Sydney City Council Green Roof Resource Manual

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1 INTRODUCTION

1.1 What is a Green Roof?

GENO Haus
Stuttgart,Germany

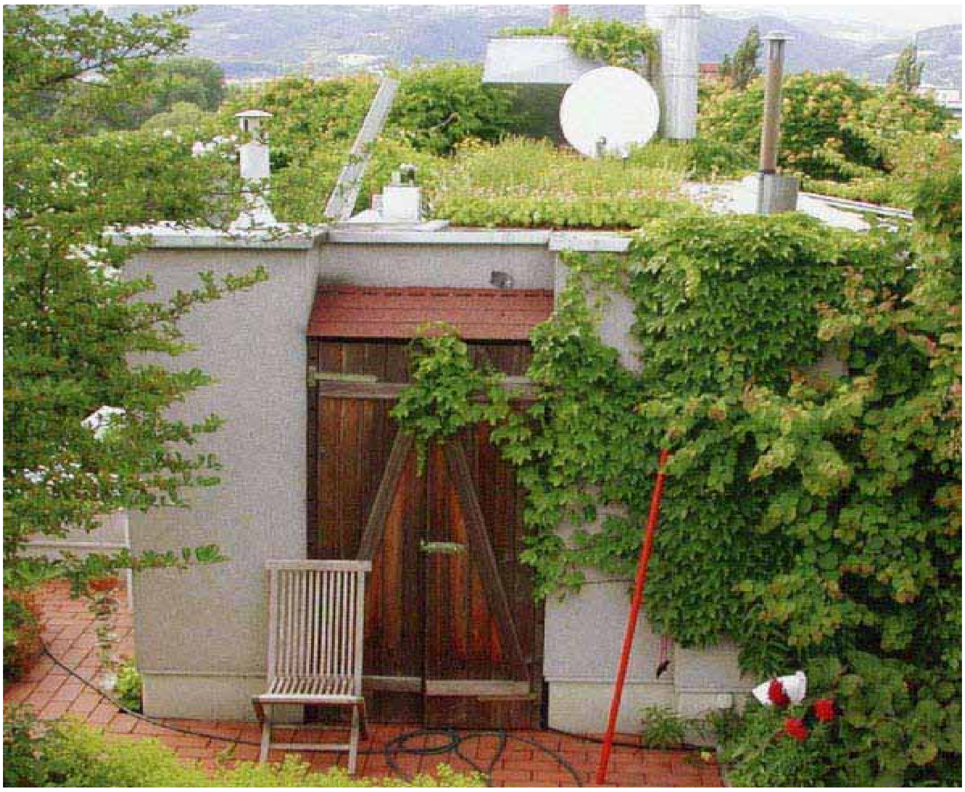
1.1 What is a Green Roof?

A green roof has a dual function; it is a roof system designed to promote the growth of various forms of vegetation on the top of buildings. It is also designed to support various forms of renewable energy and water collection technology to assist in supplying power and water to the occupants of the building. Although a green roof is only one element of a building, it is extremely important when considering the long-term sustainability of our buildings and their impact on the environment.

The environmental advantages of installing green roofs are widely known and include; thermal insulation, increasing the life span of the roof structure, minimising surface run-off, reducing the cities heat-island effect, producing renewable/no emissions energy which is fed into the electricity grid, collecting and supplying rainwater to minimise the burden on town water and reducing emissions through minimising the need for heating and cooling. There are many more advantages associated with installing a green roof and these will be discussed later.

Every green roof has a series of components that aid in either protecting the building, assisting the growth of vegetation, collecting/harvesting rainwater or generating energy. These components include, a root protection layer, waterproof membrane, drainage layer, substrate or soil layer and finally, a layer of vegetation. Green roofs also host technology such as PV cells, wind turbines and water tanks.

1.2 How is a Green Roof Roof Different From a Garden Roof



Casa Bautrager
Linz, Austria

1.2 How is a green roof different to a roof garden?

Green roofs are distinct from traditional rooftop gardens because they promote proven sustainable concepts. Typically rooftop gardens have been purely an aesthetic feature of a buildings 'roofscape'.

Whilst Green roofs still pay attention to aesthetic considerations, their main objective is to minimise the buildings impact on the environment in an economically viable way. Green roofs maximize the potential of having vegetation on the roof by collecting and harvesting storm water via a well-designed drainage system and the use of materials that have been specifically developed to significantly minimize the waste of any valuable resource such as water. Additionally, green roofs take advantage of the relatively cooler environment by supporting photovoltaic cells (PV), which operate more efficiently in cooler environments.

2 ADVANTAGES OF GREENROOFS

2.1 Visual:
Public amenity

American Society of Landscape Architects
Washington D.C, USA

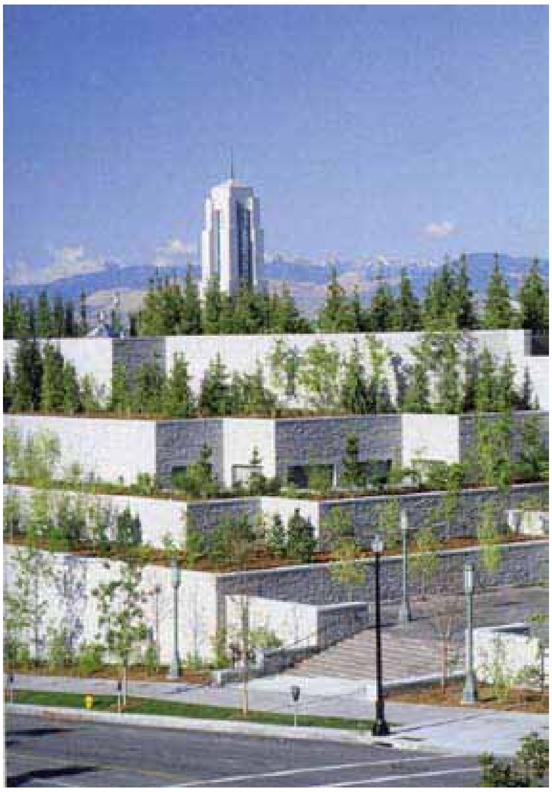
2.1a Public Amenity

Rooftops are generally an underutilised space, often reserved for exausts, air conditioning units and other plant equipment. If designed effectively, green roofs can provide for public amenity replacing the increasing amount of lost public open space due to urban development. With the addition of roof top structures, these spaces can provide an additional shaded recreational space for the building occupants and/or the public.

Many cities around the world such as Toronto, Portland, Chicago and even London, are planning to introduce more public recreational space on green roofs where access can be controlled making them safer environments to inhabit. Green roofs can become excellent spaces to hold meetings, have a quiet lunch (well above the noisy street) or to go and read a book.

It is not possible to provide amenity to every green roof. In some instances the structural capabilities of the roof deck are not designed to support the extra live load associated with having people walking on its surface or the added weight of materials associated with paving. However this will be discussed in more detail in section 3.

2.1 Visual:
Aesthetics



The Church of Jesus Christ and the
Latter Day Saints
Salt Lake City, USA

2.1b Visual Advantage

Green roofs are also more pleasant to experience or view from other buildings. Traditional roof structures are quite bleak and ugly to look at, often cluttered with HVAC equipment, exhausts and a bitumen or gravel protective layer. They are also particularly hot areas to be in because of the dark heat absorbing materials.

Green roofs on the contrary are pleasant to be in because they are cooler and offer shading from rooftop structures and taller vegetation. They are also more attractive to view from other buildings because of their soft foliage and vibrant colours.

2.2 Economic:
Prolonged life span of roof membrane

A green roof protecting the buildings membrane
source: http://us.i1.yimg.com/us.yimg.com

2.2a Prolonged Lifespan of Roof Membrane

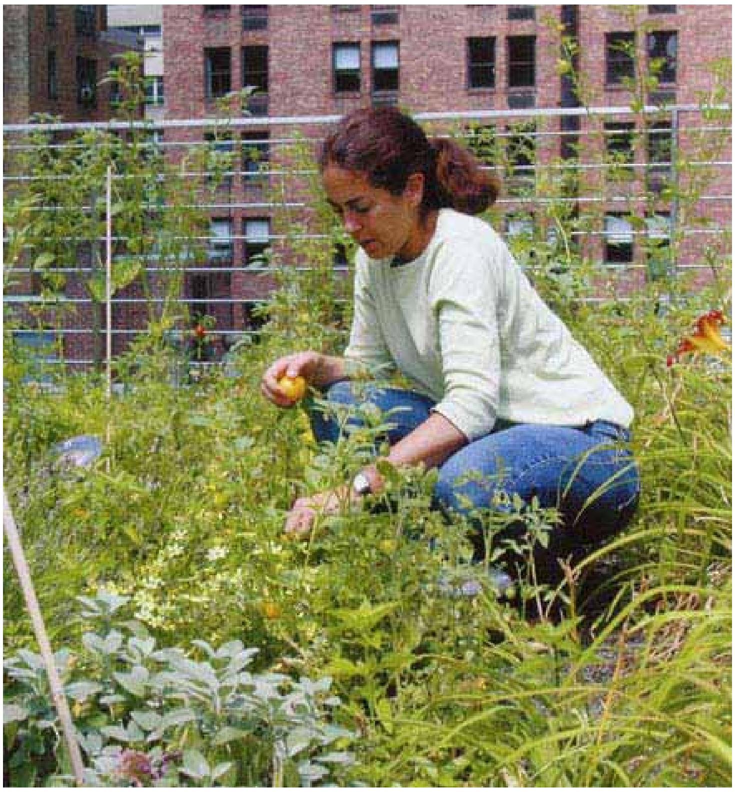
The economic advantages of green roofs are widely known to be one of the major reasons for building a green roof. Real savings can be accounted for immediately after a green roof is installed. The main economic advantages include;

* Prolonged lifespan of the roof membrane
* The production of food
* Reducing heating and cooling costs

An exposed roof deck without a layer of vegetation protecting it, is exposed to extreme heat, wind and ultra violet radiation. All of these elements deploy varying degrees of mechanical and chemical degradation, which places a large amount of stress on the roof material. Ultimately, the roof deck wears down and ages at a much faster rate than a protected roof.

A green roof, on the other hand, provides direct shading and protection to the roof membrane and therefore greatly reduces the amount of exposure to harsh environmental conditions. Not only does this keep the membrane cool irrespective of the outside temperature, but it also keeps the temperature constant, avoiding major fluctuations which can impose stress on the membrane. This means that the expected lifespan of the roof is much longer than a traditional roof deck, which amounts to real long-term savings. It has been suggested that a green roof can last 20 years longer than a traditional roof.

2.2 Economic:
Food Production



Earth Pledge
New York, USA

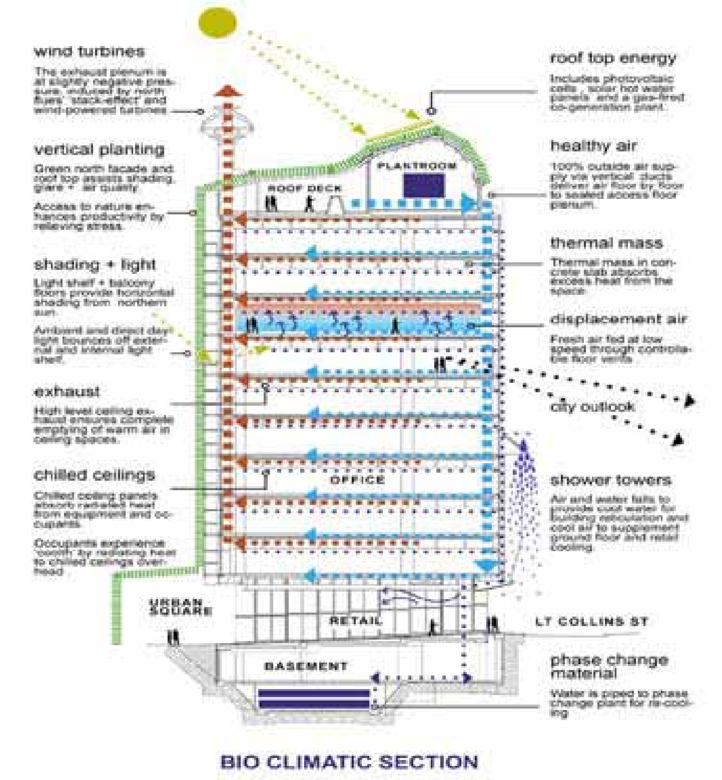
2.2b Food Production

On specifically designed green roofs there is the opportunity to develop rooftop farms, which promote the growth of food produce. This is not a new concept but one that is yet to see wide spread application. Depending on the size of the devoted rooftop farm, this type of green roof can sell fresh produce to local businesses and restaurants. Alternatively, on smaller projects the rooftop farm can satisfy the needs of the building occupants.

The advantages of growing food on rooftops are widespread. Produce can be grown at a lower cost because of the reduction in transportation costs when transporting the goods from outside the city. There are also savings in emissions brought about by the elimination or reduction of transportation. The produce on green roofs can have a greater level of control with regard to fertilisation and pesticides meaning that consumers can be assured of better quality, organic produce. This could make the green roof a viably profitable and lettable space, which, no doubt is attractive for developers.

