs.

Benefits to reduce energy consumption

The layer of soil and plants on the roof provide an additional insulating layer to the existing design of the roof insulation. This additional insulation layer helps to reduce the requirements for heating and cooling buildings, and therefore provides energy savings.

Canadians Liu and Baskaran conducted a field research in Ottawa and found that demand for energy required for air-conditioning of premises, decreased by more than 75% due to the thermal insulation effect of green roofs (Liu & Baskaran. 2003). Studies in which a typical roof and an extensive roof were compared showed energy reduction by 6.0-7.5 kWh / day for a typical roof to less than 1.5 kWh / day for the green roof. Both of the roofs in the experiment were the same size with a surface area of 72 m^2.

Improving of microclimate

In urban areas where a huge number of cars throws fuel products to the air, where the number of air conditioners is increasing, which is of course welcomed by consumers and producers, due to these aspects the temperature in the city is becoming approximately five degrees higher than the ambient temperature.

In the whole world big cities continue to expand and the heat island effect has a significant impact on the lives of the urban population. Heat island effect is a phenomenon where the ambient temperature within urban areas is higher than in suburban areas. This phenomenon has been studied well enough. For example, NASA thermal infrared photography showed that the temperature of the city center of Atlanta, Georgia, is often 6 degrees warmer than in surrounding areas (Taube 2003). Heat island effect is caused by the presence of a larger number of heat absorbing materials, such as asphalt covering all urban areas. This material absorbs heat rather than reflects, as vegetation cover does. As a result, urban areas retain heat longer and the ambient temperature is higher than in the countryside. Other negative effects of heat island effect is a smog formation, increased ozone formation, emissions of carbon dioxide and other pollutants due to increased energy production (Cheney & Rosenzweig 2003).

Proponents of green roofs consider that green roofs can reduce the heat island effect in the case of their distribution on a large scale throughout the city. Investigations in Ottawa, Canada, showed that whereas in typical roof temperature reached 55° C, an extensive green roof kept the temperature of about 21° C (Liu & Baskaran 2003). Investigations also showed that green roof lowers the temperature fluctuations on the roof during the day. Daily fluctuations in temperature on a typical roof in spring and summer months were on average 45° C, and at equivalent green roof just 6° C. Also, investigations of the green roof area (2044 m^2) in the City Hall in Chicago, showed that a significant decrease in temperature can occur in a more dense planting vegetation. (Laberge 2003).

Rainwater Retention

One of the most notable benefits of green roofs is a rainwater retention, which soil and vegetation provide. This is the most investigated potential benefit of green roofs nowadays. A typical flat roof can store about 5 mm of rainwater, however precipitation almost immediately flow down the roof in stormwater drain. This fast-moving rainwater from roofs in urban areas increase the chances of flooding during heavy rains. In old towns and cities with combined sewer systems, such rapid floods can lead to overflow of these systems and penetration of untreated municipal wastewater into nearby streams. Existing stormwater management programs take into account this danger and require to reduce the volume and intensity of storm water entering the municipal sewer system (Slone & Evans. 2003). Green roofs are a potential solution to this problem.

While green roofs in Germany are investigated since 1975, and during that time it was published more than 950 reports about extensive green roofs, only few of them have been translated into English (Herman 2003). One of the prominent German leaders in the field of green roofs is Dr. Hans-Joachim Liesecke. In his book Rainwater retention of green roofs (Das Retentionsvermugen von Dachbegrunungen) Liesecke discusses that evapotranspiration plays the most important role in the ability of green roofs to retain water, and water retention in the summer months is significantly more than in the winter months because of the evapotranspiration (Liesecke 1998). Thus, in areas where most of the precipitation falls in the winter months, green roofs may not be as effective because in the winter there is less water retention. In another study, Liesecke tested different soils of extensive green roofs with depths 80-120 mm. This investigation gave the general industry standards of the annual water retention of green roofs to German companies. For example, annual water retention for green roofs with a slope of 2% and a depth of the soil layer 20-40 mm is 40-45%, with the depth of the soil layer of 60-80 mm is 50 -55%, and the depth of the soil 100-120 mm is 55 -60%.

Water retention investigations have also been conducted in the US, where in Portland, Oregon, a cutting-edge research in this field is held. The ability of green roofs to retain water depends on a number of factors, such as precipitation intensity and seasonal variations, the level of evapotranspiration and soil moisture on the roof. During 15 months observation period in 2002 and 2003, the water retention of an extensive green roof with soil depth of 100-120 mm was 69% (Hutchinson et al., 2003). From May 2002 to October 2002, a green roof retained more than 90% of monthly precipitation, however those were the driest months of the year with rainfall less than 50 mm during the month. Significant retention of precipitation was also observed during the wet winter months in Portland. This study also showed a reduction in peak runoff from a green roof by 80% .

Protection from solar radiation, including UV

Green roofs use the reflective properties of substrate and vegetation and protect the roof structure from harmful effects of solar radiation including ultraviolet rays, temperature fluctuations and electromagnetic radiation, so roof life cycle becomes longer [10].

Attracting birds and insects

Green plantings on the roof attract butterflies, birds and insects expanding their habitat and helping to maintain a biodiversity in urban areas. In addition, green roofs allow to maintain a sense of nature, even in big cities [10].

Additional Space

Green roof for its beauty often attracts more attention than the main facades of the buildings. They are aesthetic, catching, improve the appearance of the area and the city as a whole, and their environmental impact is undeniable. Besides, they create additional space for people's rest among favorite flowers and trees, without leaving your home and without using any transportation to get closer to nature. In addition, food crops can be planted on the roofs. In Japan, for example, rice wine factory has already proposed to grow rice on its roof and then produce the drink sake from this rice [10].

Global warming

In recent years, scientists have documented the rise in average temperatures worldwide. Human-caused global warming occurs when human activity introduces too much of certain types of gases into the atmosphere. More of these gases equals more warming. The atmospheric gases primarily responsible for the greenhouse effect are known as greenhouse gases and include water vapor, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The most prevalent greenhouse gas is CO_2. As a result climate processes in the world are destabilized. This is leading to different disasters: the terrible heat and drought, fraught with fires, heavy rains and floods, storms and rising sea levels in different places. Green roofs can contribute to reducing the effects of global warming, as vegetation during photosynthesis reduces the amount of carbon dioxide, absorbs it with solar energy and releases oxygen into the atmosphere, necessary to all living creatures. In addition, plants on the roof clean the air from other pollutants, as well as moisturize it, improving the quality of urban atmosphere, so the more of such roofs will be in our cities, the easier it will be to live there [10].

The cost of green roofs

Green roof cost is certainly higher than the cost of a typical roof, but due to its numerous advantages, the additional costs will quickly pay off as a result of reducing the cost of heating and cooling, saving and accumulation of water, as well as reducing the cost of roof operating because of its longer lifecycle [10].

The maintenance of green roofs

Most green roof plantings are drought tolerant, but in order to thrive they may need supplemental irrigation from time to time. An elaborate irrigation system is usually not necessary; just roof access of a hose to water plants during extreme drought conditions is all that is necessary in most cases.

All green roofs, whether pregrown or planted in place require fertilization for the first few years they are establishing in their new environment. They also need time to build up enough organic matter in the soil media from the natural cycles of dieback, decay and rejuvenation of the plant life on the roof until they no longer require fertilization [10].

All roofs, even in our pregrown system need to be weeded occasionally. The more established and mature your green roof plants are, the fewer weed problems you will have.

Green roof plants need to be inspected for fungal diseases and insect problems on a regular basis.

The drainage system on the roof underneath the green roof modules needs to be inspected regularly to make sure there are no back ups that could cause puddling or pooling [10].

3 GREEN ROOFS IN CONSTRUCTION

3.1 Architectural design aspects of Green Roofs

To create architectural and landscape feature flat roofs with a slope of no more than 2% for the gardens on the roofs, and 4% for ground garden can be used. Green roofs have a maximum slope of up to 6% [8].

In construction preferred design of the roof with a warm attic, but you can also use a roof with a cold attic [8].

For terrestrial gardens it is allowed to use the combined roof:
- Method of water drainage should be provided internal;
- The structural elements of the roof must withstand the additional load from the elements of the garden on the roof;
- As the materials forming the "pie" of the roof should be applied roll roofing;
- On location waterproofing carpet it is preferable to lay inversion roof [8].

