Swedish guidelines for green roofs

Short English summary
Foreword

Vinnova is a Swedish government agency working under the Ministry of Enterprise and Innovation. It is Sweden’s innovation agency, tasked with promoting sustainable growth by improving the conditions for innovation, as well as funding needs-driven research.

The purpose of this text – which is a short summary in English – is to impart knowledge about high-quality and sustainable green roofs which have zero tolerance for leaks. The summary is based upon the following three texts taken from the Vinnova project ‘Quality-assured system solutions for green installations/roofs on concrete decks with zero tolerance for leaks:’

- Statement of Work - Concrete, Insulation and Water Proofing for green areas/roofs on concrete decks (2016);
- Green Roof Handbook – plant bed and vegetation (2016);

The target audience for this text is first and foremost foreign contacts who want to know more about quality-assured system solutions for green roofs in accordance with Swedish guidelines.

This document is to be seen as a summary and a point of departure for more information. In the next stage, references and links to further and more detailed information will be added to this document on the digital learning platform www.ecourse.se/nigeriagreenroof.
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Introduction

In densely populated cities, transport and infrastructure is able to operate more effectively, and there is a greater basis for jobs, culture and a stimulating city life. One negative aspect is that not enough space is set aside for valuable recreation and green zones within the city structure. Green roofs are therefore a fundamental component of our increasingly compact cities. Plants, green surfaces and parks can be placed above infrastructure, on top of covered parking facilities or on the concrete decks of buildings. This type of space requires a more careful and considered design process than others which have direct contact with existing ground. On the one hand, it is necessary to ensure that the area does not put too much strain on the construction below, and on the other, it is important to meet the needs of the vegetation, given that vegetation upon concrete decks is more exposed than vegetation on natural ground.

In this text, the term green roof refers to superstructures for vegetation on top of concrete decks. Green roof therefore refers not just to the roofs of domestic homes, but also to terraces, courtyards and park spaces built on top of concrete decks consisting of superstructures with a plant bed.

How to read this text

The purpose of this text is to introduce and briefly discuss the fundamental principles and components that generally apply for green roofs. It considers the design process first and foremost, and secondly provides information on green roof construction and maintenance.

Because this text is comprehensive in nature, it treats the various components of a green roof as parts of a holistic system. Which functions are carried out by the various parts in the system architecture? And which things must we consider when designing a green roof?

The objective of this text is not to go into all the details. When it comes to the advantages of green roofs, for example, the text points to scientific studies within the field. When it comes to executing details or carrying out installation work, the text points to handbooks and guidelines published by industry organisations.
Extensive and intensive green roofs

The existing literature on green roofs tends to divide them into extensive and intensive facilities. This division has been traditionally based upon the level of care required. The two terms are defined in the German guidelines for green roofs (FLL) and have been largely adopted internationally, despite several ambiguities. The definitions are based on appearance and care, and not on the thickness of the plant bed, which is the most decisive factor both for the construction and for the ability of the plants to survive on the roof. This means that a plant bed that is, say, 200 mm deep, is defined as extensive if it is established as a diverse meadow area, but as intensive if it is established as a place for perennial plants.

Intensive roof plantation refers to a vegetation layer with a design and configuration that requires continuous care throughout the year in order to maintain the function of the vegetation, its layout and its species composition. Extensive roof plantation refers to a vegetation layer which only requires attention once or twice per year in order to maintain the desired function and appearance.

Two green roofs with thick plant beds in Vienna. One neat (intensive) garden (6th floor) and one garden landscape similar to an (extensive) forest biotope (5th floor) on architect F. Hundertwasser’s apartment house. © Jonatan Malmberg.

Advantages of green roofs

There are many different reasons for installing a green roof. Perhaps you want to earn points in a certification system such as BREEAM or LEED. Another reason might be that the green roof can provide functions and services that will benefit the property owner, residents or community in the form of so called ecosystem services.

A number of advantages relating to green roofs are listed below. Some of the advantages apply to all kinds of green roofs, while others are more or less case-specific depending on the roof’s surrounding environmental factors and the system architecture and vegetation that are chosen.

Stormwater management

Planting vegetation on the roof means that a good deal of rain water will be taken up by the plants and substrate, and this will then be later evaporated back into the atmosphere. This helps to delay the flow of stormwater and reduces the strain placed on the city’s stormwater management system. Different

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types of green roofs have varying capacities for delay. A number of studies show that green roofs can reduce annual runoff by 40-90%, depending on the substrate depth, and that they can delay the flow of stormwater by up to 30 minutes.

**Mitigation of the Urban Heat Island effect**
Evapotranspiration from green roofs provides a cooling effect which mitigates the heat-absorbing (and reflecting) effect of non-green, hardened surfaces responsible for higher temperatures in urban areas – the so called Urban Heat Island effect. By returning moisture to the surrounding environment through evaporation, green roof surfaces are able to reduce the solar heat load. In addition, the surface of the vegetation reflects more sunlight than standard roof formations, which also contributes towards a cooling effect.

**Biodiversity**
Installing green roofs can equate to the reconstruction of surfaces for local plants which had previously disappeared as a result of dense urban development. The roofs can also function as new habitats if these kinds of previously disappeared plants are selected. In addition, green roofs positively affect beneficial insects such as pollinating bumblebees, bees and butterflies.

**Sound absorption**
Green roofs can absorb sound and contribute towards the overall reduction of noise pollution from the city environment.

**Reduction of need for air conditioning in warm climates**
Together with the increase in thermal mass provided by the substrate structure, the cooling effect of evaporation provided by green roofs can in some cases result in a reduced need for air conditioning inside buildings, which in turn results in lower emissions of carbon dioxide from the energy source. This advantage applies mostly to warmer climate zones.

**Improved well-being**
Green spaces have a positive effect on public health and well-being. If designed correctly, green roofs can even serve as valuable recreation spaces, which means that they perform a social function.