The Fairmont Hotel, Vancouver, is a good example of a rooftop farm that supplies its restaurant with fresh produce that has been harversted(195m2). It is estimated that this saves the company up to $30,000 per year on fresh produce. Earth Pledge (see image above) is a smaller venture that operates in a similar fashion by providing the restaurant below with fresh produce.

2.2 Economic:
Reducing Heating and Cooling Costs



Council House 2
Environmental Diagram
source: http://www.melbourne.vic.gov.au/rsrc/Images/CH2/bio-northsouth-10-12-03.jpg

2.2c Reducing Heating and Cooling Costs

In the short-term, savings can be achieved in heating and cooling costs because the layer of vegetation provides excellent insulation to the building. The green roof acts as thermal mass keeping the internal temperature of the building relatively constant. It keeps the building cool in the hotter months and warm in the cooler months minimizing the dependence on HVAC systems.

2.3 Environmental: Increased biodiversity

Sechelt Justice Service Centre
Sechelt, Canada

2.3a Increased Biodiversity

Green roofs replace habitats that have been lost due to development. It is therefore important to choose the variety of vegetation that suits the local environment to maximize the effect of the green roof on biodiversity. Green roofs offer a safe place for birds, insect and other plants to grow.

2.3 Environmental:
Improved eficiency of photovoltaic cells.

Primary and Secondary School
Unterensingen, Germany

2.3b Improved Efficiency of Photovoltaic Cells

In recent times, Europeans have been testing the efficiency of photovoltaic cells in combination with green roofs and have found that due to the significantly lower temperatures on green roofs, photovoltaic cells run up to 25% more efficiently. These types of projects are increasing in popularity as they reduce the reliance on dirty energy, which results in dollar savings.

2.3 Environmental: Water runoff Managment

Stormwater management
source: http://commons.bcit.ca/greenroof/faq.html

2.3c Water Runoff Management

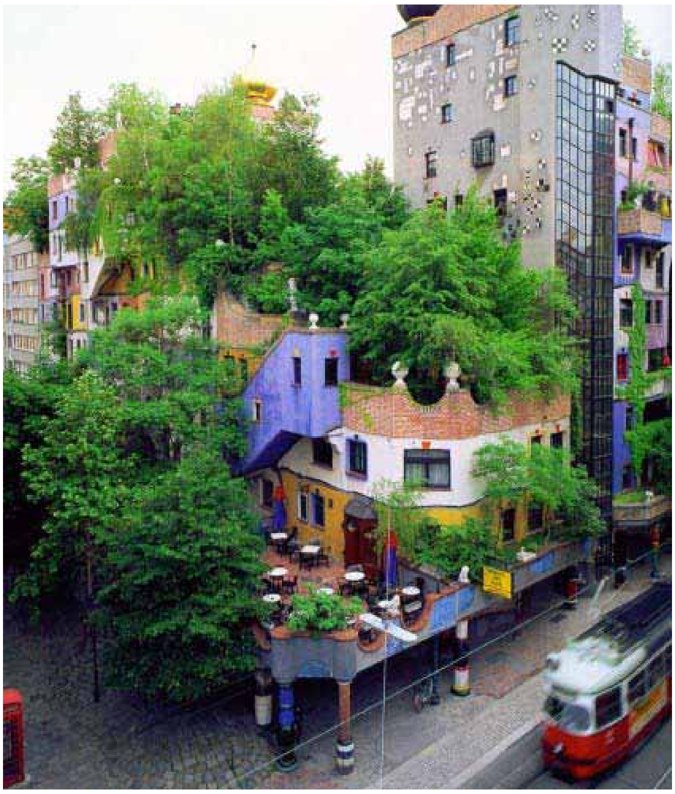
Storm water management is a key environmental advantage of having a green roof and benefits the environment at both the local and regional scale.

When water hits a traditional roof it is often distributed across the roof surface, picking up sediment as it does and being flushed down public drains and into the storm water system. In times of heavy rainfall, this system can over flow, mixing with raw sewerage and become very polluted. It then finds its way into the waterways such as our rivers or oceans.

A green roof significantly reduces the rate of flow from the roof to the storm water system because the water is absorbed into the substrate. This reduces the chance of storm water flooding. This water can also be harvested, stored and used for irrigation or non-potable use.

A second advantage is that the substrate actually filters the water as it passes through, therefore distributing much cleaner water to our waterways than water that has run directly off a bitumen surface.

2.3 Environmental: Improved Air Quality

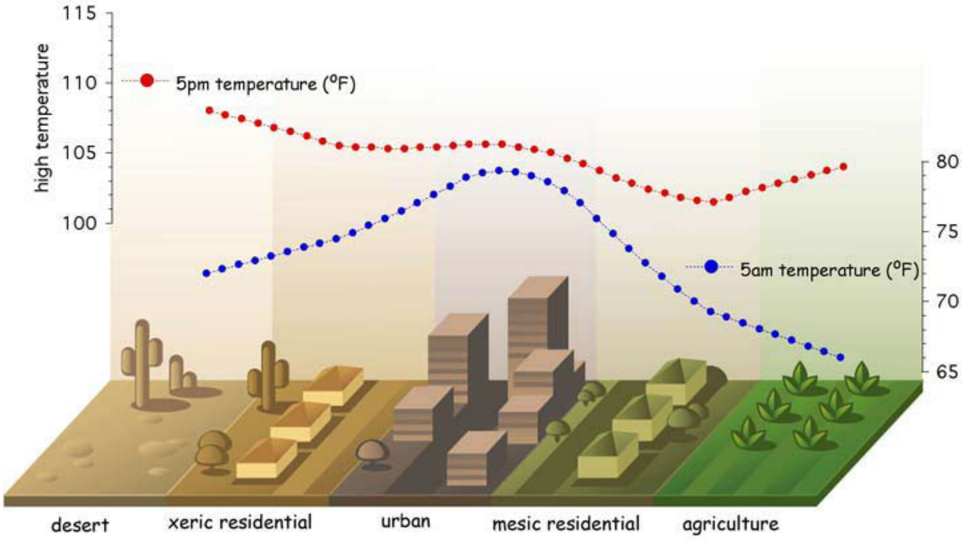


Improved air quality
source: http://greenroofs.wordpress.com/

2.3d Improving Air Quality

Vegetation also has the ability to improve the air quality in the local environment. Predominantly larger types of vegetation such as shrubs and trees can capture air borne particles on their foliage, which eventually get washed into the substrate. However, any plant converts carbon dioxide into oxygen through a process of photosynthesis therefore improving the quality of air in the local environment.

2.3 Environmental: Reduced Urban Heat Island Effect



source: http://asusmart.com/urbanclimate.php

2.3e Reduction in Urban Heat Island Effect

As was mentioned earlier, the greater incidence of green roofs the greater the environmental effect. This is of particular importance with respect to the urban heat island effect. This phenomenon occurs because of the density of hard, heat absorbent materials in urban areas, which cause an increase in the average urban temperature.

Green roofs replace heat absorbent and reflective materials and therefore lower the temperature on top of roofs. If this is duplicated over many rooftops it can reduce the urban heat island effect.

2.3 Environmental: Reduction in Noise Pollution

source: http://gothamist.com /attachments/jen/2006_11_ congestion.jpg

2.3f Reduction in Noise Pollution

Green roofs can markedly reduce noise pollution in urban environments. The layer of substrate and the layer of vegetation work in combination to minimize lower and higher frequencies respectively.

2.3 Environmental:
Reduce the Risk of Fire

source: http://www.ecobackyard.com/wp-content/uploads/2007/03/

2.3g Reduction in the Risk of Fire

Green roofs in some circumstance can slow the rate that a fire will spread through a building so long as the substrate has a level of moisture in it. A saturated substrate will have more of an effect in slowing the rate in which a fire spreads. However if a green roof is particularly dry with dead foliage, this advantage will be lost.

3 TYPES OF GREENROOFS

3.1 Extensive

Ford Motor Company
Michigan, USA

3.1 Extensive Green Roofs

An extensive green roof is the most basic form of green roof. Like all green roofs, an extensive roof comprises of the following components; A water proof membrane, a root protection layer (although typically this can be combined with the membrane in an extensive roof system), a drainage layer, a filter mat, growing medium and finally, vegetation.

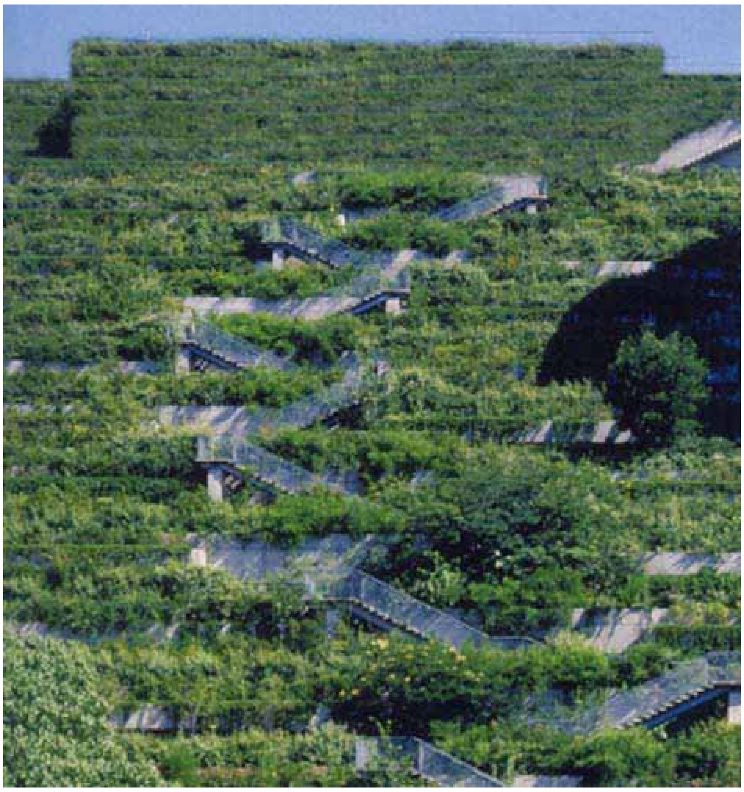
It is typically found to have a soil/substrate of no more than 15cm in depth. As a result of the shallow substrate depth, the range of vegetation is limited to low growing vegetation types including; grasses, moss and sedums. The composition of the growing medium is crucial in an extensive green roof system. It is important to avoid an overly fertile substrate as this will encourage competition amongst vegetation species and may result in an uneven coverage of vegetation. The ideal scenario is to have a moderately fertile substrate that maintains a constant coverage yearlong.

An extensive green roof system is commonly used in situations where no additional structural support is desired. Typically, an existing roof will be able to support an extensive system that can weigh up to 100kg/m2. However, it is essential to seek advice from a structural engineer before installing a green roof.

Extensive green roofs are not design to be accessed on a regular basis. This minimises the structural demand for the roof. However it is important to have some degree of access for maintenance.

Extensive green roofs require maintenance in the first 2 years to ensure that the vegetation has stabilised and there are no competing weeds. Beyond the first 2 years, maintenance is minimal and may only be required once or twice annually.

3.2 Intensive



ACROSS
Fukuoka, Japan

3.2 Intensive Green Roofs

On the other end of the spectrum, intensive green roofs are the most comprehensive roofing system. It is generally designed to maximise the environmental benefits that can be achieved from a green roof whilst also providing for public amenity. An intensive green roof can also support the production of food produce. Food production on city rooftops can drastically minimise, if not eliminate the need for transporting fresh produce and thus reduce carbon emissions.

The components of an intensive green roof are the same as all other green roofs, however each component requires much more consideration with regards to its form and materiality due to the sensitive relationship between vegetation types, water harvesting and growing medium.

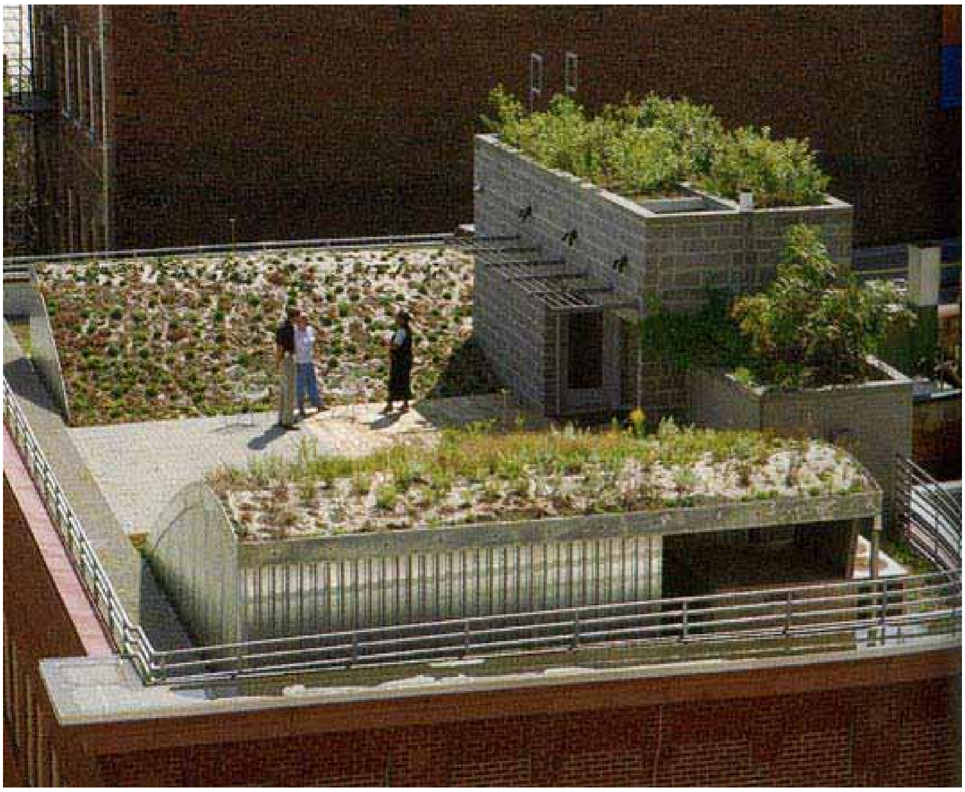
An intensive green roof needs to balance the quantity of water harvested, the fertility of its substrate and the varieties of vegetation chosen. Other considerations that are important are the load capacity of the roof deck, accessibility and other roof top structures.

