**Centre for Urban Greenery & Ecology**
CUGE Standards

# GUIDELINES ON **SUBSTRATE LAYER FOR ROOFTOP GREENERY**

CS E03:2010

Guidelines on Skyrise Greenery

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CENTRE FOR URBAN GREENERY AND ECOLOGY

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**CUGE STANDARDS CS E03:2010**

# GUIDELINES ON **SUBSTRATE LAYER FOR ROOFTOP GREENERY**

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The CUGE Standards Series is a set of published guidelines for adoption in the landscape and horticulture industry. They are written through a formal process that involves consultation with relevant bodies and reaching a consensus across all interested parties so that the final document meets the needs of business and industry. The standards take the form of either specifications, methods, vocabularies, codes of practices or guides.

The CUGE Standards Series comprises:

CS A Specifications on properties of planting media
CS B Landscape construction & management
CS C Urban ecology
CS D Landscape design
CS E Skyrise greenery



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**Substrate Layer for Rooftop Greenery**
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The CUGE Standards will be reviewed every three years. Concurrently, CUGE also gathers new information continually through on-going research.

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# Substrate Layer for Rooftop Greenery

## SECTION 1 SCOPE

### 1.1 INTRODUCTION

This specification sets out the basic requirements for the construction of the substrate layer of rooftop greenery.

Rooftop greenery is designed and installed on the rooftop spaces of new buildings and existing structures, and is very much a part of a building's surface.

The growing medium, termed the substrate layer, is a soil-alternative which allows for the roots of vegetation to establish and anchor.

### 1.2 OBJECTIVE

This specification is intended as a guide for the construction of the substrate layer of rooftop greenery.

It is intended to act as a reference point for quality assurance of the substrate layer of rooftop greenery.

The design and construction of rooftop greenery shall comply with the relevant codes of practice and standards of the relevant authorities.

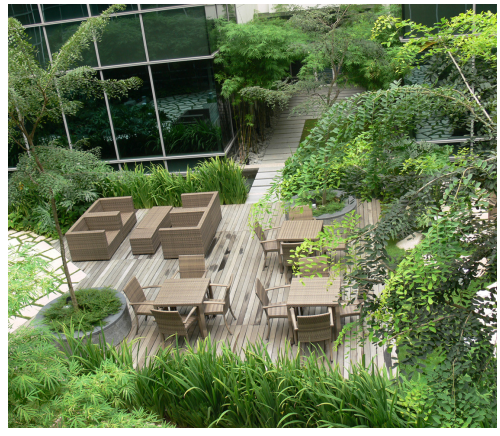
## 1.3 DEFINITIONS

### Green roof

Extensive green roofs, are in general not designed for active recreational use. They are developed mainly for aesthetic and ecological benefits. Distinguished for being low in installation cost, lightweight (50-150 kg/m$^2$) and with shallow mineral substrates, minimal maintenance is expected. Inspection should be performed, at the minimum, once or twice a year. Plants selected are usually of low maintenance and are self-generative. Extensive systems can also be placed on pitched roofs of up to an inclination of 30 degrees. They are common in European countries, especially Germany.

### Roof garden

Intensive green roofs, or roof gardens, are developed to be accessible. They are often used for recreation and other social activities. Hence they are associated with added weight, higher capital cost, more intensive planting and higher maintenance requirements. The plant selection ranges from ornamental lawn, shrubs, bushes to trees. As they are designed for usage, regular maintenance such as mowing, fertilising, watering and weeding is required.



### Substrate

Substrate, in the context of rooftop greenery, is a blend or mixture of materials that may be naturally occurring or man-made, organic or inorganic. It is intended to function as an alternative to soil for application on rooftop greenery (green roofs and roof gardens). The aggregate components of the substrate medium are usually lightweight, chemically inert, and physically stable in form.

## 1.4 PERFORMANCE REQUIREMENT

The substrate layer is the layer of soil-alternative for installation on the rooftop surface and spaces.

As the microclimate at the rooftop space can be extreme (intense sunlight and stronger winds with increasing altitudes), the selection, installation and maintenance of the substrate layer should address these concerns.