With regards to ecosystem services, it is fundamental that the configuration and design are able to exert control over the extent to which the space is able to provide ecosystem services. Some ecosystem services, such as the reduction of stormwater runoff, for example, are common to all green roofs. Other ecosystem services, such as those related to recreation, health or biodiversity, are dependent upon the design of the space.
Environmental Certification Systems

LEED and BREEAM are internationally acknowledged certification systems for sustainable planning and building.

LEED (Leadership in Energy and Environmental Design) is an American environmental certification system for buildings which was launched in the beginning of the 1990s. LEED certification is focused on the reduced usage of resources such as ground surface, water, energy and building materials.

BREEAM (Building Research Establishment Environmental Assessment Method) is an environmental certification system for buildings that was developed in the UK in the beginning of the 1990s. BREEAM is the most widespread international system in Europe. In Sweden, the Sweden Green Building Council has adapted BREEAM to Swedish conditions, BREEAM-SE.

Planning a green roof; choice follows purpose

Goal and vision

Information and communication are decisive factors for a successful green roof, but above all, it is important to have a clear idea about what you want from the roof when it comes to appearance, social environment and/or ecological function. A roof that is installed primarily to deal with stormwater, for
example, may look considerably different compared with one that functions as a common space for the residents of an apartment building. In order to achieve a successful result, it is necessary to discuss which values are desired from the green roof, what level and scope of care is expected, and how it is envisioned that the space will be used.

The choice of vegetation will determine the requirements for all underlying layers, such as the plant bed, drainage layer, waterproofing membrane, insulation and concrete deck. It will also have implications for the level of care required. If the choice of vegetation means that it will not be possible to meet any of the requirements placed on the underlying layer or on the supporting, then it is necessary to re-think either the design or the goal.

An example of a roof design in which choice of plants and material follows the purpose of a visual-aesthetic appeal.

**Loading capacity**

The loading capacity of the roof needs to be calculated both upon the installation of a new green roof and also when a green roof is built onto an existing surface. In addition to the load from the substrate of the superstructure, the roof will require the capacity to support a number of additional loads such as wind and snow loads and loads from people who are on the roof temporarily (e.g. when carrying out maintenance work on extensive green roofs, or when using an intensive green roof for recreation). It is important to consider that different vegetation layers require different structures, which in turn results in different load conditions with different loading capacity requirements, see table 1.

When calculating the load of a green roof, it is important to always include the weight of the superstructure, including the substrate when water-saturated in addition to other materials, such as the
water-saturated drainage layer and the plants. A green roof with a 100 mm superstructure could weigh around 100 kg per square meter when dry, but up to as much as 130 kg when saturated with water.

### Table 1. Examples of field loads, weights of substrate and vegetation on the joists.

<table>
<thead>
<tr>
<th>Vegetation</th>
<th>Substrate depth [mm]</th>
<th>Weight of substrate [kg/m²]</th>
<th>Weight of vegetation [kg/m²]</th>
<th>Total weight plant bed [kN/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedum/moss</td>
<td>30 – 80</td>
<td>40 – 120</td>
<td>10</td>
<td>0,5 – 1,3</td>
</tr>
<tr>
<td>Sedum/herb</td>
<td>80 – 120</td>
<td>80 – 240</td>
<td>10</td>
<td>0,9 – 2,5</td>
</tr>
<tr>
<td>Lawn, meadow, perennials</td>
<td>120 – 350</td>
<td>120 – 700</td>
<td>5 – 15</td>
<td>1,3 – 7,2</td>
</tr>
<tr>
<td>Small shrubs and perennials</td>
<td>300 – 600</td>
<td>300 – 1200</td>
<td>20 – 30</td>
<td>3,2 – 12,3</td>
</tr>
<tr>
<td>Large shrubs and small trees</td>
<td>600 – 1500</td>
<td>600 – 3000</td>
<td>40 – 60</td>
<td>6,4 – 30,6</td>
</tr>
<tr>
<td>Larger trees</td>
<td>1000 – 2000</td>
<td>1000 – 4000</td>
<td>150</td>
<td>10,2 – 40,2</td>
</tr>
</tbody>
</table>

A load limitation plan should be developed at the design and planning stage. In addition to loads from the substrate of the superstructure, the vegetation, and wind, rain and snow loads, the following loads should also be considered at this stage:

- Temporary storage of materials (such as pallets with substrate and sedum mats) on the concrete deck during the installation phase. When materials are being stored on the concrete deck during installation, it is important to remember that the weight of the materials can greatly increase the load on the part of the roof where they are stored. It may be necessary to spread the weight by distributing the load from the materials across the roof.
- Temporary and local loads from machines and other equipment used for maintenance or for recreation.
- Working loads. Human activity on the roof and loose fittings (e.g. structural elements such as dead wood, stones, etc.) are examples of working loads that need to be considered with reference to the intended use of the roofs.

### Slope

The concrete deck should always have a sufficiently good slope. This can be attained via casting in place or by mounting a concrete element with a slope. Another alternative is to build in a fall using insulation or to create a fall by adjusting the concrete or mastic asphalt roofing. A decline of 1:50 (2%) is required to ensure good water runoff.

The slope of the roof is a key factor when it comes to the selection and establishment of plant material. On roofs with a slope of more than 10°, the vegetation system may be at risk of sliding out of place. This is the case both when using vegetation blankets and also for originally-sown roofs. It is also important to consider friction between all the layers in the structure, e.g. the waterproofing layer should have a granulated surface in steep installations to prevent the lower layer from sliding away; e.g. blanket, lining or root barrier.
Originally-sown green roofs should have a slope that is no greater than 15°. Larger slopes entail the risk of erosion problems during the first growing season, whenever large surfaces and gaps are not yet covered by vegetation. It is important to note, however, that erosion problems can occur even on lower slopes for different reasons, such as poor roof drainage or as a result of the substrate’s properties. For example, light substrate material might move on the surface layer of the plant bed during heavy rainfall.

Vegetation blankets can be fitted onto relatively steep slopes. There is little risk of erosion up to 20°. For green installations on roofs with a slope of more than 20°, pre-cultivated vegetation blankets with additional reinforcement are recommended.