Intensive green roofs offer greater substrate depths, typically greater than 15cm. The greater soil depth allows a larger variety of vegetation to grow. However, different plant types have different requirements with regard to growing medium, nutrients and water needs, which will ultimately affect the selection of materials to be used in the green roof system. Therefore it is important to realise that extra consideration should be given to the selection of plant species when there are a large variety of plants to chose from.

Similarly to any green roof, consideration needs to be given to the structural capacity of the roof deck to compensate for the extra load. It is essential to obtain the advice from a structural engineer on each individual roof. An intensive green roof can have a saturated weight of up to 1000kg/m2

Maintenance for intensive green roof systems is the most involved and depends on the type of vegetation that is grown.

3.3 Semi Extensive



American Society of Landscape Architects
Washington D.C, USA

3.3 Semi Extensive Green Roofs

A semi-extensive green roof is a hybrid of the two systems (extensive and intensive). A semi-extensive roof system is appropriate when the rooftop can be viewed from adjacent buildings but the possibility for access is limited and the structural capacity of the roof deck could not support an intensive green roof.

A semi-extensive green roof allows for a slightly deeper substrate depth than a traditional extensive green roof but it still enjoys the relatively minimal maintenance that an extensive green roof system has.

Due to the relatively deeper substrate, a semi-extensive roof can support a greater variety of vegetation than an extensive green roof, which means that the architect or landscape architect has more flexibility in the aesthetic design of the green roof.

The selection of vegetation on the roof is important as it will directly determine the level of maintenance required to keep the green roof functioning properly.

A semi-extensive green roof applies an extra load to the building, as do the other green roofs. Generally the semi-extensive green roofs can weigh up to 630kg/m2 depending on the selection of materials. Always consult with a structural engineer to assess the structural capacity of the subject roof deck.

3.4 Choosing Roof Type Based on Structural Capabilities

Schiphol Plaza
The Hague, The Netherlands

3.4 Choosing a Green Roof Based on Structural Capabilities

When deciding to install a green roof on a building, one of the first and most important decisions is to choose the appropriate type of green roof (extensive, intensive or anywhere in between). This decision will be based on only a few pieces of information and is relatively easy to make.

The structural capability of the roof deck is the most fundamental determinant that will influence the type of green roof chosen. This factor is particularly important in a retrofit situation whereby the load capacity is predetermined unless additional structural support is allowed for. In a new development however, the extra load of a green roof can be accounted for if it is factored in at the early stages of the design process.

Typically, in a retrofit application, a roof deck would have been designed to support extra weight such as storm water and a protective layer of gravel. Therefore it is usually within its means to support an extensive green roof system. However it must be stressed that a structural engineer must be consulted on all projects before a green roof is installed.

3.5 Choosing Roof Type Based on Functional Requirements

source: http://www.greenroofs.org/img/grhc2004_ford1_medium.jpg

3.5 Choosing A Roof Type Based on Functional Requirements

Another determinant that assists in selecting the correct green roof type is an understanding of the functional requirements that are desired from the green roof. If for instance, the sole objective of the green roof is to achieve environmental benefits then there is no point installing an intensive green roof. In contrast if it were desired to provide public amenity for the building occupants or to grow food produce, then an intensive green roof would be the correct system to choose.

4 LANDSCAPE DESIGN CONSIDERATIONS

4.1 - Membranes

Image: Process of waterproofing followed by insulation, drainage layer and growing medium

4.1 Waterproof Membranes

Waterproofing is fundamental in a successful green roof design. When retrofitting an existing building with a green roof, an audit of the existing membrane must be undertaken by a qualified professional. Usually the green roof application will trigger the installation of a new membrane that meets green roof specifications.

There are several choices of waterproof membranes.

- Thermoplastic membranes, such as PVC (polyvinyl chloride) or TPO (thermal polyolefin) using hot air infusion methods are commonly used.

- Elastomeric membranes like EPDM (ethylene-propylene rubber materials) have high tensile strength and are well-suited to large roof surfaces with fewer roof penetrations. Modified bitumen sheets are usually applied in two layers and are commonly available.

- Liquid-applied membranes are generally applied in two liquid layers with reinforcement in between. The quality is variable.

Membrane types used on green roofs are:

- Liquid- applied
- Single-ply sheet membrane (specifically designed for green roofs)
- Built up layer system consisting of 3+ layers

4.1 - Membranes (continued)

Modified bitumen membrane with root barrier

Far Left: Fabric laid membrane on hot rubberised asphalt
Right: Root barrier membrane added to hot asphalt

4.1 Waterproof Membranes (continued)

A factor in choosing a waterproofing system is its' resistance to root penetration. Protection of the waterproof membrane should be provided by either adding a root barrier or using a membrane that is resistant to penetration (more cost efficient). (Van. SSCDG. 2005.)

Some membranes (usually bitumen or organic materials) are susceptible to root penetration and micro-organic activity and need to be separated from the growing medium by a continuous root barrier unless they contain an adequate root repelling chemical or copper foil. (Ngan, 2003.)

Chemically incompatible materials such as bitumen and PVC require a separation layer. (FLL, 2002).

When the installation is complete, the waterproof membrane should be tested by flooding and inspection. On advice, an electronic leak detection system may be installed under the membrane. In best practice, a building professional will identify the areas that require waterproofing, recommend the appropriate systems and products and provide technical specifications. (Van. SSCDG. 2005)

4.2 - Drainage

Image: After membrane is installed it is tested for leaks by flooding the area

4.2 Drainage

Good drainage is fundamental in a successful green roof design. Standing water in the soil profile has risk implications in terms of increasing the potential of moisture breaching the waterproofing membrane. If the water drains freely through the profile and is collected and drained away, the risk is reduced. In addition, most plant material requires an aerated, non water-logged soil profile for healthy growth.

Yet the capability of green roofs to retain and/or detain a certain amount of rainwater and to delay the runoff during storm events makes them valuable in managing urban storm water systems. In addition, water stored in the profile can reduce irrigation demands.

A balance should be found between the storage of water in the soil profile and the drainage of storm water on green roofs.

The drainage system must consider surface water, sub-surface water and transporting water from the roof to either the stormwater system or rain water tanks. Surface water may be removed by proper sloping of pervious and impervious surfaces to roof drains or gutters. Roof outlets must not be allowed to become covered with greenery or loose gravel and they must be permanently accessible.

Subsurface water is collected by providing sufficient void space and slope to allow excess sub-surface water to drain through the profile and be transported to roof drains or gutters where it can be removed from the roof. (Allan Wingfield, 2005)

4.3 - Drainage Materials

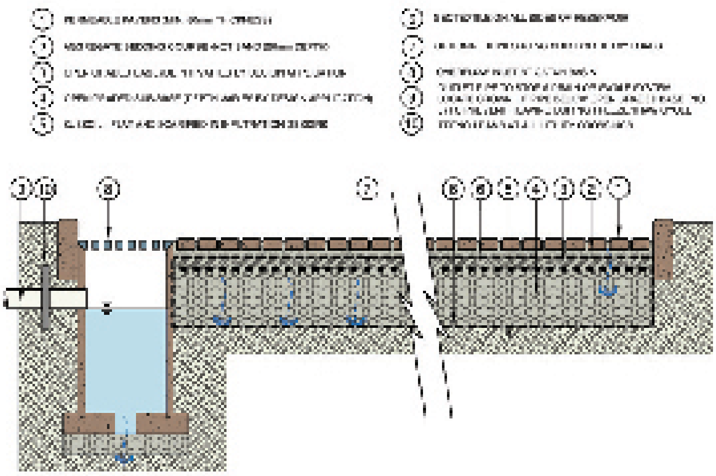


Image: Drainage aggregate profile

4.3 Drainage Materials

The drainage course materials and dimensions will depend upon construction requirements and objectives for vegetation. The construction requirements relate to; the drainage function, the design loads and the protective function. The objectives for the vegetation relate to; the prevention of water-logging, a retentive or reservoir water supply, the type of vegetation sought and increasing the depth of the course available for root penetration.

When the drainage course is being formed, a distinction is made between the following groups and types of materials.

- Mineral Aggregates:-
  - Expanded slate & clay
  - Lava & pumice
  - Gravel & fine chippings
- Re-cycled Aggregates:-
  - Brick hardcore
  - Slag
  - Crushed / foamed glass
- Drainage Matting
  - textured non-woven matting
  - studded plastic matting
  - fiber type woven matting
  - flock type foam matting

4.3 - Drainage Materials (continued)

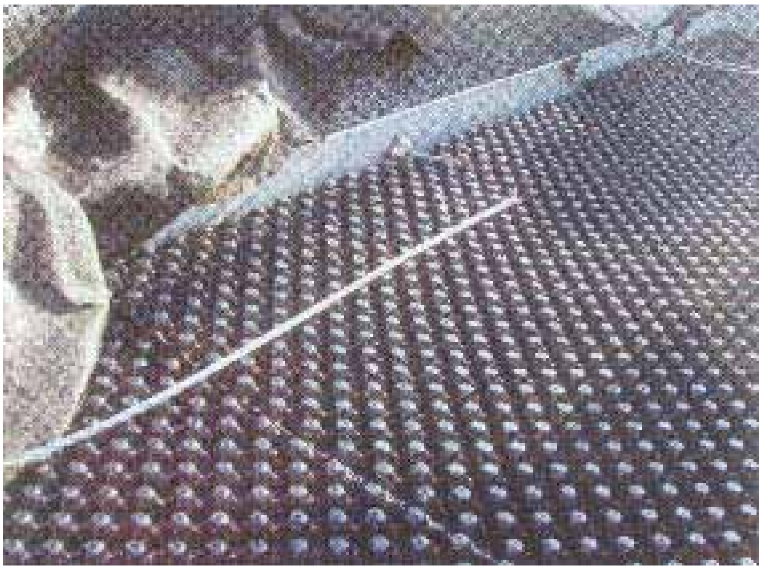


Image: Water retention and drainage mat

4.3 Drainage Materials (continued)

* Drainage Modules:-
    - high strength, thermoplastic, inter-locking cells that transport and capture high water volumes and protect the w/p membrane.
* Drainage Boards:-
    - boards made from foam pellets
    - studded rubber boards
    - shaped rigid plastic boards shaped plastic foam boards
* Drainage and substrate boards
    - boards made from modified foam (FLL. 2002)

4.4 - Modular Systems

Pre growing modular extensive trays which are crained onto the rooftop

4.4 Modular Systems

The drainage, soil substrate or medium, and the plants are self-contained within a lightweight high-density polyethylene module, of varying dimensions. In effect, these three main components of a greenroom are replaced by a fully planted module. When interlocked they offer continuous roof drainage and coverage. (Linda Velaquez, 2003)

Advantages

* rigid enough to support media/plants;
* capable of storing water and incorporating irrigation;
* create a free flowing drainage layer beneath
* removable in sections to allow repair to membranes.

4.5 - Additional Load of Drainage Course

Drainage Course Materials

Design loads at maximum water capacity for materials, matting and boards

Material Group Material Type	Grain Size In mm	Surface load Kg/m²
Mineral aggregates		
Gravel	4/8 – 8/16	16 - 18
Lava	2/8 – 8/16	11 - 14
Pumice	2/8 – 4/12	11 - 12
Expanded clay, crushed	2/8 – 4/8	6 – 8
Expanded slate, crushed	2/8 – 4/11	6 - 8
Recycling aggregates		
Brick hardcore	4/8 – 8/16	10-13
Slag	n/b	n/b
	Course depth In cm	**Surface load for entire course kg/m²**
Drainage matting		
Textured non woven fabrics	1,0	5,6 – 7,5
Studded plastic matting	1,2	2,1 – 2,3
Fibre-type woven matting	1,0	2,2 – 2,3
Fibre-type woven matting	2,2	2,2 – 2,3
Flock-type foam matting	3,5	5,6 – 5,9
Drainage boards		
Studded rubber boards	2,0	11,0 – 13,0
Foam-type drainage boards	5,0	1,8 – 2,5
Shaped hard plastic boards (R)[1]	4,0	19,0 – 21,0
Shaped foam-type drainage boards (R)[1]	6,0	16,0 – 18,0
Drainage and substrate boards		
Modified foam-type boards	3,0	22,0 – 26,0

[1] Fill to the top of the compartment with 4/8 lava *(FLL 2002)*

4.6 - Filter Course

Extensive profile

4.6 Filter Course

A geotextile layer is used to separate the drainage layer from the growing medium, preventing the fine particles present in the growing medium layer working through the profile vertically and ending up in the drainage layer and thus blocking the drainage layer or, in turn the stormwater system. An additional advantage is protecting the membrane.