Figure 3.1 Green roof (http://www.priroda.su/item/2548)

3.2 Structural design

The profile of the typical green roof is quite complex, containing many different layers, which are depicted in Figure 3.2, resembling a layer cake. The lower layer of the green roof is the actual design of the roof. The roof structure must have a waterproofing layer, so that water cannot penetrate the roofing material. Above the waterproofing layer there is a protective layer to retain moisture [8].

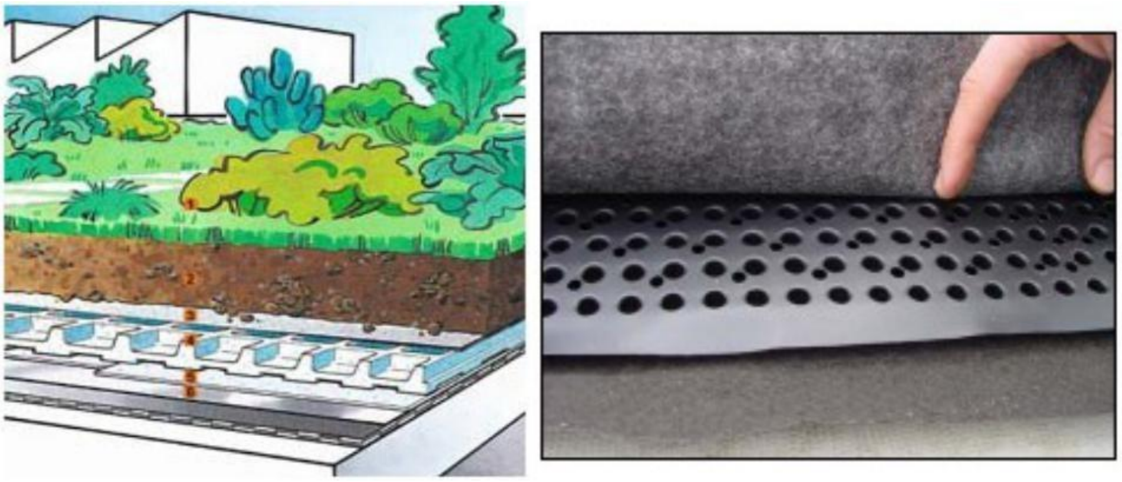

Figure 3.2 Profile of the typical extensive green roof (left) (http://facepla.net/index.php/content-info/629-green-roof-eco-deposit)

The figure on the right shows a close-up drain and water-retaining layers. Retaining moisture protective layer serves as a barrier for the roots of plants, and it also retains some of the rainwater for later use by plants. Root barriers often contain copper sulfate to retard plant growth, thereby preventing the penetration of roots through the waterproofing membrane. Above the water-repellent layer there is a drainage layer. Different roofing companies offer a wide variety of drainage materials. Some drainage layers just have drainage holes for rainwater, while the others can be equipped with miniature tanks for water storage. Water is stored in the drain layer for a period of time until it is absorbed by the soil layer, where it should take roots. Above the drainage layer a fabric filter is placed to prevent falling into the drainage layer of fine particles that impede its work. Topsoil is composed of green light for the roof ground thickness, usually from 25 mm to 150 mm for extensive roof. The vegetation layer consists of drought-resistant plants that can survive in an artificial environment on the roof. Intense green roof profile is very similar to the extensive roof but has a deeper soil layer, more plants species and possibly broader protective layers [8].

The layer protecting the roots or a layer against root is needed to protect the waterproofing from the germination of plant roots and from mechanical damage during the construction of the green roof. In plants, the most demanding to moisture, root tips have special devices that can capture crystals sand and use them as a kind of "drill", reaching the layer. Thus, they can even drill solid asphalt covering, so the definition of the optimum thickness layer against root is of paramount importance. For the same reason it is important to determine the type and design of the container for the trees and shrubs that have a fairly aggressive root system [8].

3.3 Types of Green Roofs

There are two different types of green roofs: intensive and extensive. Extensive green roofs use undersized succulents such as sedum and mosses, and have a deep layer of soil, ranging from 3 cm to 15 cm [8].

Figure 3.3 Extensive green roof in Germany (left). Intensive green roof in Germany (right) (http://www.greenroofs.com/Greenroofs101/intro.htm)

On the left Figure 3.3 shows the extensive green roof, which usually requires a minimum of maintenance. Selection of such plants in the design of the roof must be capable of survival without irrigation, and only due to natural precipitation. However, some developers still provide for irrigation of green roofs in the early stages of its creation, to help the formation of vegetation cover, and further irrigation this roof is usually not required. Exceptions can only occur during a prolonged drought, and if the vegetation on a green roof is in the early stages of growth. Typical services include a roof weeding in the spring and summer months and drainage cleaning of any obstacles such as fallen leaves and roots of plants [8].

Intensive green roofs can support much more complex and diverse vegetation, such as trees and shrubs, which can be seen in Figure 3.3 on the right, which shows the intensity of the green roof. However, a large depth of soil requires more intensive vegetation, so the depth of the soil layer to intense green roofs can vary from 150 mm to 1 m. Intensive green roof is almost always higher than extensive, due to additional structural reinforcement required any increase in weight increases the amount of soil and additional maintenance. In contrast to the extensive green roofs, intensive roofs usually require regular watering, and ensure better survival of plants in an artificial environment which may also require additional fertilizer on the roof. Because intensive green roofs can provide a greater variety of vegetation, the roof can better recreate the natural habitat [8].

3.4 Building physical aspects/principles of Green Roofs

3.4.1 Climate in Saint-Petersburg

St. Petersburg is located in the temperate climate zone, with fairly mild winters and moderately warm summers and with the characteristic variability of weather, due to the frequent change of air masses. Atlantic cyclones bring cloudy, windy weather and rain, it becomes a cause of sudden warming in winter and in summer, on the contrary, is cold. Anticyclones, which are formed in the continental air masses, set slightly overcast and dry weather, hot in summer and cold in winter. Drastic reduction of air temperature, usually associated with the invasion of Arctic air masses is causing sharp changes in weather conditions [13].

According to the North-West Management Roshydromet the average annual temperature in St. Petersburg is + 5°C, and the number of days in a year with the average daily temperature above 0°C is 232 days; the coldest month is February with an average temperature of -8,0°C to -8,5°C, and the warmest month is July with the temperature from + 17,4°C to + 18,0°C [13].

The average annual rainfall in St. Petersburg is located in the zone of excessive moisture, 637 - 666 mm, most of which (67%) falls on the warm period. The total number of days with precipitation in St. Petersburg is an average of 191 days of the year, although there are also periods of dearth, which can last up to 25-30 days. The minimum precipitation usually falls in February, and the maximum - in August, the highest recorded number of precipitation per night with an intensity of 1.1 ... 1.3 mm/h is 75.7 mm [13].

Artificial roofing reflects sunlight and the temperature in the cities on average by 10 degrees. On the green roof on a hot summer day, observed at 5-13 degrees below the air temperature, than traditionally-covered building [13].

Reducing the load from solar radiation and temperature changes in the roofing materials green roof increases the service life 20-30 years. This data is derived from the operating experience of green roof developed countries. The relative humidity is 60-100 % [13].

3.4.2 Rain, moisture, snow, ice, wind, sun radiation

One of the main functions is to keep the green roof rainwater precipitation by absorption and drainage in the soil layer, in connection with which stormwater runoff from green roofs generally does not occur until complete saturation with water. As a result, between the beginning and the advent of rain runoff from a roof green occurs a time delay which may be up to several hours, depending on the intensity and duration of rain and the roof pitch [6].

A thick layer of snow that accumulates on the roof, and exceeding the average thickness is called accumulation of snow. They accumulate in the valleys with two intersecting roofs and in areas with closely spaced dormers. In all places with a high probability of accumulation of snow, put paired rafters and perform continuous crate. Also here underlay substrate is made, usually made of galvanized steel, regardless of the primary roofing material [6].

The big problem with the removal of excess moisture is to fight with icing, which is formed mainly in the spring when the snow melts during the day time to time under the rays of spring sun, and at night as a result of the daily drop in temperature, freezes, turning into ice [6].

Today, there are one way to combat the formation of frost: antiicing system based on the use of the reinforcing cables of the hydrophobic composite. When creating architectural and landscape features it is preferable to create an internal drain excess water, so as not to face the problem of struggle against icing. However, in this case it is necessary to provide measures to prevent freezing of water in the upper part of the flow, which is cooled in the roof area [6].

To solve the problem of the negative influence of wind when applying architectural and landscape features it is necessary to provide the device parapets, the base of the roof to make as much as possible and sealed to provide additional fastening of the top cover [6].