Steeper slopes result in drier conditions, which can cause even succulent plants to dry out and die in the thinnest of structures. This can cause erosion problems. The problem can be mitigated by using different kinds of terracing systems, such as placing cartridges filled with substrate underneath the vegetation blankets. Cartridges provide space for the plant roots, keep the substrate in place and increase the stability of the plant bed. The maximum slope for vegetation blankets is 35°, depending on the system used.

An example of erosion control.

Fire Safety

According to the building regulations published by the Swedish National Board of Housing, Building and Planning, buildings and green roofs should be designed so that they impede the spreading of fire. This includes protection against spotting (fires spread by embers carried by the wind), etc. The requirements placed on the superstructure above the waterproofing/sealing layer are different depending on whether the underlying material is combustible or not.

In Sweden, fire safety requirements for roofs are regulated by the classification standard EN 13501-5 and by fire classification Broof(t2). During the fire classification process, spotting from a burning
building is simulated. The test is passed if there is no continued fire spreading in the roof covering or in its underlying layers.

According to FLL\textsuperscript{2} and Gro Code\textsuperscript{3}, the fire risk for green roofs is primarily related to the nature of the vegetation and the amount of organic content in the substrate. For park-like green roofs with greater substrate depths, the risk of fire is not considered to be a serious problem because irrigation is available.

Because of the fire risk associated with dry substrate that is rich in humus, FFL has set an upper limit for the organic material content at 65 g per litre, which equates to around 20\% of the total volume (Gro Code) or 4-6\% of the total weight.

**Dewatering**

Roofs and spaces where green superstructures will be installed should be designed with regards to the dimensioning rainfall volume and should include infrastructure for dewatering and drainage. The possibility to store rainwater could eventually also be utilised.

A plan which indicates the dewatering devices for the roof should be drawn up for each object. The dewatering plan should show the roof slope and inlet level, the placement of outlets and any spillways in addition to other dewatering components. Drainage gutters should be designed so that the water will be able to flow down to the next outlet if the preceding one becomes blocked in a way that prevents the build-up of water on the concrete deck.

Gutter outlets and spillways may not be covered by greenery or loose materials, such as gravel. The outlets must be designed in a way that ensures constant accessibility. Plants must not be able to grow into the gutter outlets and thereby prevent them from functioning correctly.

Dewatering comes into function mainly during heavy rainfall, and serves to divert excess water away from the roof construction and drainage. Ineffective dewatering means that water will remain standing on the roof, which results in an increased load and entails an unnecessary risk of leakage. In addition, standing water has a negative effect on the vegetation and entails a risk of erosion. However, in some cases it may be desirable to consciously delay dewatering in order to create a larger reservoir, to delay stormwater or to increase the cooling effect.

For dewatering to function properly, it is important that the dewatering channels and low points are planned and designed correctly.

Green superstructures are often used to reduce runoff from the concrete deck. The extent to which the superstructure impacts the runoff rate can be expressed as a runoff co-efficient ($\phi$), see table 2. The runoff co-efficient indicates what proportion of dimensioning rainfall volume\textsuperscript{4} will run off. A $\phi$ of 0.1 indicates that 10\% of the downfall will run off.


\textsuperscript{3} Gro Code, *Green Roof Code of Best Practice for the UK*, 2011.

\textsuperscript{4} A dimensioning rainfall volume in Sweden is often calculated as a 10 year frequency, i.e. has a probable return of one time per every ten years, with a duration of ten minutes. In Stockholm a dimensioning rainfall volume means a flow of 227 l/s and hectare.
Table 2. Runoff from green roof during heavy rainfall\textsuperscript{5} for various superstructure depths. The table is taken from the German guidelines for green roofs (FLL).

<table>
<thead>
<tr>
<th>Depth</th>
<th>15\textdegree slope Runoff co-efficient (φ)</th>
<th>&gt;15\textdegree slope Runoff co-efficient (φ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;500 mm</td>
<td>0.1</td>
<td>-</td>
</tr>
<tr>
<td>250-500 mm</td>
<td>0.2</td>
<td>-</td>
</tr>
<tr>
<td>150-250 mm</td>
<td>0.3</td>
<td>-</td>
</tr>
<tr>
<td>100-150 mm</td>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td>60-100 mm</td>
<td>0.5</td>
<td>0.6</td>
</tr>
<tr>
<td>40-60 mm</td>
<td>0.6</td>
<td>0.7</td>
</tr>
<tr>
<td>20-40 mm</td>
<td>0.7</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Table 2 also shows that the slope of the roof has a significant bearing on runoff.

The precise composition of the superstructure also determine what proportion of the rainfall will run off, considering that the drainage layer and filter layer (geotextiles) cause runoff to happen more slowly.

A summary of data from studies which have carefully investigated the extent to which green roofs can reduce stormwater runoff indicates a 30 – 86% reduction of annual runoff and a 22 – 93% reduction of the peak flow rate. They also indicate a delay of the peak flow of up to 30 minutes.\textsuperscript{6}

**Irrigation**

A lack of water leads to drought stress in the plants, which in turn reduces the rate of growth and has an impact on appearance and survival. The ability of the vegetation to endure periods without water and to recover following rain or irrigation varies depending on the species.

Replacing materials that have dried out is both costly and time-consuming. It is therefore particularly important to have an irrigation system in place if sensitive plant materials are being used, or if the plant bed does not have the capacity to ensure survival during longer periods without water. Dry and dead vegetation can entail a fire risk and should be removed. Abstaining from irrigation entirely entails risk, as supplementary irrigation may be required during dry, warm and windy periods, especially in the establishment phase. Access to water should therefore be guaranteed at all the times. The extent to which irrigation will be required should then be further considered with regards to the following:

- The vegetation’s water requirement
- The plant bed’s water-retaining ability
- The water-retaining capacity of the drainage mat
- Moisture-retaining layer
- Rainfall patterns

\textsuperscript{5} A dimensioning rainfall volume of 300 l/s and hectare according to FLL.
Plant analysis

Zoning the plants in accordance with their rate of water consumption and tolerance for drought is one way to optimise irrigation and to ensure a beautiful appearance for the vegetation.