Filter courses are typically used and are available as woven or non-woven materials. These filters need to be tough to withstand abuse while other layers are installed, while being open enough to provide good flow for water into the drainage layer. The purpose of the filter course is to prevent fine soil particles from washing into the drainage layer causing clogging and the reduction in the capacity of the drainage layer. The filter may be a separate layer or part of the geo-composite drainage mat or board. The filter layer may be independent of the drainage layer or an integral part of a geo-composite drain. The filter layer typically should be installed parallel with the drainage layer.

Material groups and types

Current practice, reflecting the most recent developments, calls for the use of geotextiles in the form of non-woven fabrics as filter courses. Either the fabric is laid on top of the drainage course in a separate operation or it forms an integral part of ready-made matting.

Non-woven fabrics consist of aligned or randomly laid fibres of any length. These fibers may be bonded using a mechanical, chemical or thermal process, or a combination of the three.Where non-woven fabrics are affixed mechanically with pins, they should be detector proof.

4.6 - Filter Course (continued)


Semi intensive profile

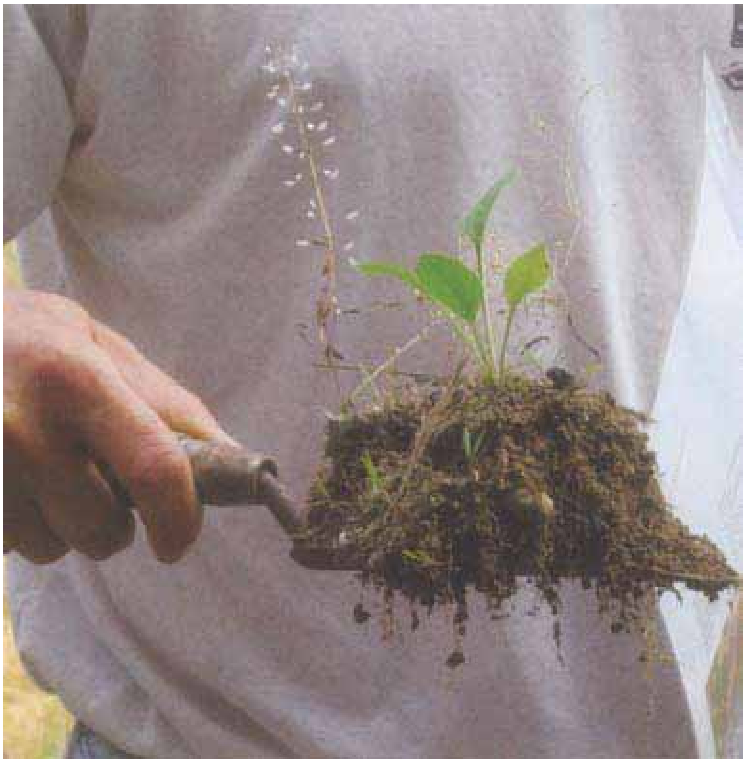
4.6 Filter Course (continued)

Requirements

In the use of geotextiles note must be taken of the following characteristics:-

- environmental compatibility
- plant compatibility
- behaviour under fire
- weight per unit of surface area
- cut through resistance
- effectiveness of mechanical filtration / aperture width
- susceptibility to root penetration
- resistance to soil-borne solutions and micro-organisms
- tensile strength, flexibility, coefficient of friction

4.7 - Growing Medium



4.7 Growing Medium

The growing medium or soil substrate can be selected from several engineered factory mixes or can be custom designed by a soil expert. By using a mixture of native soil upgraded with organic or mineral additives (peat, humus, wood chips lava or expanded clay), it is possible to achieve optimum water retention, permeability, density and erosion control necessary to support the green roof vegetation. Although sometimes successful in smaller projects, it is not advisable to use ordinary garden soil, as degeneration often results from compacting and acidification.

Light weight growing medium is often a combination of pumice, lava rock, expanded clay pellets or other light weight absorbent filler, with a proportion of organic matter (between 6 – 8 % : FLL 2004) When properly sized a mineral-based growing medium is able to retain storm water as effectively as soil high in organic matter without the disadvantage of compacting and breaking down over time. Light weight growing medium can be subject to wind erosion during the initial stage of plant stabilization and may need a control blanket or surface grid pinned to the medium.

Research has shown that using only topsoil may introduce unwanted properties (such as weeds and pathogens). Generally, a guide for substrate is approx. 75-80% inorganic (i.e. expanded slate or crushed clay) to 20-25% organic (humus plus some clean topsoil). This will provide essential drainage and soil air capacity, and sufficient organic nutrients for the shallow rooted plants. Note that weight requirements will increase with a higher concentration of topsoil. The lesser the depth of the substrate, the higher the physical demands on the plants, resulting in root damage from heat and frost fluctuations.

4.7 - Growing Medium (continued)

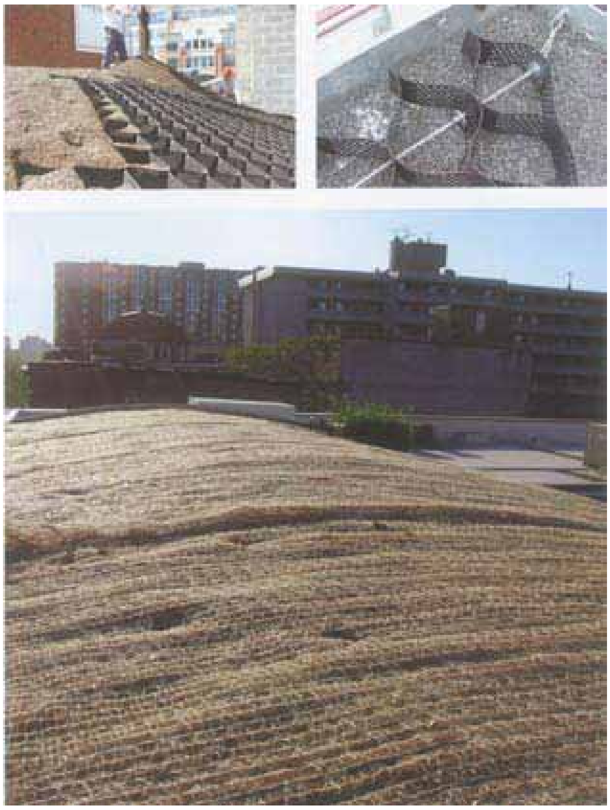


Image: Coconut husk fibre

4.7 Growing Medium (continued)

One growing media of recent note is a combination of tree sap and coconut husk fiber, a waste product from coconut plants. The media is placed in porous, biodegradable trays which are installed on roofs like tiles. The trays quickly become locked together as the plant roots grow from each tray.

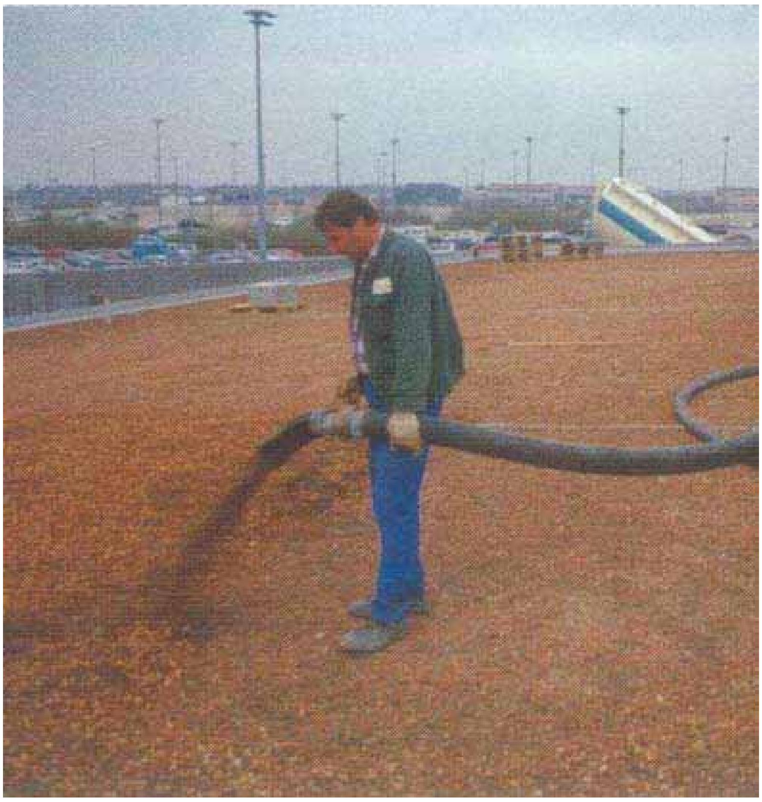
It is important to note that when designing a green roof, it may be wise to choose a plant community which may be found in nature, and then, there is one soil type, one irrigation system, one drainage issue etc. Rather than choosing a wide variety of plant species requiring a range of growing media.

One example of a similar environment to a rooftop is the Robertson Plateau beyond Wollongong. There, the growing media is derived from Hawkesbury sandstone which is poor in mineral plant food and often shallow. However, it does contain particles of weathered mud and clay, enriched by decaying plant matter and bushfires add ash with valuable minerals. When all is considered, the plant communities which grow in this soil would also thrive on high-rise rooftops in Sydney.

Landscape suppliers generally carry top soils that have been mined from a variety of local sites. Such top soils tend to be inherently variable, and it is advisable to perform some simple tests on them to be sure of their quality.

A growth media expert should advise on correct mixtures which will be site specific.

4.8 - Types of Growing Medium



4.8 Types of Growing Medium

When the vegetation support course is being cultivated, a distinction shall be made between the following groups and types of materials for vegetation substrates, depending on the materials and type of construction used. Types of greening and different forms of cultivation are also factors which are to be taken in to consideration:

- soil mixture
  improved top and underlying soil
- aggregate mixtures
  mineral aggregate mixtures with high organic content
  mineral aggregate mixtures with low organic content
  mineral aggregate mixtures with an open-pore granular structure with no organic content
- substrate boards
  made from modified foam materials
  made from mineral fibres
- vegetation matting
  with mineral/organic aggregate mixtures

In regard to requirement relating to the proportions of organic content the following differentiation is made:

- substrates with apparent density of ≤ 0.8, and
- subtrates with apparent density of >0.8
  both in dry condition

4.8 - Types of Growing Medium (continued)

Lite Soil

4.8 Types of Growing Medium (continued)

The materials and dimension chosen for this course will be determined by local construction requirements and by objectives for the vegetation.

Construction requirements relate to:

- the drainage function
- design load
- the protective function

Objectives for the vegetation relate to:

- the demands imposed by the desired type and shape of the vegetation
- the need to ensure that all functions are assured on a permanent basis
- limiting the up keeping costs whilst the site is maturing and once it has become established

In a layered superstructure where the depth of the vegetation support course is 35cm, or thereabouts, or greater, a distinction needs to be made during cultivation between an upper substrate and an entirely non-organic lower substrate.

Where extremely thin courses are used, vegetation matting can also act as the vegetation support course. When laid on a substrate course, this arrangement is classified as a type of greening. Substrates for vegetation matting shall be consistent with the group of mineral aggregate mixtures with a low organic content. In terms of composition and granulometric distribution, they differ from the mixtures installed as a course.