In addition, it is possible to install special parapets crowns air mass that will cut air flow, thus reducing its strength [6].

The amount of moisture produced, the higher the larger the temperature difference between the outside and indoors, so winter moisture quite intensively accumulates in the roof space. Moisture adversely affects both the wood, and the metallic elements of the roof structure. Moisture accumulation in the insulation material greatly reduces its thermal insulation properties [6].

Solving the problem with the accumulation of water vapor is the use of a special film with a low water vapor permeability, as well as design solutions, providing the output of accumulated moisture in the winter outside in the summer, in particular, is not solid, and partial gluing roofing materials [6].

St. Petersburg has from 31 to 62 sunny days a year, 57 days of fog, 105 with variable cloudiness [6].

3.4.3 Other aspects

Green roofs require careful architectural design an care, especially in details. When signing up the design agreements you have to estimate the planning costs (hours) of the design group. Green roofs often require the use of specialties like landscare/plant architecture [6].

The design of architectural and landscape features on exploited roofs needs to take into account the negative impact of chemically aggressive substances in the air at ground sites (on the roofs of underground garages, podium and overpasses). When the device of green roofs on roofs of buildings is necessary to consider that the height of harmful impurities concentration drops sharply, and at a height of 30 - 35 m above the air practically does not contain harmful substances and for roofing plants them in hazardous concentrations [6].

Significant damage to the roof structure and elements of architectural and landscape features can cause a variety of insects and microorganisms. It is favorable for their humidity to protect the wooden structures using special impregnation, protecting the material from micro-organisms. A certain danger can be birds, especially magpies or crows, which often peck seeds or pull out poorly rooted plants. It is necessary to avoid the use of shiny surfaces and objects that they are particularly attracted to [6].

Thermal performance is strongly dependent on the amount of water flowing into the roof substrate. Water has a negative effect on thermal conductivity. So in a wet winter climate, the green roof will add little to the overall thermal performance of the roof. Green roofs have a fixed heat transfer coefficient, as they retain water [6].

3.5 Materials of Green Roofs

As used in the construction of green roofs advanced materials combine several functions: grodana of plates and also serve as a substrate and as drainage and foamglass new material can be used, in addition to the drain layer, and as a heater. In addition, these lightweight, porous plates are very light weight and can be transported and stacked by hand [8].

The most resistant materials for these purposes are foil folgoizil and fiberglass. On the cover plates made of waterproof concrete can be seemingly layer against root to exclude, such as the concrete is impervious to acid exposure of the root system. However, it is required to lay as with time, due to alternate freezing and thawing, the plates may arise in cracks which penetrate the plant roots. In the event that during the construction of the concrete there was not enough time to cure and harden before laying this layer, the concrete surface is impregnated with a special compound based on silicone or Silin [8].

When using waterproof concrete roof covering the constructions permit filling with topsoil (or laying slabs substrate) for all of the above mentioned layers without waterproofing coating itself. When the operated roof is calculated not only to pedestrian traffic, but also to other dynamic loads, use a waterproofing of several web materials [8].

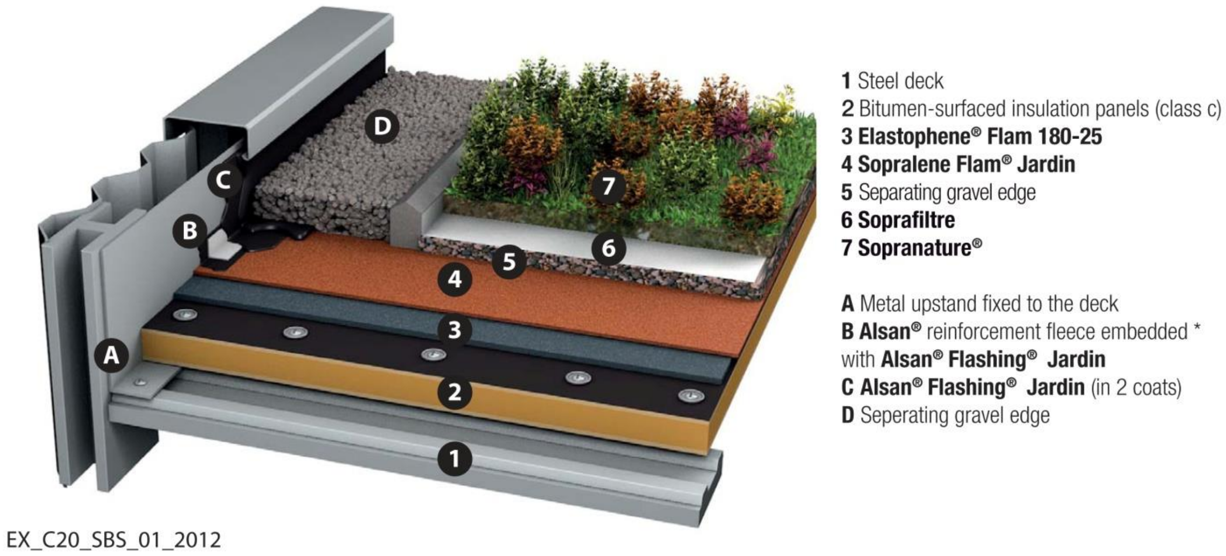

Figure 3.4. Materials in green roof (http://mekobre.com/mainpage/detail/carlisle-green-roof)

3.6 Plants and vegetation of Green Roofs

Plants for extensive green roofs

Plants for extensive green roofs should have low growth height, rapid growth/spreading, and fibrous roots that have high drought tolerance. Succulents, such as sedum, are often chosen for extensive green roofs because they withstand harsh conditions and minimize water loss. Succulents are one type of plant that utilizes crassulacean acid metabolism (CAM). Plants that utilize CAM open their stomata (pores used in photosynthesis) at night, taking up carbon dioxide, and keep their stomata closed during the day while they photosynthesize the carbon dioxide. Because of this characteristic, CAM plants minimize water loss, helping with stormwater management, while also offering the benefits of evapotranspiration (evaporating water from a plant by absorbing it through the roots and emitting it back out through the leaves as vapor–see also Green Roof Benefits). Non–CAM plants are more susceptible to heat and drought conditions and may therefore require irrigation. Grasses are often used, which offer a continuous meadow or field appearance, although they generally require more soil depth, additional watering, and maintenance [10].

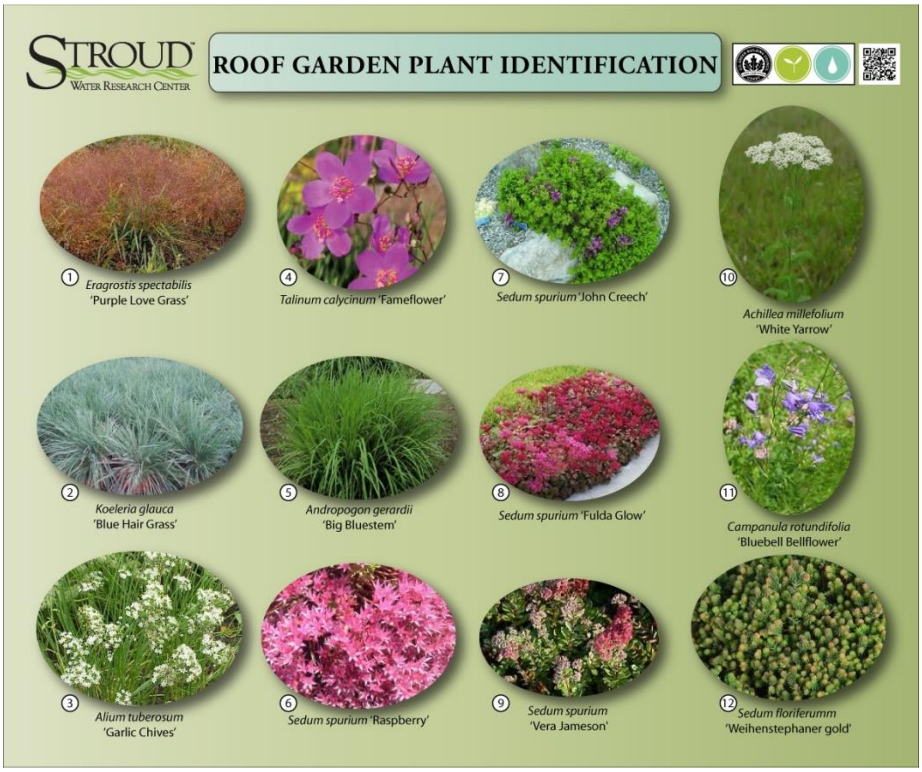

Figure 3.5 Plants in green roofs
(http://www.stroudcenter.org/mec/greenroofplants_sign.shtm)

3.7 Types of construction

There are 2 types of construction: traditional warm roof and inversion roof. The difference between the inversion roof system (also known as protected membrane system) and traditional warm roof construction is that the insulation is located above the waterproofing membrane. Permaphalt is ideal for inverted roof construction [7].