The substrate layer should function appropriately on the rooftop greenery space, such that the plants can establish without inhibition.

## SECTION 2 SUBSTRATE LAYER

### 2.1 INTRODUCTION

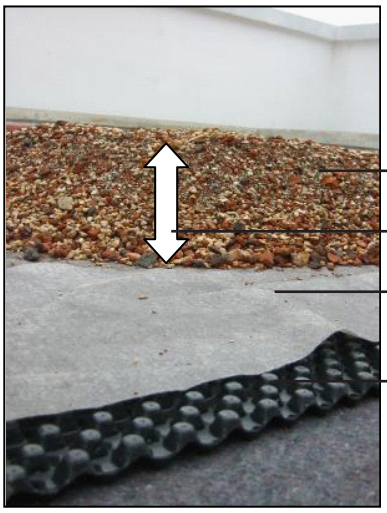



**Figure 1**
Typical build-up of a green roof system.

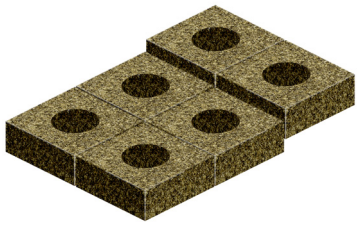
When deciding on a suitable vegetation support material, growing media or substrate for the rooftop greenery, there is a need to consider the following factors:

- The groups and types of materials that make up the substrate
- The physical form of the substrate materials
- The type of greenery desired
- The form of cultivation for the greenery

### 2.2 GROUPS AND TYPES OF SUBSTRATE MATERIAL:

| S/ No | Group / Form | Common terminology | Types of Substrate Material |
|---|---|---|---|
| 1 | Mixture | Soil mix | Improved topsoil mix |
| | | | Blend of mineral aggregates<br>- With / without organic material<br>- With open-pored or dense granular structure |
| 2 | Board | Substrate board* | Made from modified foam materials |
| | | | Made from mineral fibres |
| 3 | Mat | Vegetation mat* | Made from mineral aggregates and low organic content;<br>- With permanent or decomposable meshing |

* Substrate board and vegetation mat are more commonly used overseas. Their applications are not widely tested locally.



### Substrate board

This is basically growing media that has been compressed and moulded into boards, slabs, blocks or cubes. The growing media is typically soil-based, and sometimes heat is applied during the moulding process.

### Vegetation mat

Vegetation mat or pre-cultivated vegetation mat typically comprises three components – vegetation, growing media and natural or synthetic fibrous mat. The fibrous mat is filled with a thin layer of growing medium on which selected plant species are pre-cultivated. As the name implies, vegetation mat is typically thin (about 20 – 50 mm thick), lightweight and pre-cut into dimensions that allows portability.

## 2.3 VEGETATION SUPPORT MATERIAL / GROWING MEDIA

- "Vegetation support material" and "growing media" are generic terminology used in the landscape and horticultural fields to refer to the material in which the vegetation grow. There is a distinction between soil, which is directly from the natural earth, and substrate, which is a blend or mixture of materials that may be naturally occurring or man-made, organic or inorganic.

**Figure 2**
Image of the natural soil

**Figure 3**
Image of substrate material

- From the perspective of conserving the earth's natural resources, the minimal use of natural soil, whether top soil or sub-soil, is encouraged. Recycled materials such as crushed bricks / clay roof tiles, furnace slag, etc are encouraged in the composition of the substrate.
- Use of substrate as the growing media for roof greening is encouraged.

## 2.4 SUBSTRATE MATERIALS AND DIMENSIONS

**2.4.1 The following factors** should be considered when selecting the specific substrate material ingredients and dimensions:

- **Construction requirements** for the particular area in which the greenery is located.

- **Objectives of the vegetation** in the rooftop space.

  (For example, vegetation can be used to provide shade, act as green massing, enhancing biodiversity, etc)

**2.4.2 Construction requirements** pertaining the substrate layer are as follow:

- **Drainage** strategy of the substrate layer in removing excess rainwater from the relevant rooftop greenery area.