4.8 - Types of Growing Medium (continued)

Sedum matting ready to roll onto an extensive profile

4.8 Types of Growing Medium (continued)

Requirements

Attention shall be paid to the following properties, depending upon the type of greening which is being undertaken, in respect of vegetation support courses:

- Environmental compatibility
- Behavior under fire
- Mineral content by volume
- Structural and bedding stability of aggregate type materials
- Water permeability
- Air content
- Salt content
- Adsorptive capacity
- Proportion of foreign substances
- Plant compatibility
- Granulomatic distribution
- Frost-resistance
- Behavior of matting under compression
- Maximum water capacity
- pH value
- Nutrient content
- Seeds capable of germination/plant parts

(FLL; 2002)

4.9 - Additional Load of Growing Medium

Growing Medium

Design load at maximum water capacity for vegetation substrates, substrate boards and vegetation matting

Substrate group Substrate type	Surface load of the entire course kg/m^2
Soil mixtures, sand mixtures	
Soil mixtures with mineral and organic additives	16 – 19
Sand mixtures with material and organic additives	16 – 18
Mineral aggregates with a high organic content	
Peat-mineral material mixtures (stabilized cultivated peat substrate)	10 – 13
Bark humus / compost-mineral mixtures (stabilized cultured bark substrate)	11 – 13
Mineral aggregates with a low organic content	
Lava mixtures	15 – 18
Pumice-lava mixtures	13 – 16
Expanded clan and expanded slate mixtures	10 – 13
Slag mixtures	7 – 15
Brick clay-pumice mixtures	16 – 18
Mineral aggregates with an open-pore grain structure	
Lava	11 – 14
Pumice, cleaned	7 – 8
Pumice, not cleaned	11 – 12
Expanded clay, crushed	7 – 8
Expanded slate, crushed	7 – 8
Recycling aggregates	
Brick clay	10 – 13
Slag	n/b

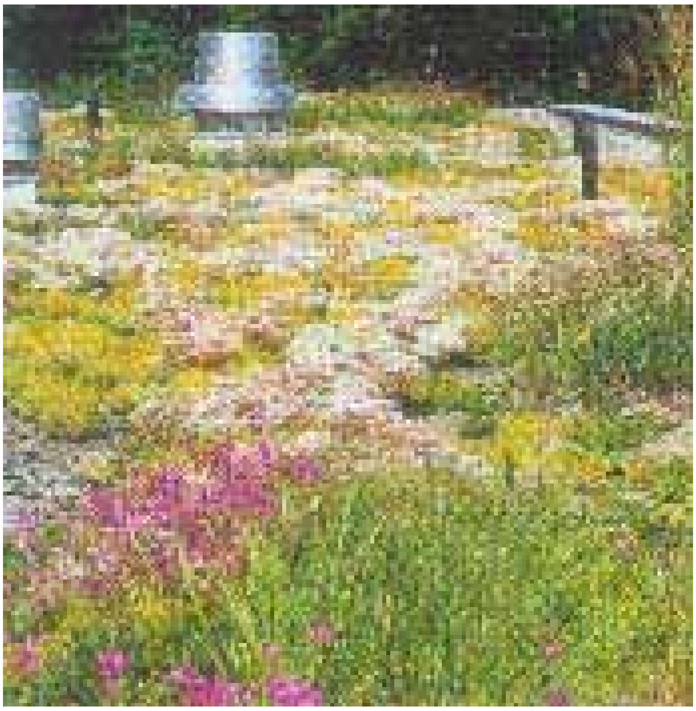
4.9 - Additional Load of Growing Medium (continued)

Substrate boards	
Modified foam boards	8 - 12
Rock wool boards	8 – 10
	Surface load of the entire course kg/m²
Vegetation matting	
Fibre-type woven matting	25 – 35
Natural-fibre matting	20 – 50
Nonwoven fabric matting	20 – 30
Turf lawn 2 cm nominal depth	30 - 40

n/b = not found

(FLL. 2002)

4.10 - Planting



Sedum and native grasses on extensive profile

4.10 Planting

Primary considerations for the selection criteria for plants include: design intent, aesthetics, site conditions (both macroclimate and microclimate), plant characteristics (including rate of establishment, longevity, disease & pest resist), growing media composition, installation of plants (pre-cultivation or direct planting) and maintenance of plants.

The design intent and eesthetics (visual appeal) refers to the functional use of the site and would best be carried out in consultation with an architect or landscape architect.

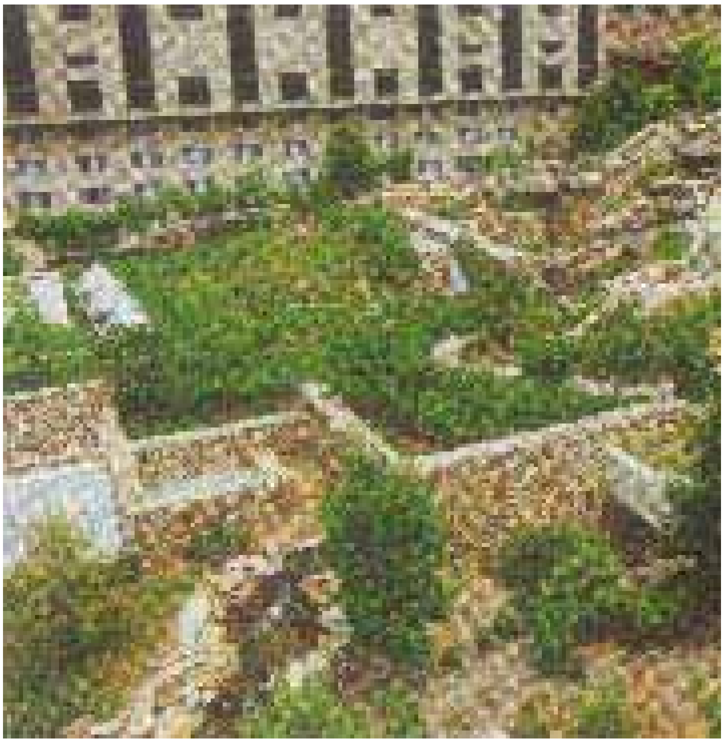
If a green roof is to be a lasting success, it is absolutely essential that site conditions are identified to see if they are suitable for vegetation. The factors which determine the quality of any given site may be listed under the following headings:

- climate and weather dependant factors
- structure-dependant factors
- planning-dependant factors

Climate and weather dependant factors:

- the regional climate
- the pattern and volume of annual precipitation
- any incidence of periods of drought
- the direction of the prevailing wind.
- the local microclimate
- average exposure to sunshine
- any incidence of periods of frost

4.10 - Planting (continued)



Intensive planting

4.10 Planting (continued)

Structure dependant factors

- areas exposed to the sun, shaded areas and areas where sun and shade alternate
- deflection of precipitation by the structure
- effect of flue gas emissions
- wind flow conditions
- exposure of roof surface
- stress due to reflecting facades
- additional water load from adjoining structural elements
- the gradient or slope of the roof surfaces
- design loads and the depth derived from the layered superstructure

Planning dependant factors

For Intensive greening, attention needs to be paid to the following factors:
- certain individual varieties, particularly evergreens, are not completely hardy under winter conditions and where the plant cover is of limited density
- shrubs and coppices in exposed conditions must be able to withstand the wind
- certain types of plants are sensitive to reflected light and thermal build-up
- all vegetation is sensitive to airborne chemical and exhaust contamination, also to warm and cold air emissions.

4.10 - Planting (continued)

Native grass - Themeda Australis
A hardy native, capable of growing in extreme conditions

4.10 Planting (continued)

For Extensive greening attention needs to be paid to the following factors

- the effect of wind and solar radiation on solar stocks
- the demands made by plants in dry locations upon air resources in the layered superstructure
- sensitivity to airborne chemical contamination, also to warm and cold air emissions
- the transformation towards forms of vegetation at alternatively damp or permanently damp locations in shady conditions or in wet areas, e.g. at zero-gradient-roofs.

Characteristics of landscaping typically used in extensive green roof systems, regenerative qualities, resistance to direct radiation, drought, frost and wind.

In extensive greening the following forms of cultivation can be defined

- moss and members of the Sedum family
- members of the Sedum family, moss and herbaceous plants
- members of the Sedum family, grass and herbaceous plants
- grass and herbaceous plants (dry lawn)

A much larger variety of plant selections is available for intensive roof-scapes due to the greater soil depths. Intensive greening covers virtually the entire range of plants and landscaping options available when planning open air amenities, giving an unlimited choice of forms. Limitations as to the use of trees and large bush-type coppices will depend on the property in question. Where there are special planting conditions, the range of options can be extended to other types or groups of vegetation.

4.10 - Planting (continued)

Pittosprum Tobira - A suitable native for semi extensive planting

4.10 Planting (continued)

- lawn
- low bushes and coppices
- shrubs and bushes (up to 150 cm tall)
- bushes (up to 3 m tall)
- large bushes (up to 6 m tall)
- small trees)up to 10 m tall)
- trees (up to 15 m tall)

Semi extensive greening which fits in between intensive and extensive greening can involve cultivation in any of the following forms:

- grass and herbaceous plants
- wild shrubs and coppices
- coppices and shrubs or
- coppices (up to 150 cm tall)

Compatibility issues of green roof type, anticipated use, temperature, humidity, rainfall and sun / shade exposure are important elements for successful plantings of any kind. Most importantly for the artificial environment of a green roof, native and culturally adaptable plants need to be reviewed for heat and drought tolerance, as most systems are designed to be low maintenance. City high-rise green roof plants experience extreme conditions so it is important to recognize the nature of such plants to ensure survival. The most important factors to consider include the levels of sunlight or shade required, growing media, heat/cold tolerance, periodic fluctuations in moisture and tolerance of windy conditions (sea-salt content)

4.10 - Planting (continued)

Sydney endemic species of Deg Rose growing at a similar altitude to a 40 storey building

A hardy Sydney creeper Apple Berry would provide good ground cover

4.10 Planting (continued)

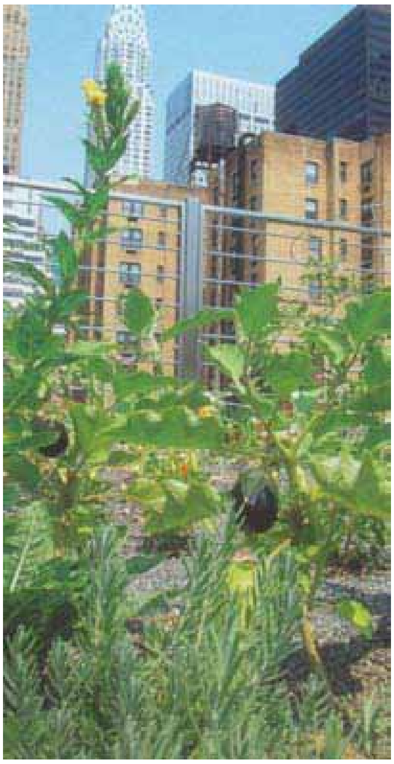
Avoid specifying or allowing volunteer plant materials with aggressive root systems (eg. bamboo, couch grass, tree seedlings). This can be avoided by the supply and installation of growing medium which is free of weeds. (Ngan, 2003)

The chances of creating a self-maintaining plant community are increased when a wide mix of species is used; hence, best practice is to avoid swaths of one species. Planting methods include seeding, hydro-seeding, spreading of sedum sprigs, planting of plugs or container plants and installing pre-cultivated vegetation mats.

Plant species endemic to the Sydney area range in variety due to the topography. The topography and underlying rock type affect the nature of soil, aspect, drainage, shelter, height above sea level and temperature.

The aim is to choose an endemic species which will grow in a rooftop environment. Ideally, choosing a variety of species from one plant community will simplify the execution and management of a green roof: i.e. same growing media, same drainage system etc.

4.11 - Agriculture


4.11 Agriculture.

Amongst their numerous ecological, social and economic benefits, green roof infrastructure provides significant potential for increasing production of food through urban agriculture.

Urban agriculture provides many interacting, synergistic, benefits to a city. Environmental benefits include: a reduction in the distance over which food is transported, therby lowering emissions of carbon dioxide and other air pollutants; lowering the heat island; increasing bio-diversity; and the potential to use urban organic wastes as a productive resource (eg, compost or biogas production).

The difference when considering food crops is that they require high levels of nutrient intake to sustain growth, which usually requires a deeper growing medium between 300 to 450 mm. This intensive profile is deep enough to provide a quality growing medium and, with appropriate protection from the climatic extremes of roof top environments (particularly wind and temperatures), will be able to grow large quantities of high quality produce. The continuing development of lightweight growing medium and hydroponic techniques means that food will be grown intensively on a wide range of roof types.

4.12 - Suitable Plants for Australian Greenroofs

Australian plants for extensive green roofs

Habit	Botanical Name	Common Name
Grasses and Tussocks	*Poa poiformis*	Blue Tussock-Grass
	Themeda triandra	Kangaroo Grass
	Dictichlis distichophylla	Australian Salt-Grass
	Spinifex sericeus	Hairy Spinifex
Succulent ground creepers	*Carpobrotus rossii*	Karkalla
	Tetragonia implexicoma	Bower Spinach
	Enchylaena tomentosa	Ruby Saltbush
Ground creepers	*Scaevola aemula*	Fairy Fan-flower
	Scaevola albida	Small Fan-flower
	Scaevola calendulacea	Dune Fan-flower
	Myoporum parvifolium	Creeping Boobialla
Climbers	*Zygophyllum billardierei*	Coast Twin-leaf
	Nitraria billardierei	Nitre Bush

Australian plants for intensive green roofs

Habit	Botanical Name	Common Name
Woody prostate perennials	*Kunzea ambigua*	Prostate Kunzea
	Kunzea pomifera	Muntries
	Leptospermum continentale 'Horizontalis'	Prickly Tea-tree 'Horizontalis
	Leptospremum rotundifolium Round Tea-tree	
	Grevillea lanigera 'Mt Tamboritha'	Mt Tamboritha Wooly Grevillea
Small low shrubs and herbs	*Pelargonium australe*	Austral Stork's-bill
	Correa alba	White Correa
	Correa reflexa	Native Fuschia
	Correa decumbens	Spreading Correa
	Ixodia achillaeoides	Ixodia Daisy
	Leucophyta brownii	Cushion Bush
	Allocasuarina pusilla	Dwarf Sheoak
	Rhagodia candolleana	Sea-berry Saltbush
	Acacia verticillate	Prickly Moses
Tufted perennials	*Dianella revoluta*	Black-anther Flax-lily
	Lomandra spp.	Mat Rush
	Patersonia longiscapa	Long Purple-flag

(Dr. Raelene Mibus,2006)

4.13 - Surface Loads Generated by Various Forms of Vegetation

Vegetaion: Surface loads generated by various forms of vegetation

Form of load	Design kg/m^2
Extensive greening sites	
Greening with moss – sedum	10
Greening with sedum – moss – herbaceous plants	10
Greening with sedum –grass – herbaceous plants	10
Greening with grass – herbaceous plants (dry lawn)	10
Simple intensive greening sites	
Greening with grass – herbaceous plants (grass roof, rough-grassed area)	15
Greening with wild bushes – coppices	10
Greening with coppices – shrubs	15
Greening with coppices (up to 150cm tall)	20
Intensive greening sites	
Lawn	5
Low bushes and coppices	10
Shrubs and bushes up to 150cm tall	20
Bushes up to 3m tall	30
Large bushes up to 6m tall	40
Small trees up to 10m tall	60
Trees up to 15m tall	150

(FLL 2002)

4.14 - Irrigation

Gravity fed drip mats laid on modular planting trays

4.14 Irrigation

Green roofs must achieve a balance between adequate drainage and being able to store water and not dry out too quickly and this is accomplished by choosing appropriate drainage products and growing media. Variables which effect water requirements are:
- selection of specific plant community, greater plant diversity or the design parameters of a green roof.