The need for irrigation varies depending on the rate of growth and appearance of the plants, and most plants will also overconsume water if it is available. The need for water is generally highest for lawns where it is necessary to supply the grass with 80% of its potential evapotranspiration. Trees and bushes can survive with around 20 – 30% less water. When it comes to green roofs, it is a good idea to select plants that maintain a good appearance even when they are subjected to dry periods without water.

In principle, the need for irrigation makes up the difference between rainfall and the vegetation’s consumption, with the plant bed’s reservoir acting as a buffer. The buffer determines how long the vegetation will be able to survive without irrigation. Rainfall varies across different areas within the same country or region, and the need for irrigation will therefore vary as well.

Irrigation systems available on the market include hose irrigation, sprinklers, drip irrigation (above or under the ground) and automated systems. Porous soils are often used for green roofs, and so drip irrigation does not provide water to as large an area around the hose as it does for plant beds on the ground. Sprinkler irrigation, on the other hand, often entails a significant loss of water through evaporation and is not as resource effective. If sprinkler irrigation is used, this should be carried out in the morning in order to reduce water loss.

The results of a test of different irrigation programs are shown in the figure below.

![Results following a dry period with 1) sprinkler irrigation, 2) drip irrigation, 3) underground drip irrigation 4) no irrigation.](image)

Climate factors

Climate factors vary according to geographic location, and are also influenced by factors such as micro-climate and building design, in addition to other buildings in the vicinity. Plant selection therefore needs to be adapted for the prevailing conditions with regards to:

- Wind;
- Rainfall and need for irrigation;
- Sunlight and shading effects;
- Temperature and climate zone;
- Micro-climate;

The micro-climate of a green roof can be influenced by a range of factors such as sunlight, shading, rain shadow, local wind conditions, reflection from glass partitions and exhaust air from ventilation systems.
Landscape Analysis

Vegetation in the vicinity can influence the development of the green roof and the selection of plants. For example, plants might be selected in order to replace/compensate for existing vegetation. The green roof may also be affected by the surrounding area if there is a risk of pollen/seeds being spread, which can lead to weeds or unwanted plants growing on the green superstructure, resulting in an unwanted fire risk or the risk of roots penetrating the waterproofing membrane.

Carrying out a landscape analysis during the design and planning phase can help to survey and identify vegetation in the vicinity that is either suitable for the green roof or unwanted on the roof.

Components of the green roof

Vegetation

Generally speaking, the range of vegetation choice gets broader with increasing substrate depth. Substrate depth and type should be planned in accordance with your goals for the roof and the vegetation selected.

Plant beds on a green roof are often thin, which results in lower water and air contents compared with plant beds on natural ground. Plants on roofs are often subjected to higher degrees of wind and sunlight than plants on ground surfaces, which also means that they will experience drier conditions during the growth period. This of course varies from place to place, and some roofs can be quite well protected.

It is above all the substrate depth and quality that will determine which plants will be able to survive on the green roof. For thin roof landscapes with an extensive care level, even small differences in substrate depth can have an effect on the composition of the vegetation and on which plants and species will be able to survive.
The properties and nature of the plants

It is necessary to make intelligent choices regarding the plants and their adaptation abilities in order to ensure that they will be able to survive the often dry and windy conditions of the roof environment, either with or without economic irrigation. Looking around for natural systems when selecting plants is a good place to start.

It is also necessary to consider the slope of the roof and its compass direction. Substrate on a sloping roof generally dries out more quickly than it does on a flat roof because the slope increases runoff, and sloping roofs will catch more sunlight if they are facing southwards.

There are a range of morphological adaptions which help certain plants to survive in dry environments. Different types of plants have different mechanisms for surviving dry periods:

- The most common method of adaptation is the one used by succulent plants, i.e. storing water in leaves and parts of the stem. It is generally necessary to use plants with this method of adaptation on very thin substrates, as it is the only kind that will survive at all. Succulent plants include orpines and they belong to genera such as Sedum and Phedimus.
- Plants with a tight cushion shape or tough retracted rosettes also fare well in dry conditions as these plant formations do not give off much evaporation and are able to protect the plant quite well from the sun. Other adaptive features that perform the same function include tough leaves and a light leaf colour.
- Many drought-resistant plants adapt to dry conditions by using large and effective root systems to increase their water uptake volume.
- An alternative way for plants to survive dry conditions is to enter into a state of hibernation during unfavourable dry conditions. This is common in plants from regions which experience distinct seasonal variations between dry seasons and rainy seasons.
- Another way to ensure that your green roof will survive dry periods is to use plants from the Allium genus. Allium plants survive well on green roofs as they are able to make use of water
when it is available in the spring and then continue to thrive during dry conditions in the summer. There are many types of allium which can grow and bloom in soil that is both dry and lacking in nutrients.

- Early-flowering annuals can survive over summer on green roofs by releasing their seeds early in the spring.

Sedum cuttings

The range of choice for green roofs is greater for plant beds with a thickness of around 100 mm and up, provided that the green roof is not intended for recreation (it will not be stepped on).

It is possible to establish park and tree systems on roofs, but this requires a building with a high loading capacity that can support a substrate depth of more than 600 mm. For larger trees, a substrate depth of 1,000 mm or more is preferred, and it may be necessary for the tree’s roots to spread out horizontally.

Plant choice based on function

It is possible to optimise the function of the green roof by selecting the right plants:

**Plant choice for recreation or specific aesthetic value.**

Roofs that will be used for recreation or as social spaces and/or which have a clear design concept often require the same level of care as regular gardens. Lawns are often used for green roofs with recreation spaces. In order to achieve a good quality lawn, the single most important factor is substrate type and depth. As a general rule, lawns require irrigation and a substrate that is compatible with the chosen irrigation system. Thin plant beds result in lawns that are more sensitive to wear.
A garden-like superstructure.