Inverted roofs offer several significant advantages;
- The thermal insulation acts as a protective layer to the Permaphalt membrane
- The Permaphalt and structure are protected against extreme thermal changes during winter and summer months, giving considerable thermal stability to the system.
- No separate vapour control layer is required
- The system forms an ideal specification for insulated balconies and rooftop terraces

- When fully protected and subject to normal service conditions, Permaphalt will provide an effective barrier for the design life of the roof/substrate on which it is incorporated [7].

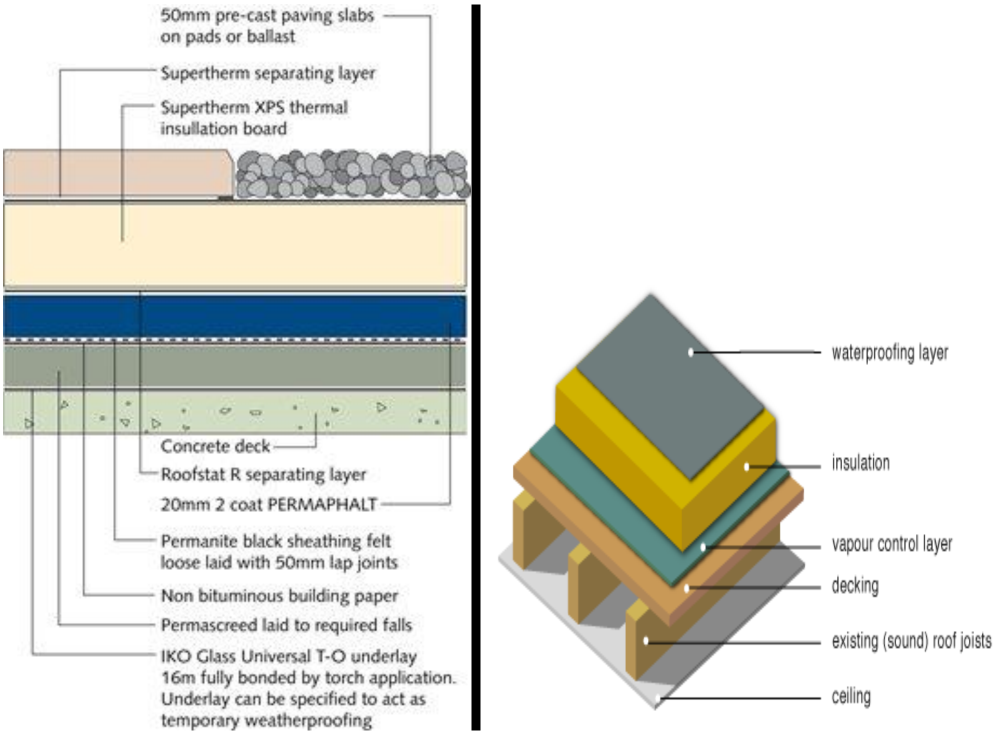

Figure 3.6 Traditional and inversion roof (http://fitzpatrickcruiseltd.co.uk/sitemap-image.php)

Plants for intensive green roofs

An intensive green roof is more like a conventional garden or park and can have virtually no limit to the plant types that can be used. Due to the differences in growing medium between an extensive and intensive green roof, the latter can accommodate deeper plantings with more diversity. However, as stated earlier, it must be established that the building below can handle the extreme weight associated with an intensive roof. Not only is the growing medium deeper and therefore heavier, the plants themselves will grow larger, with larger root systems which must be accounted for. In addition, growth rate and mature size of plantings on intensive green roofs must be evaluated for visibility and effects on the historic character of the building. Due to the added weight and greater maintenance needs, intensive green roof plantings will also be more expensive to install. Urban agriculture is growing in popularity providing opportunities to grow and harvest food from rooftops in cities. From herbs and salad greens to tomatoes and cucumbers, many individuals and restaurants are looking for opportunities to produce food locally [10].

For green roofs inversion roof is better because waterproofing is protected, and lifecycle will be longer. Considering heat insulation it is better to use waterproofing insulation as extruded polystyrene foam, geotextile, the profiled membrane. For example 60 mm Extruded Polystyrene Insulation has U-value 0.4 [10].

In a typical arrangement of the upper waterproof layer damaged over time, which entails a number of undesirable consequences:
- water vapor and rainfall penetrate;
- condensation in the insulating material layer;
- a significant amount of condensate causes it to run off into the inner room and the formation of stains on the ceiling;
- in the cold season, the condensate is frozen and can tear waterproof coating on the substrate, while it formed cracks and fissures;
- as a result of all these phenomena roof loses its performance and comes into a state of complete disrepair [10].

3.8 Installation of Green Roofs on site

The process of construction of extensive and intensive green roofs is relatively the same, but there may be slight variations. First, the roof of the building to be constructed and fully sufficient load-bearing structures have to withstand the additional weight of the drainage layers, soil and vegetation. For example, depending on the type and drainage layer selected ground installation extensive green roofs can add 13.6 kg/m^2 additional load on the roof. Due to the additional weight of the green roof construction it may be needed to change the supporting structures of the roof. For example, the outdoor shelter with a roof area of 42 m^2, which is based on the pillars without walls, the initial weight of the roof can withstand seven columns section 100x100 mm. With the added weight of all materials when installing a green roof to support it will need seven columns section 152x152 mm instead of the previous size [8].

Slopes on the base of the roof of the exploited and green roofs should be 1.5-3%. At the slopes of less than 1.5% is likely stagnation of water on the roof, which can lead to waterlogging and its gibed established plants [8].

After the completion of the roof waterproofing layer is laid, and then glued. You must first check the waterproofing layer to make sure the roof will not leak. In many cases, the waterproofing is already in place. Especially carefully carry out the joint space with vertical planes and equipment: railings, ventilation shafts, the walls of the superstructure to prevent the penetration of moisture in the lower layers of the landscaped roof structure [8].

When the roof is completely built, begins construction of its own green roof. Above the waterproofing membrane there protective and drainage layers, which include a layer of retaining moisture, root barrier fabric filter and drainage medium. There are various designs of these layers, some companies offer a single product combining root barrier fabric filter and drainage medium, while others deliver each layer separately. Whether these different systems are combined into one product or more, but each layer must extend across the roof surface [8].

Typically, moisture retention mat is placed first, followed by the root barrier drainage environment. After all the protective layers and drainage are installed on the roof the layer of soil can be distributed. Figure 3.7 illustrates how the drainage layers are stacked on the roof during the construction of the green roof [8].

 

Figure 3.7 Left - cutting protective layers for placing on the roof. Right - laying protective layer before placing on the roof of the soil (https://pro.homeadvisor.com/article.show.Low-Slope-Reroof-with-EPDM.13858.html)

German roofing companies developed pneumatic mechanisms for transporting the soil to the roof. It is a much more advanced method than those used in most other countries [8].

Figure 3.8 shows the different methods used for the transportation of soil on the roof. After the soil is layered, you can begin to plant vegetation. The vegetation can be planted using a variety of forms, such as seeds, roots, shoots or plant mats. Because more green roofs are built, in the world more efficient methods may soon be developed for the transportation of soil [8].

 

Figure 3.8 Pneumatic conveying of soil on the roof in Germany. On the left - a truck used for transporting the soil to the right - the pump hose is used to supply ground to the roof, and the workers, spread it with a rake (http://iconroofing.ca/our-services/roofing-repairs/)

The successful construction of green roofs depends on the interaction of the drainage layer, soil and vegetation. The vegetation is present on green roofs, they survive in spite of their strong heating, as rainwater is stored in the soil and drainage layer for a certain period of time. Rain drops on a green roof and is absorbed into the soil, which, having a highly absorbent, keeps the water a certain time. For extensive green roofs it is recommended to use a light soil, in order to minimize the need for additional support and strengthen the structures [8].

Stormwater runoff from the green roof is when the water content in the soil reaches a maximum and it cannot absorb more water, and when the drainage material has also used all its power and cannot hold more precipitation. This usually occurs after a prolonged period of rain or very high intensity. As a result of runoff from the green roof it cannot be observed for several hours after the onset of rain. When the flow stops with green roofs, water is retained in the pores of the soil and the drainage layer for consumption by plants. Precipitation is absorbed by the soil and temporarily stored in the drain layer, then it goes back into the natural water cycle through transpiration by plants and evaporation from the soil [8].