Ideally, even thin systems work optimally with two layers, separated by a geotextile. The lower level is very light-weight granular mineral material (usually fired clay). The roots of the plant will penetrate through the geotextile and will concentrate along the bottom of this layer. Here the roots will find best conditions for survival (cool temps and more consistent moisture). Irrigation would be included in the granular layer – further encouraging propagation of roots at the bottom. If the substrate is chosen to have good water retention qualities, this system will support a variety of plants without irrigation. When roots are encouraged to grow higher up in the profile, they are much more vulnerable to the effects of varying temps and moisture.

If the substrate / drainage system cannot hold a certain amount of free water, then additional forms of water storage may be necessary and can be supplied by several methods (modular systems which have water storage cups incorporated).The most ecologically correct systems would be those that are considered sustainable, requiring no or little human interaction.

Completely self sustainable passive water retention systems include using ponding elements fixed directly to the protection membrane, and generally can be installed on roofs up to a 4% slope. A more active system can incorporate the ponding ridges along with a drain with weir level regulator and an automatic irrigation control.

4.14 - Irrigation (continued)

Solar powered automatic water collection and irrigation system

4.14 Irrigation (continued)

Another option is an active, sustainable, solar powered automatic water collection and irrigation system. These systems also have the added sophistication of a maximum and minimum on/off switch to make allowances for possible overnight rainfall filling the reservoir. Additional cisterns can be added to store excess rainwater and recycled later.

Again, depending on variables mentioned above, the roof design may have water retention capabilities e.g. a damming fixture can be installed into the drainage outlets, with inspection chambers or adjustable terrace grills for easy maintenance. Similarly, using large drainage channels which can store up to 40mm of water underneath. The water reaches the plants by capillary action, and the inspection chamber allows access for maintenance (a compliment to this would be a retention fleece mat below the growing media which also has the ability to retain moisture)

Additionally, either a simple automatic drip irrigation system with a manifold delivering water at the base of the profile can be installed, or a complete (heavy and costly) irrigation system can be incorporated into any intensive green roof design which can withstand the weight.

A permanent, subsurface drip irrigation system will deliver water into the root zone and keep it there. Two versions exist (flat and sloped surfaces) and consist of five elements – (i) pressure compensating drip line (ii) polyester geotextile to transfer water to the soil (iii) treated geotextile to inhibit root intrusion and bacterial slime growth (iv) poly tape cover to spread water (v) polyethylene base to inhibit gravitation loss of water. The line delivers water at about 15 psi. Each emitter releases water into the geotextile very quickly, transforming the line from a point source of water to a continuous source by capillary action.

4.14 - Irrigation (continued)

Modular tray planting which incorporates storage for water in the drainage cells

4.14 Irrigation (continued)

Obviously, the nature of the plant species selected will determine a need for irrigation or not, hence, grouping plant species with the same irrigation requirements is preferable.

If the intent is to harvest water for irrigation for use on the roof, reticulation and storage of the harvested water will need to be a consideration. Collected water should be gravity fed to the storage point and hence, buildings that have a location for water storage at a lower level will require a pump.

4.15 - Typical Greenroof Profiles

Typical Green Roof Profiles

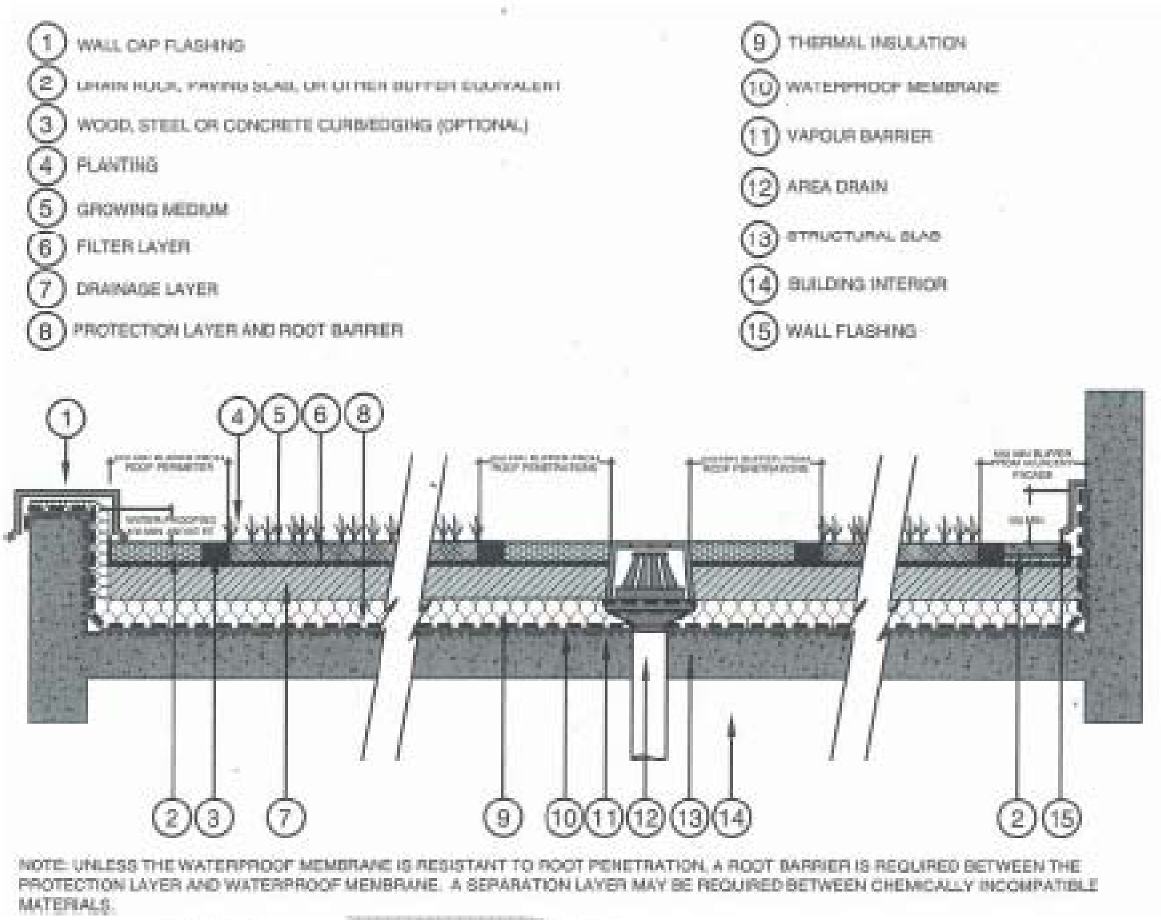


Fig 1. Typical profile for Multiple Layer Extensive Green Roof

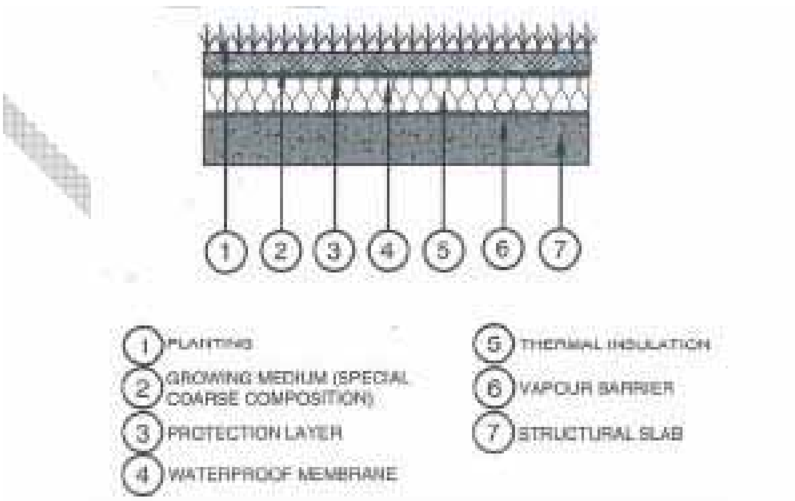


Fig 2. Typical profile for Single Layer Extensive Green Roof

4.15 - Typical Greenroof Profiles (continued)

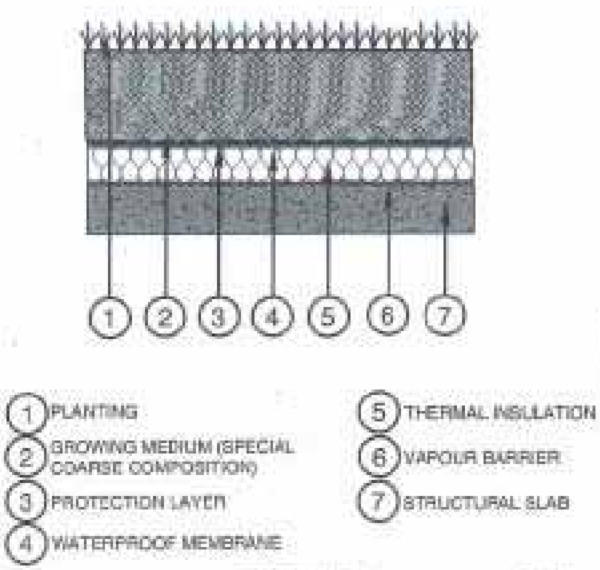


Fig 3. Typical profile for Single Layer Intensive Green Roof

(Van. SSCDG 2005)

5 ARCHITECTURAL DESIGN CONSIDERATIONS

5.1 - Shading and Shelter

American Society of Landscape Architects
Washington D.C, USA

5.1 Shading and Shelter

One of the main considerations to take into account when designing a green roof is the increased exposure to sun and daylight at the upper level of a building. On any rooftop, but particularly rooftops that are higher than surrounding buildings, there will be increased sunlight and a lack of shadow to reduce the intensity of the sun. Under such conditions it is important to provide shade, particularly in summer, for any occupation on the roof. Designers should consider the use of shade structures offering either 100% or a reduced amount of shade to substantial areas of the roof.

The roof area can be treated as a single storey building in regard to passive solar design where the orientation, form and shape of the shading structure can influence the access to winter sun and the provision of summer shade. The orientation of the rooftop structures may also be oriented towards the sun and principle wind directions independent of the form of the building below.

The design of shading structures needs to take account of the increased wind pressures at the higher levels of a building and be engineered to withstand the increased uplift forces and the likelihood of severe storm events, including hail.

5.2 - Roof Top Rooms / Meeting Places

Villa Savoy Solarium
Source: http://parisoasis.blog65.fc2.com/blog-entry-166.html

5.2 Rooftop Rooms/Meeting Places

Part of the intention in developing a green roof, is to increase access to the roof areas for both the occupiers of the building and the general public. This access to the roof can allow for a number of activities to occur, including:

- Access to the green garden areas for maintenance
- Access to green gardens for education and teaching
- Access to the green technologies for service and maintenance
- Provision of a meeting place for educational activities
- Access to areas for cultural activities such as religious or spiritual meetings
- Access to spaces for general meetings (eg: of the body corporate)

Such meeting places can take one of two forms, which we may characterise as “Roofless Walls” and “Wall-less Roofs”.

Roofless Walls take the form of courtyards, where extending the walls of the building or creating new walls can deflect the increased wind pressures that are found at the rooftop. Such structures provide protection for not only people but also the planting from particular wind directions. It should be noted that the wind pressures on roof tops are significantly increased over those found at ground level (see structural considerations). These walls can take various forms; a celebrated example is the use of the curved wall on the roof of the Villa Savoye by Le Corbusier, near Paris (picture).

Wall-less roofs may take the form of a “veranda” where shade is provided from the roof above which is supported essentially on posts or columns. This form of rooftop structure can provide shade (see above) and can provide rain protection for outdoor areas to provide a suitable place for meetings.

5.3 - Plant Rooms

American Society of Landscape Architects
Washington D.C, USA

5.3 Plant Rooms

Where plant rooms are required for services to the building two approaches can be taken.

The area of plant room can be reduced to a series of storage areas on the roof, surrounded by the green roof technologies and green planting. In this instance, the intention is to use the walls of the plant roofs for green walls for further plant growth and to mount green technologies to the roof of the green room.

The second approach is to encorporate all the plant room activities into an additional floor at the top of the building and then cover the entire plant room with a green roof. This approach has the advantage of allowing for additional space for green technologies to be stored in the plant room, in particular the use of solar thermal and solar air conditioning and the plant equipment required for that. In addition, on low rise buildings, water storage can be maintained at the top of the building to provide a header, or supply, to the rest of the building which can also be encorporated into the plant room.

5.4 - Other Structures

M Central
Sydney, Australia

5.4 Other Structures

Where an intensive green roof is involved it is important to think of what other structures may be required to enable access and maintenance.