**Plant choice for ecological compensation and biodiversity.**

Ecological compensation is a way of making up for the loss of natural value as a result of human activity. The first principle of development should always be to try and avoid causing damage altogether, but if this is deemed to be an unreasonable requirement, then compensation measures can be used as a last resort. On the one hand, compensation can consist of restoring that which has been lost, or on the other hand, it can consist of creating environmental value and/or ecological functions in connection with the new construction.

Specially designed roofs that are adapted to locally present biotopes can form part of a compensation effort. However, note that green roofs cannot fully replace ground environments when it comes to the various ecosystem services that a habitat on the ground can offer. This is the because they cannot replicate the ground’s soil composition, microlife and hydrology. Conditions on the roof are different to those on the ground.

**Plant choice for urban climates and the reduction of stormwater.**

Green surfaces covered in vegetation help create a positive city climate by increasing moisture in the air and reducing temperatures, in addition to other things. All surfaces covered in vegetation profoundly impact upon the water and temperature balance in the urban area. Green roofs impact the city temperature predominantly through the combined effect of evaporation and transpiration (commonly referred to as evapotranspiration), and also by reflecting sunlight.

Benefits to the local disposal of stormwater has been one of the main arguments in favour of using green roofs in Sweden. The vegetation-covered roofs are able to reduce annual runoff from stormwater. They also have a significant impact on the runoff peak flow rate. The thickness of the structure is the most decisive factor when it comes to reducing runoff, although plant choice can also play a role here. If you desire vegetation which has a maximal effect on the urban water balance and which considerably helps to reduce the city temperature, then you should select plants with high evapotranspiration rates.
Establishment of plant material

Establishment can take place on site using sedum cuttings, plug seedlings, pot plants and seeding. In Europe, pre-cultivated vegetation blankets are common, but establishing on the roof by planting seeds can work just as well.

Establishment by planting seeds.
Plug seedlings prior to establishment on a roof.

Substrate

The substrate makes up the plant bed. It anchors the vegetation and provides moisture and nutrients. It is important for the substrate to contain enough air, even during periods of heavy rainfall. In addition, the substrate should not be too heavy, as it is a significant factor that impacts the load of the superstructure.

Air, water and solid material

Plant beds consist of three components: water, air and solid material. The solid material makes up the skeleton of the substrate and determines the size and shape of the pores based on particle size and composition. The pore system of the plant bed consists of the total space between the particles and within the particles (e.g. in pumice-stone). Plant beds should ideally be around 50 % pores which in turn should be filled 50 % with water and 50 % with air, see the figure below.
Optimal distribution between soil, water and air in the plant bed. The size of the pores determines how much water the plant bed can contain. Small pores hold water better than larger pores, while larger pores are better at holding air.

In addition to its ability to retain water and air, the permeability and nutrient content of the plant bed are also important properties.

Permeability refers to the extent to which water is able to move freely throughout the superstructure. This quality is important as many varieties of plants cannot tolerate standing water, and because standing water increases the load on the supporting construction.

When it comes to nutrient content, balance is desired as this will facilitate good establishment of the vegetation without resulting in nutrient leakage. For many thin types of green roofs, such as biodiverse roofs and those with meadow vegetation, a low nutrient content is preferred.

There are various methods which can be used to analyse and test the properties of a substrate. A discussion of these methods is beyond the scope of this text, however.

The thickness of the superstructure is often limited by the concrete deck, in part because of loading limitations and in part because of determined elevations for doorways and windows. It is therefore rarely appropriate to use normal plant soil on top of the concrete deck as it retains too much water at a restricted depth on top of the superstructure. By using supplementary materials in the substrate, these qualities can be altered in order to increase or decrease the ability of the substrate to retain water and air, or to make it more or less permeable. Supplementary materials also affect the load of the substrate.

Supplementary material, soil and organic material

The main components in a substrate include supplementary materials (crushed brick, pumice-stone, scoria, zeolite, biochar, leca), soil (gravel, silt, sand and clay) and organic material (compost, peat, coir fibre, etc.).

Examples of components in a substrate. From left to right, sand, compost, pumice-stone and crushed brick.
Supplementary materials should supply the properties that natural soil is lacking. The right use of supplementary material can increase both the capacity for water retention and the permeability as well. The purpose of supplementary material is to reduce the load by increasing porousness and therefore reducing weight. Really good supplementary materials can even hold a good deal of water within their internal pores, and thereby increase the total water reserve of the substrate. Examples of supplementary materials include volcanic rocks such as pumice-stone and scoria, in addition to other materials including leca, crushed brick, expanded shale and biochar.

As a general rule, supplementary materials should be free from concrete residues.

There is a huge difference between various types of soil, but the common denominator is that they all come from the same loose part of the earth’s crust, and so all contain varying amounts of clay, silt and sand. The quality is often determined by a particle size distribution curve which shows the content of the various fractions. The quality is determined by the content of the ingoing fractions. If slit or clay dominate, for example, the soil will retain moisture, whereas if sand dominates, it will be dry.

Organic material contains good nutrients and has a good ability for water-retention. Depending on its origin, it may also contain nutrients that are released during decomposition. One example of an organic material that can be rich in nutrients is compost. On the other hand, peat - another organic material – is very poor in nutrients and can have different qualities depending on the degree of humification (decomposition).

The substrate should not have an overly high level of organic matter content, as this presents a risk of subsidence when the material breaks down and also entails an additional fire risk. An overly high level of organic material content can even lead to undesired plant development.

The suitability of a substrate depends on the function and vegetation planned for the green roof. For a successful substrate, it is recommended that the above mentioned key characteristics and key ingredients of a substrate are tested and quality-approved.