- **Load bearing capacity** of the structure supporting the greenery area.

- **Protection** of the rooftop surface, supporting the greenery from deterioration and damage.

**2.4.3 Objectives for the vegetation are as follow:**

- **Requirements of the vegetation** in the landscape design.

- **Time** - The substrate should function in accordance with the landscape scheme for long term with minimum human intervention.

- **Cost** - The cost of expected vegetation and substrate maintenance.

## 2.5 OTHER CONSIDERATIONS

### 2.5.1 Other purposes

In the event that the substrate is used for any other purposes such as contouring, earthworks, specialised fields, or tree planting, it may be necessary to incorporate an additional layer that consists of an even granulometric distribution of granular material beneath the substrate layer. This is to ensure better drainage of excess water, hence avoiding water-logging issues.

### 2.5.2 Use of vegetation mats

- Vegetation mat can double up as the substrate layer as well, and can be used where an extremely thin substrate layer is required.
- Vegetation mat laid on a separate substrate layer can be considered in the following cases:
    - Dry seeding – With or without adhesives for fixing
    - Wet seeding – With or without shoots
    - Scattering of plant parts such as the shoots
    - Use of linings to cover the mat that may be biodegradable or structural
    - Laying of turf – With or without reinforcement support mesh
    - Planting of individual plant plug or pre-cultivated plant elements

## SECTION 3 REQUIREMENTS – PHYSICAL AND CHEMICAL PROPERTIES

Where soil is still preferred as the planting media over substrate layer, (e.g. in roof gardens or green roofs) the soil mixture should meet the minimum soil mixture requirements for general landscaping use, as set out in CS A01:2009 – Specifications for Soil Mixture for General Landscaping Use.

### 3.1 GRANULOMETRIC DISTRIBUTION

- The general guide is to avoid particles or grains that are too fine or too large.
- **Fine particles** - Particles or grains with sizes lesser than 0.063 mm in diameter such as those of clay and silt content are too fine. The guide for different types of green roof is:

| Types of green roof | Guide |
|---|---|
| Roof garden | Fine particles not exceeding 20% by mass (of the substrate) |
| Green roof | Fine particles not exceeding 15% by mass (of the substrate) |

- **Large particles** – For flat roof structures, the maximum size of the particle or grain depends on the corresponding depth of the substrate layer:

| Depth of Substrate Layer | Maximum grain size |
|---|---|
| Up to 100 mm | 12 mm diameter |
| More than 100 mm | 16 mm diameter |

- The Granulometric Distribution Range for vegetation substrates for the different types of green roof can be found in this Section as follows:

| **Types of green roof** | **Granulometric Distribution Range** |
|---|---|
| Roof garden | Please refer to Chart 1 (on page 27) |
| Green roof | Please refer to Chart 2 (on page 27) |

Please refer to Table 1 on page 26

## 3.2 ORGANIC CONTENT

- The limits for organic content within the substrate are:

| **Types of green roof** | **Amount of Organic Content Recommended** |
|---|---|
| Roof garden | (10-25%) by volume |
| Green roof | (5-10%) by volume |

- While a high organic content in the substrate layer may benefit the growth of the vegetation, it can also affect the fire resistance of the substrate adversely.

## 3.3 STRUCTURAL AND BEDDING STABILITY AND SETTLEMENT OF SUBSTRATE

- These refer to the structural and bedding strength of the substrate that comprises soil and aggregate mixtures, or pure aggregate mixture.

- Such strength is determined by the granulometric distribution of the mixture and the shape of the particle grain that makes up the mixture. Hence, only materials that are properly crushed should be used. This also applies to green roofs.

- Settlement or consolidation of the substrate:

  - This is not a defect of the substrate and should be allowed for upon the completion of the installation work.

  - This could be due to a number of factors including weight of the substrate itself and/or the materials that are on the substrate, effects of water, and biological processes or loads applied during maintenance.