In the past, typical roof gardens have provided paved areas for pedestrian activity to minimize the wear and tear on the vegetation. However, most paving tiles absorb heat and reduce the benefits of a green roof.

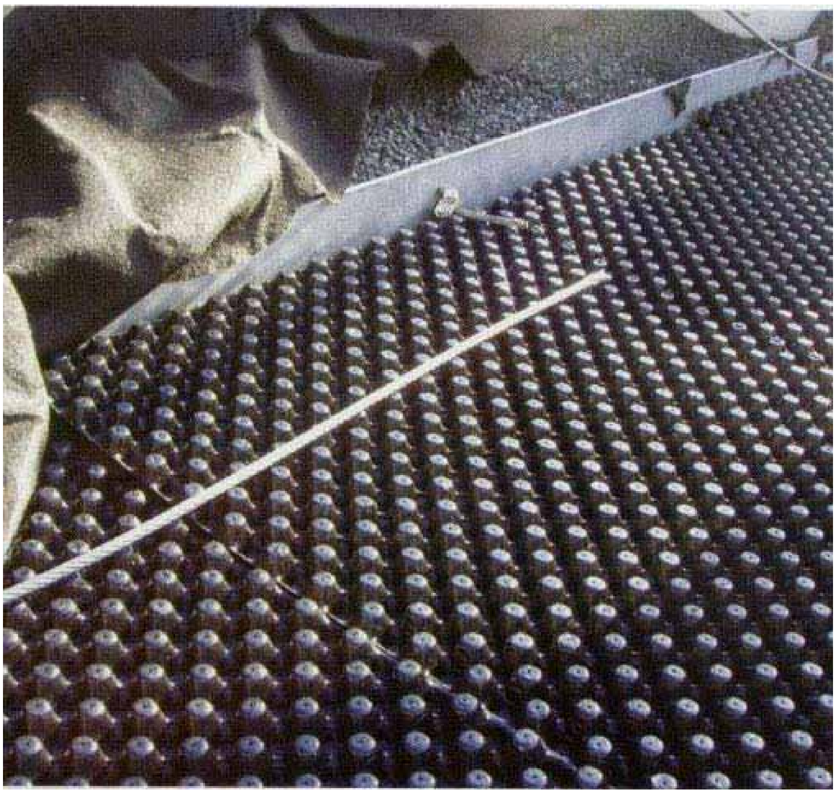
One suggestion to overcome this problem is to install floating walkways or raised platforms, which allow for a layer of substrate to lie beneath. This still enables people to access the green roof for maintenance and recreation but protects the vegetation so that the building reaps the full benefit of having a green roof.

Other structures that may be required on an intensive roof include storage for maintenance equipment and garden supplies. It may be possible in some cases to incorporate storage facilities within the plant rooms (see above). However, where plant rooms do not provide enough space other provisions will need to be considered.

In some cases where the roof is subject to ongoing maintenance or food production, a waste disposal system will need to be thought of. It is important to be able to separate between organic and non-organic waste so that it can be recycled effectively.

6 WATER TECHNOLOGIES

6.1 - Water Collection


Water collection mats

6.1 Water Collection

It is vital for the operation of the green roof to be able to collect all the water that falls on the roof area. Once the green technologies and green planting are installed, it is imperative that the water be collected from all these surfaces, despite the difficulty in the disperse nature and filtered nature of the water.

A key component in the collection of the water is the design of all the green planting beds to be in separate containers suspended above the waterproof membrane where the water is to be collected.

In this way the water that is collected in each garden bed may be filtered at its source prior to entering that water collection system. This may be done by the use of filtration at the base of the green planting beds and may also be done by fitting a filtration system to the water outlet from each garden bed.

The water is collected along the roofing membrane and is usually directed to a series of downpipes. Where retrofit is taking place, the existing downpipe system can be used provided it can be connected to a storage system. Where a new building is under construction the downpipes can be located so that they feed directly to a storage system on the floor below the green roof (a pant roof floor – see above) or the water can be directed to the basement of the building where the water storage takes place.

Sydney's annual rainfall is typically approximately 1600mm of rain per annum. Recent rainfalls indicate that this amount of water can vary widely from year to year, in line with climate change and drought conditions. Recent indications are that the total rain load for one year can be as little as 50% of the annual, ie: 800mm, of rain. Nevertheless, this provides a minimum of 1000 litres for every square metre of roof area provided that the water can be collected in its entirety without losses.

6.2 - Water Storage

KPMG
Dusseldorf, Germany

6.2 Water Storage

The water collected from the roof should be stored in tanks large enough to cope with the fluctuations in rainfall. It should be noted that Sydney's climate has not only a variable rainfall but also that rain may fall in both intense periods and as very light rain.

Storm periods with intense rainfall can create difficulties for the stormwater system, such that the installation of detention or retention tanks within the building can slow down the water flow and reduce the impact on the stormwater system.

For a storage system to be affective in reducing flow to the stormwater system, the tank has to be sized to provide sufficient storage for this maximum rain-flow event. In this case the water storage required is greatly in excess of that needed for the supply of water for the green roof and other uses within the building. That is to say that the sizing of the water storage is more dependent on an analysis on the reduction of storm flow than it is in the provision of water for various uses within the building.

Thus, the size of water tanks required will necessitate a large volume to be taken within the building. These tanks can be located on a plant room floor at the head of the building or more commonly, as basement water tanks at the lowest level of the building, even under car parking requirements as the requirement to pump water for water pressure is a relative low energy demand, particularly in regard to the space advantages in locating the water storage beneath the building.

Water storage systems for larger buildings usually entail the construction of a purpose specific tank using concrete structures, which are waterproofed and integral to the building, rather than the use of steel, polyethylene, or other tanks. The use of polyethylene liners to these purpose built tanks can reduce the requirements for waterproofing to the tank directly.

Access to the water storage tanks is vital to enable maintenance to be undertaken on the tank and to be able to undertake any repairs if required.

6.3 - Water Use and Filtration

6.3 Water Use and Filtration

It is important to identify the potential sources of water use prior to the design of the system. Where buildings have a small ration of roof area to total floor area, the water collection will be low relative to potential demand. Thus the water collected on the roof maybe best stored for reuse in the green planting on the roof as its first priority and only then water being used throughout the rest of the building.

Alternatively, the water collected within the building from fresh water supply (from basins, showers etc) can be collected in a grey water system and recycled for use in the roof (see below).

Unlike a conventional roofing system, where the water collected is relatively uncontaminated except by air pollution, the water collected on a green roof may collect contamination from the green plant material and any fertiliser which is used and from pollution from human occupation of the roof as well as any air pollution. Thus it is necessary to cleanse that water before it is used for any purpose within the building.

6.3 - Water Use and Filtration (continued)

Water Use and Filtration (continued)

Water can be filtered, and therefore cleansed, in a number of ways:

- The first filtering of solid contaminants can take place in pipe work leading to the storage tank. These are some times referred to as a first flush diverter that harvests off a small portion of the water that contains the initial contaminants. Given the desirability of collecting all water from the roof, no water should be diverted, but rather a solid filter to remove large-scale elements should be introduced prior to the entry into the tank.
- The tank itself provides the possibility of filtration of the large particulate matter, which can fall to the bottom of the tank.
- The water can be further filtered through a series of physical filters such as sand filters, similar to swimming pool filters, or cartridge filters that can be cleansed and replaced. These physical filters can be used to remove not only large scale physical matter but also particulates down to a nominated micron size.
- Bacterial contamination can be removed by the passing of water through a UV filter in order to sterilise the water to a level which may be raised to be fit for potable uses.

In designing for the storage systems within buildings it is important to make an allowance for the filtration area and for its ongoing servicing. The filters typically use either a physical barrier or an osmotic membrane, both of which require the use of electrically driven pumps to force the water through the filtration system this will increase the energy demand which can be offset with the use

6.4 - Grey Water Systems

6.4 Grey Water Systems

Grey water refers to the water collected from uses where minimal contamination may have occurred such as the water from basins, showers, baths and certain sinks. This is distinct from water that may be collected from toilets and urinals and commercial sinks where the water has a higher level of contamination, particularly with faecal content and is referred to generally as black water (see below).

The advantage of grey water is that it is only lightly contaminated and the contamination can be removed relatively easily, giving a grade of water that can be reused within the building for a number of purposes, in particular for use on roof and plant material for toilet flushing and for use within laundries directly into the washing machines.

Grey water cleansing systems are now available as a packaged system, which allows for the collection of the grey water to be cleansed and then stored either with the rainwater or in separate tanks. In order to separate the grey water from the black water it is necessary to install a separate collection system, which requires the construction of two sewer collection systems; one for grey water uses and the other for black water. This will increase the capital costs of construction however the grey water and black water systems often run in parallel using the same vertical risers and can lead to a reduction in the overall size of pipe work required for each of the stack systems.

Grey water is typically cleansed on a daily basis by the operation through a specialised filtration system and the water is then stored in a tank which may be combined with the rain water or maybe a standalone tank. The grey water collected from the building has an initial filtration system via a sump that requires space to be set aside for the sump storage system as well as for the filtration system generally.

Typical grey water systems are available from such companies as Perpetual Water (see website), Aqua Clarus (see website).

6.5 - Black Water Systems

6.5 Black Water Systems

Black water refers to water that has been contaminated with bodily fluids or with organic matter which renders its filtration difficult. Although it is possible to cleanse this water on site, it typically requires the installation of a quasi-sewerage system in order to filter, cleanse and polish the water sufficient for uses within the building. Wherever a building is connected to a sewer system it may be more advantageous and cost effective to direct the black water directly to the sewer system rather than to install a complex sewerage system in order to recover the water.

In this regard it is important to note that it is essential to collect all the rainwater and use it throughout the building for purposes where it can be recollected and polished in a grey water system to be used once, or more times throughout the building before being passed into the black water system for direction into the sewer.

7 SUSTAINABLE ENERGY TECHNOLOGIES

7.1 Solar Water Heating

Solar Hot Water Systems
source: http://www.quixotic-systems.com/imx/w4thermal.jpg

7.1 Solar Water Heating

Solar water heating is an excellent and reliable alternative to electric water heating. Not only does it use free renewable energy that converts to real savings but also it reduces greenhouse emissions of up to 7 tonne P/A when used in a domestic situation (Aussie Solar).

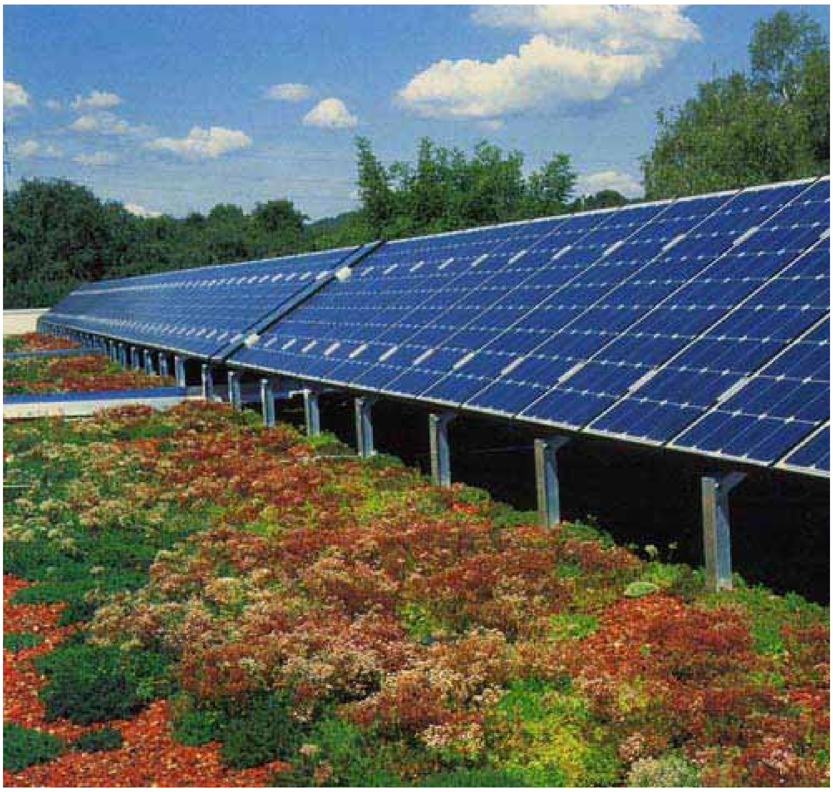
Green roofs provide a perfect opportunity to install a solar hot water system because they provide uninterrupted solar access to the flat solar collectors

Solar hot water systems come in a variety of different types but can be categorized into two main groups; active solar hot water systems and passive solar hot water systems. The difference between the two types is that active systems have pumps and circulators whilst passive systems do not.

Every solar hot water system has two main components, a tank and a solar collector. The size and type of solar hot water system required will need to be discussed with a suitable consultant before installation. They will be able to inform you of the particular details that will best suit your project.

Another advantage of installing a solar hot water system on a green roof is that a government rebate is paid for the installation of all new solar hot water systems. This makes the installation and payback period more affordable.

7.2 Solar PV



Primary and Secondary School
Unterensingen, Germany

7.2 Solar Photovoltaic Cells (PV)

Green roofs provide an excellent environment for the installation of PV cells and the generation of solar power. Rooftops by nature are the perfect place to install PV cells because of their unimpeded access to solar energy.