Substrate depth

The substrate depth (the depth of the plant bed) is determined by the amount of volume needed for the roots of the vegetation, the composition of the substrate and its water and air retaining capacity in addition to the loading capacity of the concrete deck. The substrate acts as an anchor for trees and bushes and should be able to provide them with water, air and nutrients. The needs of the vegetation often conflict with what the floor structure can tolerate, which can lead to an inadequate plant bed that requires a great deal of attention. This can be mitigated to an extent by using a better substrate with special supplementary material such as pumice-stone. Using common plant soils is almost never an option on concrete decks, given that it is not possible to build plant beds that are sufficiently thick. If the construction height is limited, porous supplementary material is required in order to make the plant bed lighter and/or to provide adequate air and water-retaining qualities.

The substrate depths recommended by FLL for various types of vegetation are given in table 3. It is important to remember that the choice of substrate also influences the optimal substrate depth and that ordinary ground soil without supplementary materials should never be used for superstructures that are less than 700 mm.

Table 3. Recommended substrate depth for different types of vegetation according to FLL (mm).
Consider that in thin plant beds, every last centimetre has a significant impact on the qualities of the plant bed and the development and survival of the vegetation.

**Moisture-holding layer**

It is important that there is water in the plant bed in order to ensure that the plants are able to transpire. The amount of water that the plant bed can hold depends on the moisture-holding ability of the substrate and its distance from the drainage layer. Table 4 indicates the estimated water reserve for plant beds, at drainage equilibrium, with different types of materials and at varying distances from the drainage.

**Table 4. Water available to plants at drainage equilibrium for a number of plant beds with different substrates and distances from the drainage. Values given indicate the difference between substrate depths and should not be used for new designs.**

<table>
<thead>
<tr>
<th>Soil type/substrate type</th>
<th>Water available to plants (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Substrate depth (mm)</strong></td>
<td><strong>500</strong></td>
</tr>
<tr>
<td>Clayey sand</td>
<td>170</td>
</tr>
<tr>
<td>Silty sand- Sand</td>
<td>120</td>
</tr>
<tr>
<td>Clay loam</td>
<td>110</td>
</tr>
<tr>
<td>Coarse sand</td>
<td>190</td>
</tr>
<tr>
<td>Pumice-stone soil</td>
<td>170</td>
</tr>
<tr>
<td>(pure pumice-stone)</td>
<td></td>
</tr>
<tr>
<td>Pumice-stone mixed with sand</td>
<td>250</td>
</tr>
<tr>
<td>(pure pumice-stone)</td>
<td></td>
</tr>
</tbody>
</table>

A moisture-holding effect can be maintained in the structure via substrate choice, filter cloths, geotextiles, stone wool insulation mats, certain drainage mats and vegetation. In certain cases, it may be necessary to strike a balance between the need to retain water, the load placed on the concrete deck and the needs/tolerance of the vegetation.

It is important to use stable materials with documented qualities. The supplier should also be able to provide information regarding how much water will be retained. Note that a good moisture-holding ability often correlates with a poor ability to retain air. The plant bed above the moisture-holding layer
should therefore be able to meet the vegetation’s need for air. This can be achieved by carefully considering the structure of the plant bed.

Drainage layer

The purpose of the drainage layer is to remove excess water from the roof. Puddles of water equate to an extra weight and also reduce the level of oxygen in the plant bed. The choice of drainage depends on factors such as the size of the roof, its slope, the positioning of downpipes, the qualities of the substrate and the planned vegetation. It is also important to consider logistic and economic factors when selecting a drainage system. The drainage layer is usually installed between the substrate and the waterproofing membrane and consists either of drainage mats or of another drainage material.

Drainage layers must include a capillary break, i.e. it should not be possible for water to be transported via capillaries to the layer above. To achieve this, the layer should have a thickness which is greater than the material’s upper capillary rise height. In addition, the smallest pore in the material must be larger than the largest pore in the plant bed above.

Drainage mats are the most effective way to establish a capillary break at a limited construction height and load. Drainage mats are made from a plastic material and look like egg cartons in appearance. The basic principle is to create a space for the free flow of water away from the roof and to raise the substrate away from any uneven parts of the roof where water has accumulated. Many drainage mats perform a dual function in that they both allow for the transport of water away from plant bed while they also store water within the system.

Different types of drainage mats, (to the left) system with high loading capacity and moderate water-storing capacity; (to the right) drainage mat with drainage function only.

Drainage material can also consist of, for example, gravel, pumice-stone, leca, bricks or glass foam. No matter what material is chosen, the most important quality to consider is that the drainage material must contribute towards the creation of a capillary break.

Filter layer and protection blanket

Geotextiles are permeable textiles used both to protect the waterproofing membrane and/or root barrier from physical strain and mechanical damage, and to separate different types of material within the superstructure. Geotextiles consist of a woven cloth or blanket made from polyester or polypropylene.
Geotextiles are often used to separate the plant bed and the drainage layer. Geotextile reduces loss of small particles and reduces the risk of clogging within the drainage system.

Geotextiles used to protect root barriers and/or waterproofing membranes should have a minimum weight of ≥ 300 g/m². Protective layers for the waterproofing membrane and/or root barrier are used for protection both during the construction stage and also throughout the lifetime of the roof. Geotextiles can protect against any strains brought about by building work during the construction phase. Throughout the lifetime of the roof, the geotextile can protect against mechanical wear from thick roots during windy conditions, and from foundations and fixings, in addition to other things.

Root protection

Plant roots naturally seek after access to water, and many failed attempts at installing green roofs have been the result of roots puncturing the waterproofing membrane and penetrating down through seams, edges and connecting points. Root protection is therefore needed for most green roofs (with the exception of superstructures with a substrate depth of less than 50 mm, for which root protection is not normally used in accordance with Swedish praxis). It is very important to protect the waterproofing membrane from penetrating plant roots.

Root protection can be applied in several ways;

1. integrated in a waterproofing membrane, for example root resistant bitumen- or EPDM-based waterproofing products;
2. laid as a separate layer, for example polymer-based sheets such PVC, PE or TPO or bitumen-based mastic asphalt.
3. applied as a chemical barrier, for example Preventol® or Herbitect®.