  - The allowable limits to substrate settlement are:

| **Depth of substrate layer** | **Maximum amount of settlement** |
|---|---|
| Up to 500 mm | 10% of the nominal depth of the substrate layer |
| More than 500 mm | Not exceeding an average of 50 mm |

## 3.4 BEHAVIOUR OF SUBSTRATE BOARDS UNDER COMPRESSION

- Allowance should be made for the long-term compression of substrate boards exerted by vertical loads. The limits are:

| **Thickness of substrate board** | **Maximum compression** |
|---|---|
| 30 to 50 mm | 20% of the nominal thickness |
| More than 50 mm | Not exceeding 10 mm |

- Substrate board is more commonly used overseas. Its application is not widely tested locally.

## 3.5 WATER PERMEABILITY

- Water permeability of the substrate shall be adjusted to suit the type of construction planned for the drainage course.

- The value of vertical permeability modular, $k_f$, of the substrate that has been compacted, and that for substrate boards that have just been installed are as follow:

| **Types of green roof** | **Permeability modular, $k_f$** |
|---|---|
| Roof garden | 0.3 – 30 mm |
| Green roof | 0.6 – 70 mm |

- The minimum values for permeability are as follow:

| **Types of green roof** | **Minimum Recommended Permeability** | |
|---|---|---|
| | **mm per min*** | **≈ ℓ per sqm per hour*** |
| Roof garden | 0.6 | 36 |
| Green roof | 1.0 | 60 |

** Denotes: These recommended figures are estimates.*

## 3.6 WATER STORAGE ABILITY / MAXIMUM WATER STORAGE CAPACITY

- The maximum water storage capacity of compacted and/or installed substrate, is as follows:

| **Types of green roof** | **Maximum water storage capacity** |
|---|---|
| Roof garden | At least 45% by volume |
| Green roof | At least 35% by volume |

- The maximum water storage capacity of the substrate should not exceed 65% by volume. This avoids an excessively wet substrate, which will significantly reduce the substrate porosity, which in turn affects air content.

## 3.7 AIR CONTENT

- At field capacity of the substrate, the minimum air content within the substrate should be as follows:

| Types of green roof | Minimum air content |
|---|---|
| Roof garden | 15-20% by volume |
| Green roof | At least 25% by volume |

## 3.8 pH VALUE

- The pH value of the substrate should be considered in relation to the needs of the vegetation.

- The optimal pH value is as follows:

| Types of green roof | pH value |
|---|---|
| Roof garden | 5.5 - 8.0 |
| Green roof | 5.5 - 8.0 |

- Having taken into consideration the needs of the vegetation, any reduction of the pH value below the value range indicated above should be avoided, after the installation of the green roof.

## 3.9 SALT CONTENT

- Setting the limits for soluble salt content within the substrate is necessary from the perspective of potential environmental pollution (such as leaching of salts), and the primary aim is to achieve the lowest possible salt levels.

- The limits for soluble salt content within the substrate are as follow:

| Types of green roof | Soluble salt content |
|---|---|
| Roof garden | Maximum 1.5 g/ℓ |
| Green roof | Maximum 1.5 g/ℓ |

- For vegetation that is sensitive to soluble salts, the salt content shall not exceed 1.0 g/ℓ.

- Alternatively, salt content can be measured by Electrical Conductivity (EC) which is the ability of the soil to conduct electrical current.

- The EC of the substrate layer should be less than 2.0 dS/m. (Please refer to CS A01:2009 – Specifications for Soil Mixture for General Landscaping Use)

## 3.10 NUTRIENT CONTENT

- For roof greening, low nutrient content should be maintained to avoid the problems associated with leaching during the stage between construction and planting.
- The limits for nutrient content within the substrate are as follow:

| **Nutrient** | **N** | | **$P_2O_5$** | | **$K_2O$** | | **Mg** | |
|---|---|---|---|---|---|---|---|---|
| Testing method | $CaCl_2$ | CAT | CAL | CAT | CAL | CAT | $CaCl_2$ | CAT |
| Nutrients content (mg/l) | ≤ 80 | ≤ 80 | ≤ 200 | ≤ 50 | ≤ 700 | ≤ 500 | ≤ 200 | ≤ 200 |

- Any requirement for additional nutrients should come from a suitable fertiliser. The application of suitable fertiliser should be conducted after the planting stage, or during the final round of maintenance at the establishment period. However, application of suitable fertiliser should continue during the post-establishment period to nourish the plant during its development.
- Please note that should soil be used instead of substrate, the quality of the soil should be in accordance with the CUGE Standards CS A01:2009 – Specifications for Soil Mixture for General Landscaping Use.