3.9 Cost and live cycle costs of Green Roofs

With the initial cost of installing a green roof in mind, there are many financial benefits that accompany green roofing [7].

Green roofing can extend the lifespan of a roof by over 200% by covering the waterproofing membrane with growing medium and vegetation, this shields the membrane from ultra-violet radiation and physical damage. Further, Penn State University’s Green Roof Research Center expects the lifespan of a roof to increase by as much as three times after greening the roof [7].

It is estimated that the installation of a green roof could increase the real estate value of an average house by about 7% [7].

Reduction in energy use is an important property of green roofing. By improving the thermal performance of a roof, green roofing allows buildings to better retain their heat during the cooler winter months while reflecting and absorbing solar radiation during the hotter summer months, allowing buildings to remain cooler. A study conducted by Environment Canada found a 26% reduction in summer cooling needs and a 26% reduction in winter heat losses when a green roof is used. With respect to hotter summer weather, green roofing is able to reduce the solar heating of a building by reflecting 27% of solar radiation, absorbing 60% by the vegetation through photosynthesis and evapotranspiration, and absorbing the remaining 13% into the growing medium. Such mitigation of solar radiation has been found to reduce building temperatures by up to 20 °C and reduce energy needs for air-conditioning by 25% to 80%. This reduction in energy required to cool a building in the summer is accompanied by a reduction in energy required to heat a building in the winter, thus reducing the energy requirements of the building year-round which allows the building temperature to be controlled at a lower cost [7].

Depending on the region in which a green roof is installed, incentives may be available in the form of stormwater tax reduction, grants, or rebates. The regions where these incentives will most likely be found are areas where failing storm water management infrastructure is in place, urban heat island effect has significantly increased the local air temperature, or areas where environmental contaminants in the storm water runoff is of great concern. An example of such an incentive is a one-year property tax credit available in New York City, since 2009, for property owners who green at least 50% of their roof area [7].

3.10 Maintenance, use and service of Green Roofs

In general, the maintenance of roofs includes the following activities:

- Check the tightness of the roof.
- Maintenance of sanitation and drainage systems.
- Garbage collection.

- The fight against the formation of ice dams.
- Snow clearance [7].

In order to increase the service life of the roof without major repairs permanent and periodic monitoring of the state of the roof structure is needed. Visual routine inspection is carried out 4 times a year (spring, summer, autumn and winter), extraordinary inspections are carried out if necessary. Seasonal surveys are designed to identify and timely eliminate specific defects. The examination is required to inspect roofs abutting the roof to the horizontal sections of different designs:
- walls, parapets, end ventilation units;
- drains of domestic waterflow, eaves and gutters;
- exhaust and sewage risers;
- uprights and braces television aerials;
- access to the roof [7].

In addition to studying the condition of the roof structures, check its water resistance by inspection of premises ceilings, located under the roof, and recorded in the plan places where there are damp patches. Comparing moisture overlap with the roof up, determine the causes of damp stains:
- defects in the conjugation of the roof membrane with different designs of the roof;
- condensation of moisture on the bottom surface of the ceiling due to the freezing roof [7].

Rainwater hoppers, chutes and troughs should be inspected in the spring (at the time of melting snow) and autumn (during the leaf fall) at least 2 times a month. During such inspections cleaning of the filters from the leaves in the gutters funnels and removal of debris and dust in the valleys, gutters should be carried out [7].

Accumulations of debris and dust hinder the normal flow of water and contribute to the development of vegetation on the surface of the roof. This can lead to disruption of the integrity of the roof (waterproofing layer destruction). Foreign objects and debris should be removed from the roof surface during routine inspections [7].

Another maintenance task is timely cleaning of the surface of the roofs from snow and ice [7].

Maintenance green roofs, besides the above items, includes the following events:
- irrigation;
- fertilizer;
- cropping plants;
- weed control;
- pest control [7].

4 GREEN ROOF BUILDINGS IN SAINT PETERSBURG

Nowadays there are not so many green roofs in Saint Petersburg. Only two examples are known to a wide audience.

4.1 A residential complex Diadema

The green roof of a seven-storey residential complex Diadema on Krestovsky island is the first green roof in St. Petersburg, made in 2011 by the German roofing and landscape company «ZinCo».

Figure 4.1 Green roof of a residential complex "Diadema"

Elite residential complex "Diadema" consisting of four houses is built in a unique green historic area near of St. Petersburg near parks of Apothecary and Stone Islands. Flats on the first and second floors, as well as apartments, have green landscaped terraces with snow melting systems, also a unique atrium with a winter garden creates a comfortable environment in the middle of the building.

Figure 4.2 Green landscaped terraces (left) and winter garden (right)

The green roof area is 4000 m² and has only grass. The area of the winter garden territory with trees and shrubs is 1880 m². The slope is from 1 to 1.5%. The accumulating and drainage layer DSE 20 with a height of cells 20-40 mm provide water retention of in average 7.4 liters/m^2. The thickness of the substrate is 200 mm. Rolled turf is used as a vegetative cover. All terraces have the hole for drainage in the center, all the water runs off into storm water drain through the weir with a triangular flow meter.

4.2 A multifunctional complex Airport City

Several green roof projects were performed in St. Petersburg in recent years, where the technology of a German company «BAUDER» was used. This company is a leader in the production of green roof systems in Europe for more than 150 years. The first of their projects in Saint Petersburg was a multifunctional complex Airport City on Startovaya Street.

Figure 4.3 Green roof of the multifunctional complex Airport City

A green roof of the multifunctional complex Airport City was built in 2012 using an original «BAUDER» technology. For this project several species of plants stonecrop (sedum) with different flowering times were specially selected to make the view from the windows more attractive.

Figure 4.4 Green roof of the multifunctional complex Airport City

A feature of this complex with a total area of 17,000 m^2 is the use of not only the green roof, but also other "green" technologies, including energy saving and heat regulation system. The total area of the flat roof is 5,000 m^2, slope is from 1 to 1.5%. The accumulating and drainage layer DSE 20 with a height of cells 20 mm provide water retention of in average 7.4 liters / m^2 if a substrate thickness is 100 mm.

Six kinds of stonecrops were used for planting: Sedum reflexum (reflexed stonecrop), Sedum sexangulare (tasteless stonecrop), Sedum album (white stonecrop), Sedum album chloroticum (white stonecrop with small flowers), Sedum album murale (white wall stonecrop), Sedum spurium fuldaglut (Caucasian stonecrop), Sedum grisebachii. They were planted with a density 25 pieces per 1 m^2. Part of the plants was planted in soil with a depth of 50 mm, another part - in soil with a depth of 100 mm providing an opportunity to compare their growth and survival depending on the soil depth.

For successful growing plants should have a shallow root system, be light-, drought-, wind- and frost-resistant. These requirements are met in all six types of stonecrops presented in Figure 4.5.

When creating a green roof an important fact is that the grass cover should be formed on the soil as soon as possible, because the sooner it comes, the less soil will be lost as a result of wind erosion.

Figure 4.5 Six types of stonecrops on the roof of the "Airport City". From the left to the right: Sedum reflexum; Sedum sexangulare; Sedum album; Sedum album chloroticum; Sedum album murale; Sedum spurium fuldaglut; Sedum hybridum (https://en.wikipedia.org/wiki/Sedum_reflexum)

5 CONSTRUCTION SOLUTIONS FOR THE ROOF SYSTEM OF GIDROCORPUS

5.1 About Gidrocorpus

As an alternative arrangement of green roofs in the possible renovation of the building Gidrocorpus of Peter the Great St. Petersburg Polytechnic University was selected [14].

Gidrocorpus is Faculty of Civil Engineering of Peter the Great St. Petersburg Polytechnic University. It is the name of the building at st. Polytechnique 29A. Gidrocorpus project was developed by the institute "Lengiprogor" in 1973, and its construction was completed in 1975. Construction of Gidrocorpus was difficult for the university when it was divided into several institutes [14].

Design features, as shown by calculations, allow the slab covering laboratories to withstand more evenly distributed load of 250 kg/m^2, which makes arrangement of an extensive green roof with the renovation of the building possible[14].

Figure 5.1 Gidrocorpus of Peter the Great St. Petersburg Polytechnic University. Modern look - on the left, Right - the project of reconstruction (http://www.citywalls.ru)

As it can be seen from the following plan (Figure 3.2), the total area of the three laboratories with flat roofs, a slope of 1.5%, is 2595 m^2 [14].