There is a range of different products available on the market, so it is important to gather information from suppliers and independent organisations about the product’s effect and previous test results. Many products have been tested by FLL and are therefore demonstrably suitable for use in green roof systems.

Some important things to consider:

- Root protection is not permeable and so should not be placed above a drainage mat or drainage layer. As with waterproofing membranes, root barriers need to be protected from mechanical damage during installation, establishment and when undergoing subsequent maintenance. For this reason, a protective textile is usually placed over the root barrier before the drainage layer and substrate are installed.
- When the root protection is installed, either as a separate layer or as a component in the waterproofing membrane, it is important to ensure that edges and seams overlap each other in accordance with the supplier’s instructions. All seams should be glued or welded together.
- In some cases, root protection can be chemical, and may be poisonous to the plant roots. The reason for using herbicides is to prevent the roots from penetrating through the waterproofing membrane, particularly at the seams. Roots which come into contact with chemically active root protection absorb the substance only in small amounts, which stops the roots from growing further. That the herbicides do not leak out should be documented for all types of chemical protection. In Europe, there are on-going discussions at the moment concerning the use of chemical root protection following observed cases where the substance has leaked out.
- Rhizomes are not roots, but more aggressive underground stems which are not affected by chemical root protection in the same way as regular roots. Some examples of plants with
rhizomes include Bamboo and wheatgrass. Lists of plants that fall under the rhizome category can be found in both the Swedish and German green roof handbooks. The plants included in these lists are not suitable for green roofs.

- Concrete should not be considered waterproof and should not be used as root protection in green roof installations. Concrete protects against wear from roots but does not prevent them from penetrating through and eventually damaging the underlying sealing layer.

Waterproofing membrane

It is incredibly important to make sure that leakage does not occur at all during the lifetime of the green installation. Green roofs which leak can be very expensive to repair, and we therefore want to avoid this.

Green roofs on buildings or constructions must be put together from scratch and be completely watertight. For this reason, a waterproofing system, which protects the underlying construction from moisture and flooding, is generally installed above the concrete deck.

Details, and the way in which these are installed onto the roof’s surface, are crucial for attaining a successful end result and for the lifetime of the construction. Details should be chosen, installed and maintained so that it is impossible for leakage to occur at their connections throughout the lifetime of the construction.

Moisture damage as a result of leaks from green roofs is usually caused by one of the following:

- The waterproofing membrane has been compromised as a result of movement in the protective concrete;
- The waterproofing membrane has been damaged when being pulled up against neighbouring walls;
- Improper installation of expansion joints;
- Improper installation of connections and penetrations;
- Damage caused during construction, especially to the waterproofing or soft insulation.

Material Requirements

All materials used must meet the requirements set out by REACH (Registration, Evaluation, Authorisation and restriction of Chemicals). REACH is a regulation that came into force on June 1st 2007 and which applies to the whole EU. The purpose of REACH is to improve our protection of public health and the environment against the risks associated with chemicals.

According to the Swedish BBR (Building Regulations published by the Swedish National board of Housing, Building & Planning), all building materials used in new constructions must have a lifetime expectancy of at least 50 years.

From July 1st 2013 onwards, CE conformity marking has been obligatory for all construction products in Sweden in accordance with the Construction Products Regulation (CPR). In addition, a Declaration of Performance (DoP), which includes all of the material’s technical data, is also required. A description of the qualities which may affect the performance of a waterproofing membrane is beyond the scope of this text.

Waterproofing Material

There is a wide range of products on the market intended for waterproofing green roofs/installations on concrete decks. These come as rolled-up mats/cloths or as liquid materials. The strength of the
Waterproofing required depends on the type of superstructure chosen, and on whether or not people will need to pass across the waterproofing membrane before it is covered over. The waterproofing membrane also needs to be able to withstand strain from movement during construction and from the environment of the superstructure.

Below follows a list of different waterproofing materials;

**Bitumen-based waterproofing**

- Bitumen-based waterproofing membranes are often modified with other polymer materials such as SBS (Styrene-Butadiene Block Co-Polymer) and APP (Atactic Polypropylene). SBS-modified bitumen-based waterproofing membranes are used above all else in Scandinavia, as the material is elastic even at low temperatures.
- Mastic asphalt or polymer-modified mastic asphalt
- Bituminous mastics

**Synthetic waterproofing – Prefabricated sheets**

- PVC (Polyvinyl Chloride)
- TPO/FPO (Flexible polyolefins) usually made of PP (polypropylene) or PE (polyethylene)
- EPDM rubber sheet (Ethylene-propylene rubber)

**Synthetic waterproofing – Liquid applied**

- Polymer-modified bitumen
- PMMA (Polymethyl methacrylate)
- Epoxy plastic
- Polyurethane
- Polyurea

Liquid waterproofing is used less often in Scandinavia, while a range of different bitumen-based and synthetic waterproofing options are used in the Swedish market.

**Installation of a green roof**

The waterproofing membrane should be monitored and 100% watertight, and placed 300 mm above the projected plant bed surface. In order to minimise the risk of damage to the waterproofing membrane, the surface must be clear of debris and protected at all times. If there are points in the waterproofing membrane that need to be walked across, these should be protected by planks or sheets, which should in turn lie on top of a geotextile or root protection sheet. Weak zones with a limited loading capacity should be indicated clearly and the substrate should be evenly distributed so that the load is not concentrated in one spot. The design engineer should designate appropriate places for the intermediate storage of loads and materials.

It may be a good idea to protect certain points on the roof from plant growth using vegetation-free zones/capillary breaking materials. Such points may be, for example, spaces beneath ventilation hoods, by windows that reflect sunlight, by suspension walls or other construction components.
It is important to plan out the various stages and the times at which materials will be delivered throughout the construction phase so that everything is put in place at the right time, and so that storage time is minimised (particularly for vegetation).

Green roof maintenance

Green roof maintenance can be divided into three stages: maintenance after installation, establishment/guarantee maintenance and on-going maintenance.