## 3.11 SEED GERMINATION / REGENERATIVE PLANT PARTS WITHIN THE SUBSTRATE

- The ingredients, components or raw materials that are used to make up the substrate should not contain any living plants or any regenerative plant parts, particularly roots.
- During the extraction and preparation of the substrate, care must be taken at all times to avoid the inclusion or importation of seeds. It is therefore prudent to protect and shield the substrate during production (or mixing) stage as well as storage (whether at the store or on site).
- Where natural soils are used in the substrate, subsoil or earth is preferred to topsoil. This is to reduce the risk of importing seeds that are capable of germinating.

## 3.12 PROPORTION OF FOREIGN SUBSTANCES

- Foreign substances are defined as materials that are not intended in the make-up of the substrate. These include materials such as glazed wall and floor tiles, glass, metals, plastics, etc.

- The limits of foreign substances within the substrate (for both roof garden and green roof) are as follow:

| **Foreign substances of particle size exceeding 6 mm in diameter** | **Limit** |
|---|---|
| • Wall and floor tiles<br>• Glass<br>• Ceramics | Maximum 0.3% by mass |
| • Metals<br>• Plastics | Maximum 0.1% by mass |

- For plastic materials that are measured in terms of planar area rather than weight, the total area of such plastics per litre of substrate should not exceed 10 sq cm.

- In normal situations where there is insignificant contouring work involved, the substrate layer should be installed parallel to the underlying layers.

- The minimum depth of the substrate that is specified for the area must be adhered to and maintained. This depth is defined as the vertical depth of just the substrate when it is settled rather than just after it has been installed. Please refer to Figure 4.

**Figure 4**
Substrate depth

- For substrates that contain a mixture of soils and aggregates, they must be installed at a naturally-moist state rather than when completely dry.

- For substrate boards however, they should be installed when they are dry.

## 4.1 ADDRESSING EROSION ISSUES

### 4.1.1 Wind erosion issues

- Watering arrangements (whether manually or through the use of an irrigation system) should be considered to keep the substrate fairly moist and to prevent the surface of the substrate from drying out that may otherwise lead to wind erosion of the substrate. This is especially important in areas that experience high wind conditions and during the establishment phase of the vegetation.
- In assessing the risk of the substrate being eroded by wind, the sliding or drift factor of the substrate (related to coefficient of internal friction of the material) should be considered in the context of the wind speeds, rather than solely on wind speeds alone.

### 4.1.2 Substrate erosion

In the event where there is a long time lapse between installation and planting stage of the green roof, additional measures such as those described below should be taken to prevent erosion of the substrate:

- **Build-up of the system** – There must be appropriate specifications of the layered structure that makes up the green roof system. For this, tap on the expertise of credible green roof specialists who are familiar with the local climate conditions. The options, whether used separately or a combination of, include but are not limited to:
    - Use of substrate mixture that is of higher density, even when it is in a dry state.
    - Installation of additional layer of hard stone chippings (such as granite chippings, pebbles, gravel stones, etc) as a form of “mulch” on top of the substrate at the areas susceptible to erosion.
    - Use of plant species that are ground covering, fast-growing and long lasting.

- **Temporary measures** – These include but are not limited to:

    - Keeping the substrate permanently moist (but not saturated).

    - Use of a soil fixer or soil conditioner on the seed, shoots and surface of the substrate. Such activity is recurrent and may be repeated over time.

    - Use of erosion protection netting, such as the jute net. As it is made of a decomposable material, having a netting that is of the right intensity is important to ensure that it will perform its function throughout the initial maintenance period beyond the establishment period.