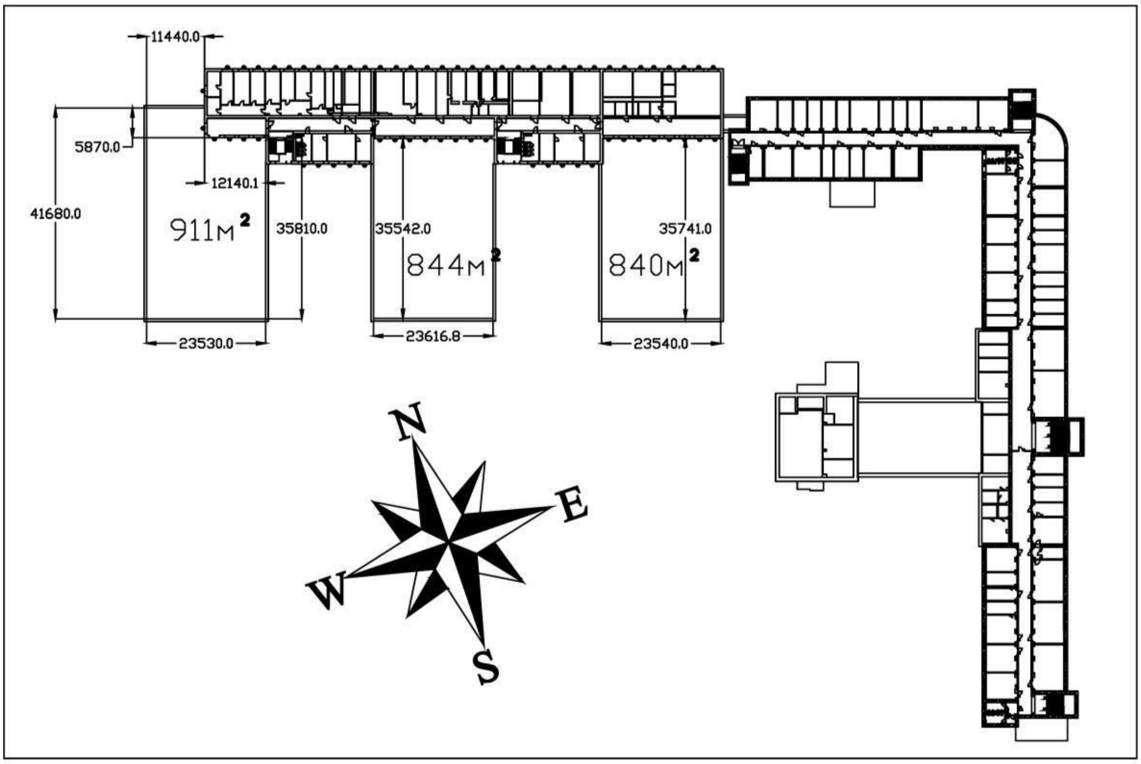

Figure 5.2 The total area of the three laboratories (http://www.citywalls.ru)

To assess the possibility of arrangement of a green roof on the flat roof of the laboratory study of archival documents the project with the participation of employees of the Department was carried out [14].

Figure 5.3 View of the Gidrocorpus roof

The study found that the model used in the project design, product and units of buildings and constructions series 1.462.1-1/88. Carried out in accordance with SNIP 2.01.07-85 "Loads and effects" calculation of load has shown that it can exceed 300 kg / m^2. Any possible deviations from the project, as well as defects that have arisen during the operation, were found during the examination. Given the above, it is concluded about the possibility of placing on the slab roof of the building more evenly distributed load in the range of 100 - 250 kg/m^2 [14].

5.2 Calculation of runoff from the roof of Gidrocorpus

Construction of green roofs due to their water-retaining properties will allow rational use of stormwater runoff and save on payment of his abduction in the municipal sewage system. In accordance with the "Methodology for calculation of the volume of organized and unorganized rain, melting and drainage flow in the St. Petersburg municipal sewer system," the amount of storm water discharged into the municipal sewage system is determined by the formula:

$W_r = 10 x \Psi_{av} x H_r x F$, m^3

where W_r - the volume of rainwater

Ψ_{av} - the average coefficient of rainwater

H_r - a layer of fallen precipitation during the warm period of the year

$F = \Sigma Fi$ - the total area of the territory, hectare

When calculating the value of the coefficient Ψ_{av} for roofing and asphalt concrete pavements is taken equal to 0.6, the value of Nr - equal to 468 mm and F = 0,2595 hectare. As a result, the annual volume of exhaust from the roof rainwater is 728.7 m^3. Most of this flow will be charged a green roof, and the rest of the runoff can be collected in the catchment and used in laboratories.

5.3 Types of constructions

Many foreign companies produce special materials for "green" roofs. In the Russian market there are the following companies: ZinCo (Germany), Index (Italy), Flordepot, Imperbel, and "Technonikol" (Russia) [9].

«ZinCo» Green Roofs:

The “Sedum Carpet” is a standard build-up for extensive green roofs. It is a shallow and lightweight green roof type with an attractive "back-to-nature" appearance that requires little maintenance [9].

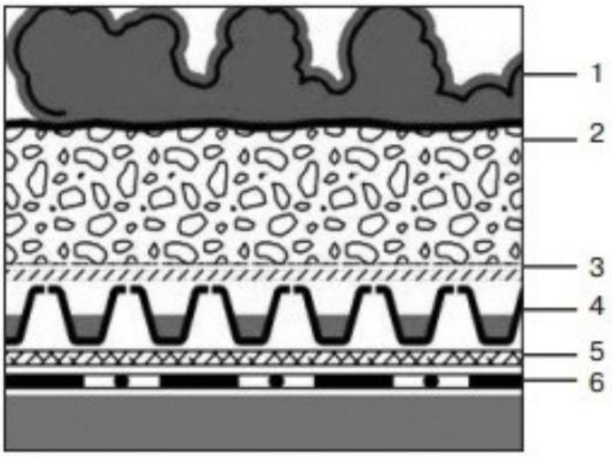

Figure 5.4 The “Sedum Carpet” (http://www.zinco-greenroof.com)

1- Sedum carpets or plug plants according to plant list “Sedum Carpet”

2- System substrate “Sedum carpet” 60 cm

3- Filter Sheet SF

4- Floradrain FD 25-E

5- Protection Mat SSM 45

6- Root Barrier WSB 100-PO [9]

Characteristics of the system:

- angle of slope 20o-100o
- height 90 mm
- water retention 32 l/m^2
- weight after moisture saturation 105 kg/m^2 [9]

Floradrain® FD 25-E is the appropriate drainage and waterstorage element for this system. It has the necessary compressive strength, a low profile height, little weight and is walkable. Proven Sedum species, in combination with the adapted substrate and system build-up, guarantee a durable green roof. The system substrate “Sedum Carpet” is particularly suitable for extensive green roofs as well as the plant community “Sedum Carpet”, containing various low-growing Sedum species that are wind- and frost-resistant [9].

The main blooming time is early summer with yellow, red and white flowers dominating. During the year, “Sedum Carpet” is represented in various shades of green. Red shades show particularly in autumn and are a nice change in the green roof´s appearance [9].

Sedum cuttings are produced by cutting off the shoot tips of selected types of Sedum. This is only possible during the non-flowering period (spring or autumn), as flowering shoots do not easily grow roots. With Sedum cuttings, good ground cover is achieved within 2–3 years. A faster ground coverage is achieved with plug planting [9].