**Maintenance after installation:** The first goal right after installation is to ensure that the vegetation becomes established on the roof as planned. The most important activities at this stage are irrigation and carefully checking that the vegetation anchors and roots itself successfully.

**Establishment/guarantee maintenance:** Once the vegetation has become established, it is necessary to provide care which supports and benefits the vegetation. This type of maintenance needs to be undertaken for 1-2 years, depending on the vegetation system. Activities at this stage include weeding and replanting.

**On-going maintenance:** The purpose of on-going maintenance is to preserve the original function of the green roof.

Maintenance can include the following activities:

- fertilisation;
- removal of weeds and woody plants;
- seam and top dressing;
- fixing up eroded surfaces, e.g. as a result of wind erosion;
- removal of debris from the gutters and the roof (branches and piles of leaves)
- checking that runoff is happening as it should;
- checking the technical installations;
- checking the irrigation system.

Pesticides should never be used on a green roof. The poison can be easily carried off with runoff from the roof and end up in stormwater receptors. For the same reason, it is important to use fertiliser frugally.

Roof safety, anchoring and additional solutions

There is a range of components and systems on the concrete deck that need to be anchored in order to function correctly, and to deliver their desired function without posing a risk to visitors on the roof.

Safety systems

Fall protection systems are required on all concrete decks above ground level which are intended for human use. Roofs to be used for recreation and play should have permanent fall protection in the form of a fence or railing. All concrete decks located more than two metres above ground level, which are not intended for human use, should be fitted with attachment points for temporary work.

If installation is being carried out without the use of attachments to the roof construction, a safety railing with ballasts in the form of plates or substrate can be fitted to the frame in order to provide the
stability needed to prevent against falling and the wind.

Access for future care and maintenance of the green facility should be considered right from the planning and design stage and necessary safety devices should be designed accordingly.

A roof plan should be drawn up for each green facility. This should consider all of the necessary safety devices for the roof, including type and placement of devices used for work on the roof, snow fences, etc. Accident protection and health and safety measures should be considered during construction, planning, and at the ‘call-for-tenders’ stage. The measures should be adopted in order to prevent falls from occurring when carrying out installation or maintenance and during the regular operations of the building, and in order to prevent falling through building elements such as windows on the roof.

Permanent fall protection.

Anchoring of trees and shrubs

Whether or not it is necessary to anchor trees and bushes on the concrete deck depends on various factors such as climate, location and substrate depth. In courtyards on concrete decks, the vegetation is subjected to less wind loads compared with those on higher roofs. Anchoring is needed mostly for trees and bushes exposed to very windy conditions. A strong and well spread-out plant bed is the best form of protection against overturning vegetation as it provides the vegetation with an opportunity to anchor itself long-term using its root system.
Solar cells and green roofs

House roofs with a low slope are suitable for a solar panel and green roof combination. Stands are used on low slopes to adjust the slope of the solar panels and their orientation towards the sun. It is possible to establish green areas beneath and in between the stands.

The rated output of solar cells is given at a solar cell temperature of 25 degrees. Its efficiency decreases when temperature increases by about -0.4% for each raising degree. Evapotranspiration, albedo and evaporation from the vegetation and substrate result in a cooler micro-climate compared with sealing membranes, concrete, single and other construction elements. This means that green roofs can be beneficial to solar cells and that the solar cells are generally more efficient compared with solar cells installed on roofs that are free of vegetation.

In general, a mix of plants and species of varying forms will result in higher degrees of evapotranspiration. The panels in turn benefit a varied range of plant life as they provide different micro-climates, located in front of, underneath and behind the panels as a result of the effect of wind turbines, shading and surface temperature.

For all systems which combine green roofs with solar panels, it is necessary to consider the total weight of the superstructure, including stands, panels, the components of the green roof (plant bed, drainage layer, etc.) in water-saturated condition, and any singles or concrete that are used as ballasts.

Water environments on concrete decks

Water functions that can be installed onto concrete decks include dams, streams and/or fountains. There are several advantages to installing open water areas: from recreation and aesthetics to ecological advantages such as micro-habitats for aquatic plants, shore plants and bathing and drinking places for birds and insects.
When designing, installing and carrying out maintenance on water functions on concrete decks, there are some important principles and practicalities that you need to consider.

First of all, it is necessary to make sure that you design the facility in relation to the loading capacity of the concrete deck. Secondly, a double waterproofing system will be needed: water installations must have their own separate waterproofing system above the concrete deck’s waterproofing membrane. Water installations constitute their own system and require pond liners, for example.

![A water structure (as well as a beehive) on a green roof in London.](image)

**Conclusion**

A systems approach is essential for planning a green roof. The different components of a green roof built-up all have their specific function, but in the end all the components need to work together as a system.

This demands the important but also fruitful aspect of mutual learning and dialogue between different fields of expertise (construction and insulation, waterproofing layer, green roof built-up, vegetation).

With careful planning, exciting green roofs with important functions can be installed in urban landscapes.

**Common terminology**

**Ecosystem services**

An ecosystem involves the interactions between a community of living organisms in a particular area
and its nonliving environment. Ecosystem services are the benefits for human beings that arise from healthy functioning ecosystems, notably pollinating, mitigation of flooding, production of oxygen, and etc.

**Evapotranspiration**
The movement of water to the air as a result of both transpiration of plants and evaporation from other surfaces such as ground and surface water.

**Extensive green roof**
Refers to vegetation layers which do not require more than one or two maintenance interventions per year to maintain the desired function and appearance.

**FLL**
_Forschungsgesellschaft für Landschaftsentwicklung und Landschaftsbau e.v._ The publisher of the German guidelines for green roofs.

**Intensive green roof**
Refers to vegetation layers with a clear design idea where several management initiatives per year are needed to maintain the function of vegetation, the creative-visual expression, and species composition.

**Permeability**
Permeability refers to the extent to which water is able to move freely throughout the superstructure.

**Runoff coefficient**
Indicates the percentage of precipitation water that runs off after it rained.