**Figure 5**
Laying of jute netting over green roof areas that are prone to wind erosion.

- Special situations – This is applicable for exceptional situations such as that of very high wind-prone areas, and steep pitched roofs. The actions include but are not limited to:

    - Use of wet seed, or

    - Use of pre-cultivated vegetation mats on which suitable ground covering, fast-growing and long lasting plant species are grown

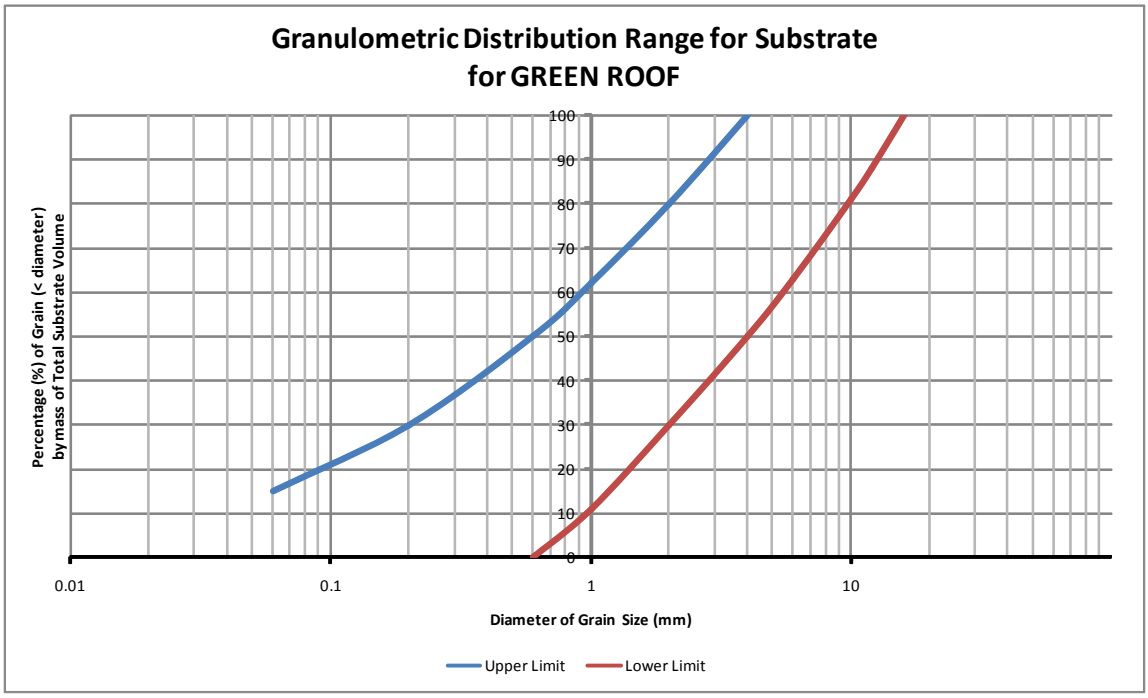
- For pitched roofs, especially the very steep ones that exceed 25° slope, additional efforts such as frequent watering and application of fertiliser should be put in to ensure that the vegetation thrives and fulfils its function of erosion protection.

**TABLE 1:** Coordinates for the Granulometric Distribution Range for Vegetation Substrates Used for green roof and roof garden.