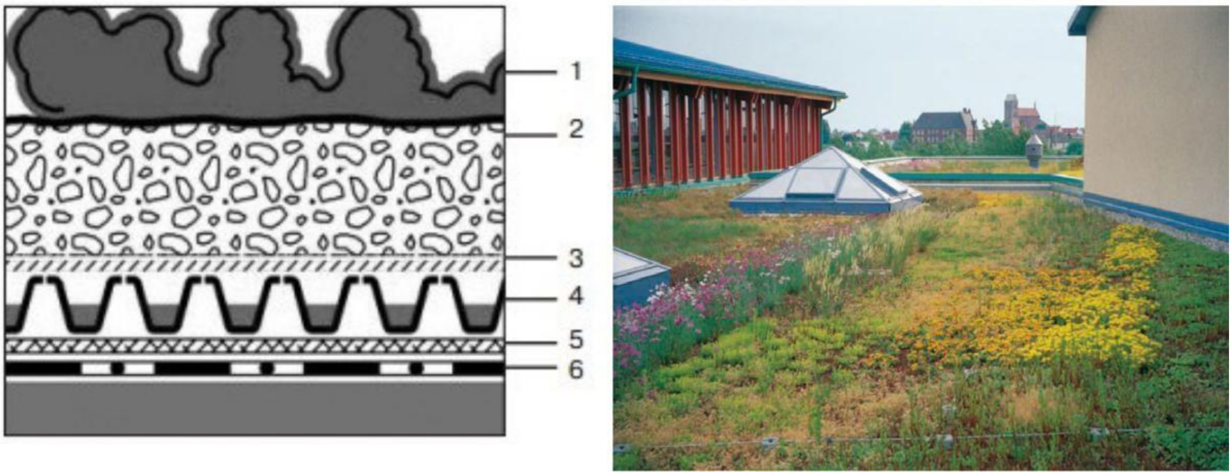

Figure 5.5 The System “Rockery Type Plants” (http://www.zinco-greenroof.com)

1- Plug plants according to plant list “Rockery Type Plants”

2- System substrate “Rockery Type Plants” 70 cm

3- Filter Sheet SF

4- Floradrain FD 25-E

5- Protection Mat SSM 45

6- Root Barrier WSB 100-PO [9]

Characteristics of the system:

- angle of slope 0o-2o
- height 115 mm
- water retention 35 l/m^2

- weight after moisture saturation 108 kg/m^2 [9]

Extensive green roofs call for plant communities that can easily deal with sun, wind and drought. The system build-up “Rockery Type Plants” leads to an extensive green roof with sophisticated design and individual character. The substrate has a minimum depth of 70 mm and the vegetation consists of various species which provide a long blooming period and set different accents throughout the vegetation period [9].

Water and nutrients are mostly supplied through natural processes. Rainfall collects in the Floradrain® storage cells and roots are provided with water through diffusion. Water is also stored in the protection mat. Excess water is drained away by the Floradrain® element [9].

Sedum species and other perennials are primarily used as a ground cover. The vegetation of “Rockery Type Plants” is obtained by root ball plants. Hand-planting ensures the design agrees with the landscaping drawings.
The system build-up “Rockery Type Plants” can also be combined with seed-sowing. Different seed mixtures, such as “Meadow Scents”, “Country Colours” and “Grassy Pasture” provide green roofs with a very attractive back to nature appearance [9].

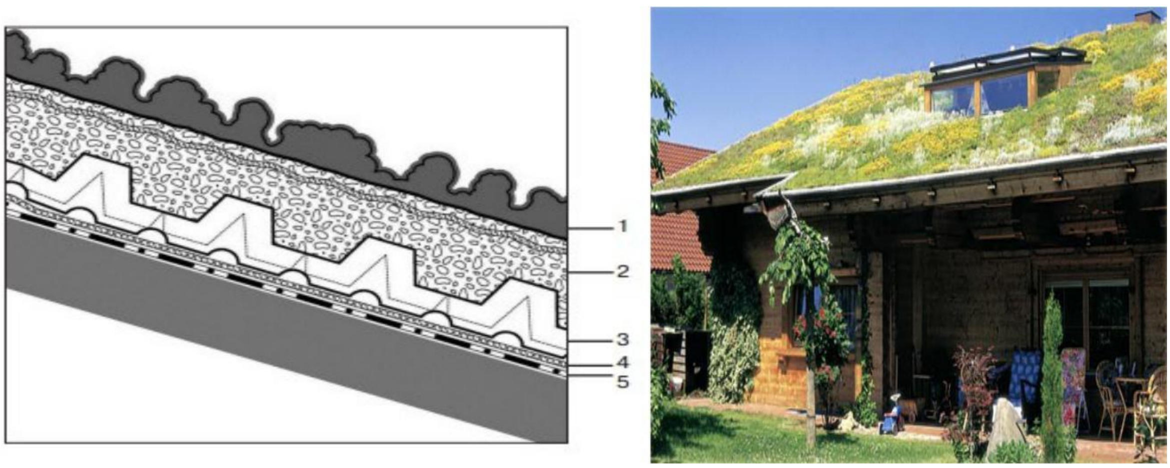

Figure 5.6 Pitched Roofs with Gradients up to 25 (http://www.zinco-greenroof.com)

1- Plug plants according to plant list "Pitched Roof"

2- System Substrate "Rockery Type Plants", from 50 mm above the Floraset® elements

3- Floraset® FS 75

4- Protection Mat BSM 64

5- A root resistant waterproofing is a precondition for a green roof; additional root barriers cannot be applied on sloped roof surfaces [9]

According to general regulations for roofs with waterproofing, flat roofs should have a fall of at least 2 %. Pitched roofs start with a slope of 10° (18 %). From 10° on, the green roof system build-up differs significantly from system build-ups below 10°. Shear forces increase with the roof slope and have to be transfered into stable beams. The substrate layer has to be protected against erosion. Plant selection and planting methods are to be adjusted to the relevant slope and exposure [9].

A professionally waterproofed roof surface, e.g. with bituminous or highpolymer membranes, is a precondition for a durable long-lasting green roof. The waterproofing should be root resistant and a protection mat with high water storage is needed. Floraset® FS 75, a multi-functional drainage element of expanded polystyrene is the perfect element for pitched green roofs [9].

It is very important to take the green roof upkeep and maintenance aspects into account from the early planning stage of the project on. Skylights can be installed as access for the maintenance personnel [9].

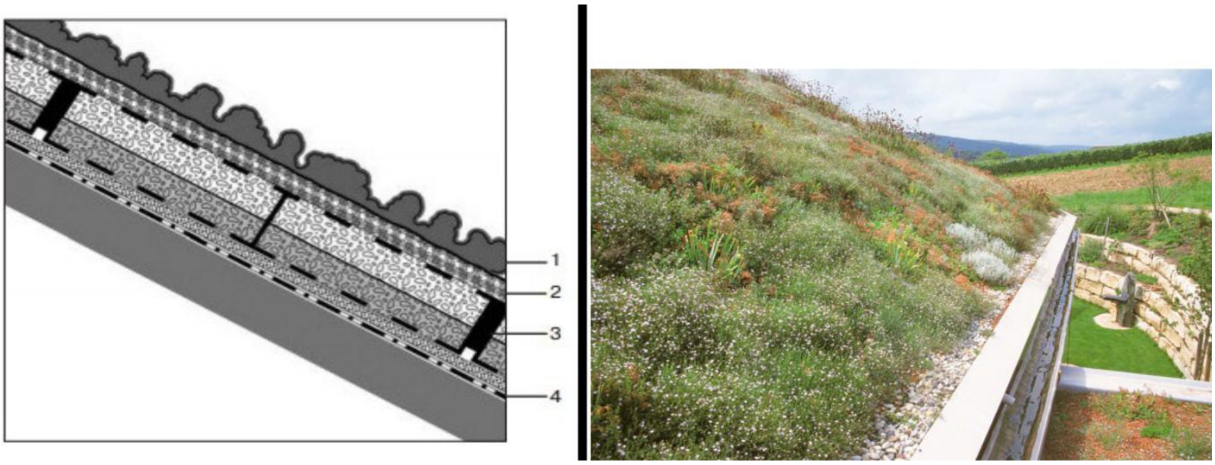

Figure 5.7 The System “Steep Pitched Green Roof” (http://www.zinco-greenroof.com)

1- Vegetation Mat “Sedum Carpet”

2- System Substrate “Heather with Lavender-light” (10 mm above Georaster®-Elements)

3- Georaster® elements

4- A roof resistant waterproofing is a precondition for a green roof; additional root barriers cannot be applied on sloped roof surfaces [9].

The system build-up “Steep Pitched Green Roof”, based on the ZinCo Georaster® elements, enables the installation of green roofs with slopes exceeding 20° and up to 35°. Above 35° special solutions can be designed by the ZinCo engineers [9].

The Georaster® elements are made of recycled polyethylene (HD-PE) and interlock without requiring tools, creating a stable structure. This structure is safely accessible and can be infilled with system substrate. The Georaster® elements cater for plenty of space for the plant root systems to establish and develop. The plant selection has to be well adapted to the extreme conditions of steep pitched green roofs, where the solar radiation is the highest on the south facing roof side and the water run off is much faster compared to a flat roof. The irrigation should be planned for, even if it is only needed in times of drought. It can avoid gaps in the vegetation coverage, which would lead to erosion. A transfer of existing shear forces into stable eaves and into additional shear barriers is necessary [9].