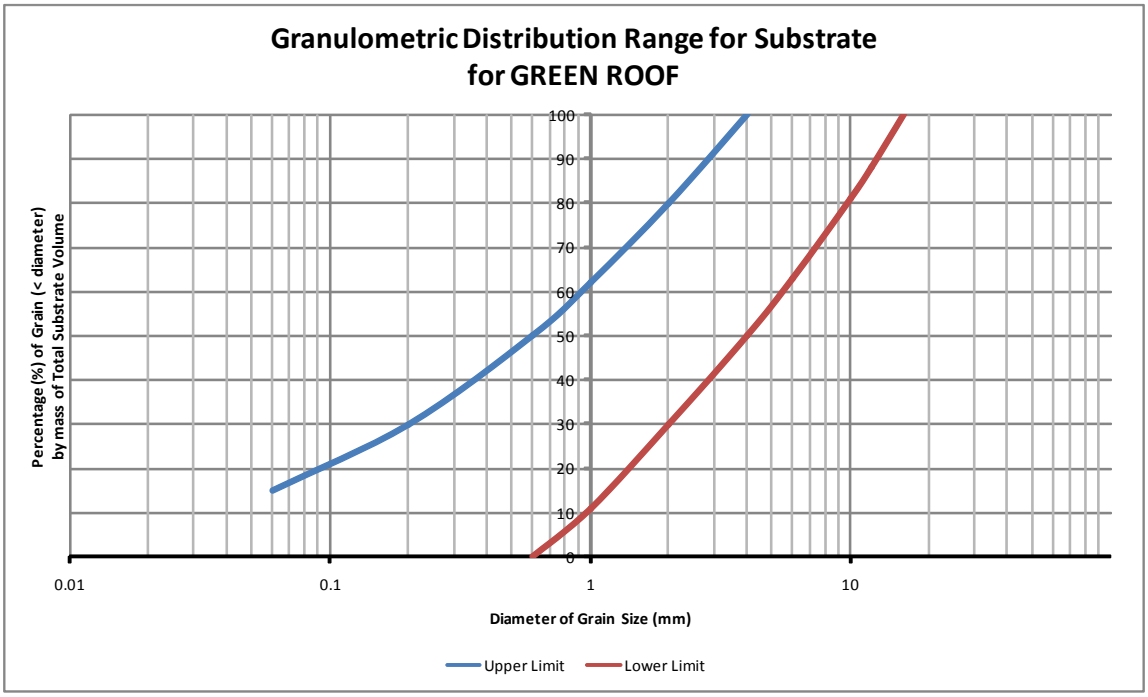
| Particle Types | Grain size (mm dia) | Coordinates | | | |
|---|---|---|---|---|---|
| | | Substrate for roof garden (Intensive greening) | | Substrate for green roof (Extensive greening) | |
| | | Upper limit Percentage (%) | Lower limit Percentage (%) | Upper limit Percentage (%) | Lower limit Percentage (%) |
| Coarse Silt * | 0.06 | 20 | 0 | 15 | |
| Fine sand | 0.2 | 36 | 10 | 30 | |
| Medium sand | 0.6 | 70 | 21 | 50 | 0 |
| Coarse sand | 1.0 | 100 | 28 | 62 | 11 |
| Fine gravel | 2.0 | | 40 | 80 | 30 |
| Fine gravel | 4.0 | | 58 | 100 | 50 |
| Gravel | 6.0 | | 72 | | 63 |
| Gravel | 10.0 | | 92 | | 81 |
| Gravel | 12.0 | | 100 | | 88 |
| Gravel | 16.0 | | | | 100 |

* Silt – Soil particles between 0.002mm and 0.05mm, with high or medium-high specific area influencing stability of soil structure; also used as a texture class name for medium and medium-fine soil materials. (Extracted from CS A01:2009 – Specifications for Soil Mixture for General Landscaping Use)

## Chart 1




## Chart 2



## REFERENCE STANDARDS

| | |
|---|---|
| Germany FLL | Guidelines for the Planning Construction and Maintenance of Green Roofing – Green Roofing Guidelines – 2008 edition |
| CS A01:2009 | CUGE Standards – Specifications for Soil Mixture for General Landscaping Use |

**About the National Parks Board and Centre for Urban Greenery & Ecology**

The National Parks Board (NParks) is responsible for providing and enhancing greenery of the Garden City of Singapore. Beyond managing public parks, the park connector network, lush roadside greenery, nature areas and nature reserves, NParks is committed to enhance the quality of life through creating memorable recreational experiences and lifestyles.

The Centre for Urban Greenery and Ecology (CUGE) is an initiative of NParks. Through its research and training programs, CUGE advances knowledge and expertise in urban greenery and ecology in the landscape and horticulture industry in Singapore. It works closely with industry partners to promote good work practices and create a thriving, creative, innovative and professional industry that will support Singapore's aspiration to be a City in a Garden.