Georaster® elements can also be installed under reinforced lawns, footway constructions, in slope protection, etc [9].

“Bauder” Green Roofs

Extensive Green Roofs

Water retention ≥10 l/m^2:

Figure 5.8 “Bauder” extensive Green Roof
(http://www.bauder.at)

1- Vegetation
2- Substrate – minerals with an organic content 8 cm
3- Filter sheet Bauder FV (polypropylene 105 g/m^2)
4- Drainage and waterstorage element Bauder WSP 50 (expanded polystyrene, 0,6 kg/m^2, height 50 mm, waterstorage 10 l/m^2)
5- Protection Mat Bauder FSM 600 (polyester 4 mm, 600 g/m^2, waterstorage 3 l/m^2
6- Separating layer (polyethylene membrane Bauder PE 02 (0,2 mm, weight 190 g/m^2) [9]

Characteristics of the system:

- angle of slope 0º -5º
- height 13 cm
- water retention 44 l/m^2
- weight after moisture saturation 123,7 kg/m^2 [9]

Planting of large areas with Bauder SDF Mat: drainage mat and filter sheet are in one layer [9].

Figure 5.9 Bauder SDF (http://www.bauder.at)

1- Vegetation

2- Substrate – minerals with an organic content 8 cm

3- Protection, drainage and filter sheet Bauder SDF (material for drainage – polyamide, 400 g/m^2, material for protection and filter layers – polyester 200 g/m^2, thickness 20 mm, weight 600 g/m^2) [9]

Characteristics of the system:

- angle of slope 1º -5º
- height 10 cm
- water retention 32 l/m^2
- weight after moisture saturation 111,2 kg/m^2 [9]

Drainage with a big load on the surface, continuous layer under green zones and terraces:

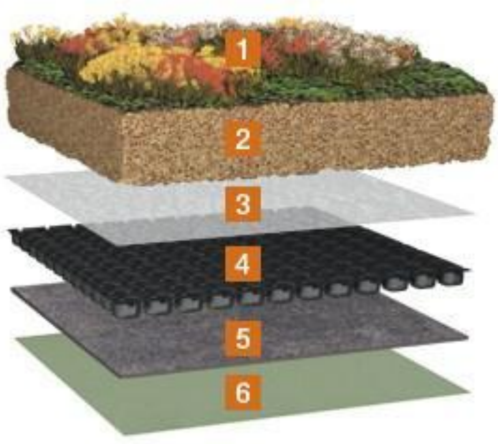

Figure 5.10 Drainage with a big load on the surface (http://www.bauder.at)

1- Vegetation

2- Substrate – minerals with an organic content 8 cm

3- Filter sheet Bauder FV (polypropylene 105 g/m^2)

4- Waterstorage element Bauder DSE 20 (HDPE, height 20 mm, weight 1,2 kg/m^2, waterstorage 7,4 l/m^2

5- Protection Mat Bauder FSM 600 (polyester 4 mm, 600 g/m^2, waterstorage 3 l/m^2

6- Separating layer (polyethylene membrane Bauder PE 02 (0,2 mm, weight 190 g/m^2) [9]

Characteristics of the system:

- angle of slope 1º -5º
- height 10 cm
- water retention 41,4 l/m^2
- weight after moisture saturation 121,1 kg/m^2 [9]

Intensive Green Roofs

The largest water retention (≥21,5 l/m^2):

Figure 5.11 “Bauder” intensive Green Roof (http://www.bauder.at)

1- Vegetation

2- Substrate – minerals with an organic content 8 cm

3- Filter sheet Bauder FV 105 (polypropylene 105 g/m^2)

4- Drainage and waterstorage element Bauder WSP 75 (expanded polystyrene, 0,95 kg/m^2, height 75 mm, waterstorage 21,5 l/m^2)

5- Protection Mat Bauder FSM 600 (polyester 4 mm, 600 g/m^2, waterstorage 3 l/m^2

6- Separating layer (polyethylene membrane Bauder PE 02 (0,2 mm, weight 190 g/m^2) [9]

Characteristics of the system:

- angle of slope 0º -5º
- height 28 cm
- water retention 117,5 l/m^2
- weight after moisture saturation 306,5 kg/m^2 [9]

Figure 5.12 Pitched Green Roof. Slope 5º - 15º: (http://www.bauder.at)

1- Vegetation

2- Substrate – minerals with an organic content 8 cm, filling into drainage element

3- Drainage and waterstorage element Bauder WSP 50 (expanded polystyrene, 0,6 kg/m^2, height 50 mm, waterstorage 10 l/m^2)

4- Protection Mat Bauder FSM 600 (polyester 4 mm, 600 g/m2, waterstorage 3 l/m^2 [9]

:

Figure 5.13 Pitched Green Roof. Slope 15º - 25º (http://www.bauder.at)

1- Vegetation

2- Substrate – minerals with an organic content 8cm, filling into drainage element

3- Shear protection – lathing.

4- Drainage and waterstorage element Bauder WSP 75 (expanded polystyrene, 0,95 kg/m^2, height 75 mm, waterstorage 21,5 l/m^2)

5- Protection Mat Bauder FSM 600 (polyester 4 mm, 600 g/m^2, waterstorage 3 l/m^2 [9]

5.4 Green Roof for Gidrocorpus

It was concluded that it is possible to place additional distributed load on the roof slab from of 100 to 250 kg/m^2, which corresponds to the technical characteristics of the main types of extensive green roofs of Bauder company.

We considered five projects offered by Bauder: 3 of extensive type (WSP 50; SDF; DSE 20), and 2 of intensive type (WSP 75; DSE 60). Based on the evaluation of the bearing capacity of the Gidrocorpus roof, the choice was made in favor of extensive landscaping, which in a water-saturated state requires the possible additional load of at least 70 kg/m^2. For projects with Intensive roof a minimum load is 300 kg/m^2, which can exceed the carrying capacity of the Gidrocorpus roof.

Choosing from 3 types of extensive green roofs, we chose SDF Mat as the most economical way. The total weight of the system after moisture saturation is 111,2 kg/m^2 (including substrate and vegetation). A total height of the superstructure above the roof surface of 100 mm, water retention ability of such green roof is 38 l/m^2, which requires minimal maintenance and no additional watering in the climatic conditions of St. Petersburg.

Fig. 5.14 SDF-Mat on the left, a project of a Gidrocorpus green roof on the right. (http://www.bauder.at)

Figure 5.14 shows a possible decision of a green roof for Gidrocorpus after reconstruction using a technology of economical extensive landscaping of the company Bauder.

Green roof on the Gidrocorpus will protect the waterproofing layer from adverse climatic effects and extend its lifecycle at least twice.
The green roof will improve the thermal and acoustic insulation of the building and will provide savings of up to 70% of the energy consumed for heating and cooling of the building. Also the green roof will improve air quality and create a new living space and habitat for birds and insects.

In each project the green roof it is necessary to balance the soil depth and density of the plants, as to create vegetation on a green roof quickly and cost effectively. Such an approach needs to be applied for reconstruction of the Gidrocorpus roof. As the vegetation for SDF-Mat, fast-growing species of sedum can be used, for example, Sedum reflexum and Sedum sexangular or drought resistant grass. Such a roof will not only have a more attractive appearance, but also have a number of practical advantages.

6 CONCLUSIONS

Construction of green roofs is becoming now one of the fastest growing areas of landscape architecture and is becoming increasingly popular in St. Petersburg and other cities of Russia. Considering the insufficient number of domestic works of green roofs in local climatic conditions, a number of environmental advantages of extensive green roofs with different types of vegetation in conditions of St. Petersburg was investigated. It was found that Russian people still do not see prospects in the construction of green roofs, the high cost of the roof also plays a role in the decision making.

The possibility of building a green roof on the Gidrokorpus was evaluated and recommendations for its installation were developed. We chose the Bauder SDF as the most suitable decision for the Gidrocorpus. As the result this decision was provided to the company Delta-t.

Building a green roof will not only bring economic benefits, enabling efficient use of stormwater runoff and save on payment of his abduction in the municipal sewage system.

Green roofs improve the thermal and acoustic insulation of the building and provide savings of up to 70% of the energy consumed for heating and cooling of buildings. They protect the waterproofing of the roof from adverse climatic influences, extending at least half of its life cycle. Their installation will improve air quality by reducing pollution, give the building a new unique view and create new living space and habitat for animals.
A construction of green roofs also brings economic benefits - it enables efficient use of stormwater runoff and saves money on abduction in the municipal sewage systems.

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