Recent studies have shown that a green roof provides an even better environment for PV cells than a traditional rooftop. As a result of relatively cooler conditions on top of green roofs (brought about by the layer of vegetation), PV cells operate with greater efficiency. Cooler conditions also improve the life span of the PV cells because constant high temperatures can threaten the long-term stability of the cells.

PV cells come in two different varieties (flat-plate systems & concentrator systems) and a multitude of different sizes depending on the functional requirements of the system. The type and size of the system must be discussed with a licensed solar panel operator.

Similar to solar hot water systems, a government rebate can be obtained for the installation of a new PV cell system, reducing the payback time period.

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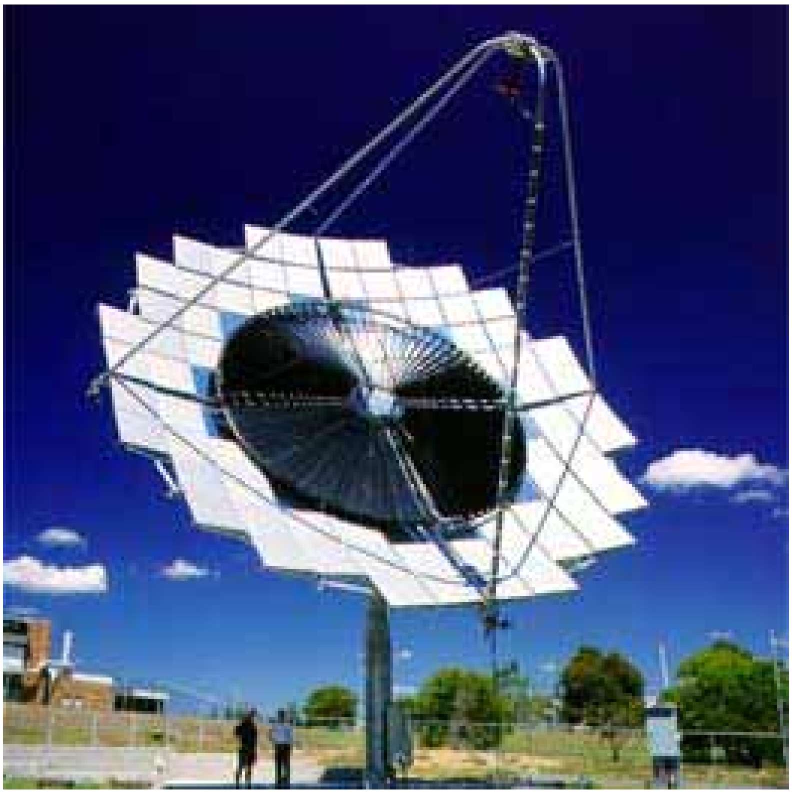
7.3 Solar Thermal



Parabolic solar thermal dish

source: http://www.det.csiro.au/assets/solar_sm.jpg

7.3 Solar Thermal

Although solar thermal technology is most commonly used in large-scale solar energy plants, there are opportunities to use this technology on green roofs.

Solar thermal as a renewable energy source is different from photovoltaic cells in that it does not convert the suns energy directly into electricity. Solar thermal technology concentrates the suns energy via a series of specifically directed reflectors or mirrors onto a receiver, which stores the collected heat. The collected heat is then used to heat a circulated fluid (water). This heat can then be stored and used both day and night.

Typically, solar thermal technologies are most efficient in larger scale operations. Large parabolic reflecting dishes (see above) absorb heat from the sun and store the heat to generate electricity. This type of solar thermal technology can be installed on larger green rooftops. However, care should be taken if the same green roof is available for public amenity because the parabolic dish can reflect harsh and unsympathetic light.

A more common application for solar thermal technology on a green roof would be its use in solar hot water systems. A general, domestic solar hot water system is a type of solar thermal technology.

7.4 Wind Power

Wind Turbines
source:http://www.theage.com.au/ffximage/2004/06/22/wind_farm,0.jpg

7.4 Wind Power

Rooftops are typically a windy environment, especially on taller buildings in urban environments. This provides opportunity to install wind power generators on rooftops to supplement other renewable energy technologies. It must be noted that wind power technology should be used as a supplement only because it may not be able to provide reliable energy to fulfil all of a buildings requirements.

When considering putting a wind power turbine on a green roof, special consideration needs to be paid to its location and the safety of any users that might be accessing the green roof space.

A consultant should be contacted to see if wind generated electricity is suitable for your green roof.

8 MAINTENANCE

8.1 How to Maintain A Green Roof

Milwaukee Metropolitan Sewerage District
Wisconsin, USA

8.1 How to Maintain a Green Roof

Different Green Roof types require different amounts of maintenance depending on where they lie on the intensive-extensive spectrum (see Section 3: Types of Green Roofs). As a general rule, all types of green roofs require a higher level of maintenance in their first 2 years until colonization has occurred and the vegetation has stabilized.

The first maintenance check should be carried out after the water proof membrane has been installed. The roof should be flooded to check for any leaks or weaknesses in the membrane. Once the membrane has been checked and cleared for having no leaks then the remaining components of the green roof can be installed. After the vegetation has been installed, the requirements for maintenance include; watering in dry periods (if an irrigation system has not been connected to a water supply), removal of weeds, light fertilization with slow release complete fertilizers, and the replacement of dead plants.

It is recommended that the maintenance contract for the first 3-5 years be awarded to the same company that installed the green roof, as the installers should have experience with green roof systems. It is advisable that the maintenance service be included in the original bid price. (Peck and Kuhn, 2001)If it is not possible to arrange this, a clear separation of responsibilities must be identified between the original contractor who installed the green roof and the new contractor who will maintain the green roof.

8.1 How to Maintain A Green Roof (cont.)

8.1 How to Maintain a Green Roof (continued)

Once the vegetation has been established, a typical extensive green roof should require only one or two annual visits for weeding of undesired plants, clearing of plant-free zones and inspecting of drains and the membrane. Other types of green roofs will require more frequent maintenance, particularly if food is being produced (see section 8.2 for more information on maintenance and food production).

Consideration should also be given to the selection of materials used on a green roof, as this will have a direct impact on the amount of maintenance required. Hardy, long lasting materials that behave well in external environments are preferable so that there is minimal upkeep involved. Materials should also be environmentally friendly with respect to the amount of energy consumed to produce the material. Locally sourced materials are preferred to imported expensive ones.

How to Manage Food Production on Green Roofs

Centro de Informacion
Mexico City, Mexico

8.2 How to Manage Food Production on Green Roofs

Managing food production on rooftops is a new concept in Australia but has been practiced to some degree internationally for some time. Food production can only be sustained on an intensive green roof and will require some type of irrigation system and labour intensive management.

The size of the area allocated to food production will ultimately determine the level of maintenance that is required. In some buildings, the food production may only be enough to satisfy the building occupants. However, in larger buildings, with a greater area allocated to food production, food could be sold at local markets or directly to restaurants.

Not only does local food production save money in transportation costs, which can be passed on to the consumer, but it also is excellent for the environment. The consumer can purchase fresh, locally grown, organic fruit and vegetables at an affordable price and because the food is produced locally, emissions are drastically reduced, if not eliminated because the food does not have to be transported long distances from the farms to the table.

One management technique that is being used in New York is the establishment of Community Supported Agriculture (CSA). These are smaller, locally based farms whereby members pay an annual fee which helps the farmers establish and maintain the varieties of crops. In return the members receive a weekly share of the harvest throughout the growing season. This ensures fresh produce is always delivered and quality control can be measured.

How to Manage Food Production on Green Roofs (cont.)

8.2 How to Manage Food Production on Green Roofs (continued)

If the green roof is small and the supply of fresh produce is only required to satisfy the needs of the building occupants, a cooperative may be set up whereby a rostered maintenance schedule is developed. In this case each member of the cooperative would be responsible for some degree of maintenance. This would only be suitable in smaller applications.

The type of maintenance that would be required for food production would include, irrigation, light fertilization, harvesting and ensuring the health of the crops is maintained.

9 FINANCIAL CONSIDERATIONS

Costs

9.1 Costs

Currently there is no accurate information in Australia to suggest how much an installation of a green roof will cost. It will depend largely on the functional requirements, size, depth of the substrate, selection of materials and quantity of renewable energy technologies and water technologies.

It has been suggested that green roofs can cost up to $55/m2, not including vegetation. However the cost will vary greatly depending on the type of vegetation that is to be planted and whether or not the vegetation has to be planted on an individual basis or can be pre-grown on a vegetation mat.

Return on Invenstment

Funding Models

9.3 Funding Models

Different funding models have been set up internationally to support the growth of environmentally friendly practices. In the United States, the Clinton Climate Initiative has been established to fund programs that result in substantial reductions in greenhouse gas emissions. The fund is worth $5 billion and is used to finance retrofit projects at no net cost. The loan and interest repayments are repaid through the savings achieved by a reduction in energy consumption. The fund is available to municipalities and private building owners to reduce greenhouse gas emissions in the city.

The Bronx Environmental Revolving Loan is a similar type of funding model that provide zero interest loans to local businesses and private building owners who implement energy efficient measures such as installing a green roof.

Incentives and Grant Programs

9.4 Incentives and Grant Programs

There are numerous incentives and grant practices that have been established world wide in which Australia could lend from. Fortunately, there are already rebates offered for the installation of various renewable energy technologies and/or the installation of water tanks for grey water systems (see Sections 6 & 7).

In NSW, both residential and non-residential applicants are eligible for rebates. Under the Climate Change Fund (CCF), successful applicants are entitled to a rebate of up to $1500 for rainwater tanks, $1200 for solar hot water systems and $300 for ceiling insulation. For more information on NSW rebate schemes visit www.environment.nsw.gov.au

Other financial incentives could be introduced to expand the Climate Change Fund that would specifically target applicants who wish to install a green roof. The City of Toronto, for example, has a program running in which applicants are eligible to receive a $50/m2 rebate up to a predefined limit for the installation of a green roof.

Below are some of the policies that are working successfully overseas.

Green Roof Incentives

- Subsidies/Financial incentives

Supported by a legislative framework that supports Green Roofs on new buildings, Germany, also offers many incentives for the retrofit of existing roofs. A survey of 186 German cities found that 48 offered financial subsidies for ecological gardening activities such as water reuse systems, removing impervious surfaces, building green roofs, green facades, trees, wildflower meadows, shrubs and hedges, biotopes, bird houses, composts etc.

9.4 Incentives and Grant Programs

How does it work?

The most common method of direct financial incentive for green roofs in Germany is to provide a specified sum per square metre. Such direct financial incentives offered by German cities for green roof installations range from 5 to 60 Euro/sqm. Other methods used include calculating the percentage of costs and construction or construction and design. Often 10 to 50% of cost is subsidised. Programs often provide design and technical advice to support this funding.
In North Rhine Westphalia, green roofs are recognised for their water retention benefits and generous subsidies of 25% of the costs of roof greening (to a maximum of 1,500 Euro) are provided in the city state of Bremen.

Other cities, such as those in the state of North Rhine Westphalia combine direct and indirect financial incentives. Subsidies are provided through reduced runoff fees, and as recognition in meeting requirements of the Federal Nature Conservation Act and local development plans.

Direct financial incentive programs have also been utilised to target specific areas of a city that may be lacking in green space. An example of this can be found in Munich, where green roof retrofits attract a subsidy of 30 Euro/sqm in specific areas.

9.4 Incentives and Grant Programs

Benefits

According to Goya Ngan direct financial incentives include the following benefits of interest:

- Voluntary
- can be used to target specific areas
- a method that is appropriate to apply to retrofitting green roofs on existing buildings

Weaknesses

Ngan's review found that the sustainability of funds provided through direct financial incentives is questionable. Berlin's direct financial incentive program, the Courtyard Greening Program achieved 54 ha of greened courtyards and roofs and 32.5 ha of greened facades. However, subsidies totalled 16.5 million euro and, as a result of deficits, funding for the program has been substantially reduced to a minimum of projects.
(Ngan, 2004)

Stormwater fee discounts –

An example of the polluter pays principle is Gernmany's Wastewater Charges Act. In Germany, charges are levied under the Wastewater Charges Act by the federal states for discharging wastewater into a body of water. Under a split wastewater system, property owners are charged an annual sanitary disposal fee, and an annual stormwater disposal fee.

9.4 Incentives and Grant Programs

Stormwater source controls, such as green roofs, may earn a discount on fees, for example in North Rhine Westphalia. The program is funded through a portion of the revenue raised from the wastewater charges. Green roofs are often provided with a discount between 50 to 100% on wastewater fees in German municipalities. This equates to an average saving of .50 Euro/sqm per year.

Under such a program benefits have included:

- reduction in stormwater runoff and the problems associated with this.
- Encourages construction of impervious surfaces and source control of stormwater.
- Annual revenue from stormwater fees ensures longevity of funding available.
- A more permanent incentive, rather than a one off payment. This may assist with long term mainte nance of green roofs

Some issues identified though this program have included:

- The administrative costs of the program
- The need to monitor compliance of green roof systems with stormwater retention functions (Ngan, 2004)

9.4 Incentives and Grant Programs

Assisted Development Application process

An appropriate incentive for encouraging green roof retrofits is through assisted development application process. Current retrofits are required to complete a development assessment process to the same standard as larger scale developments and with associated fees. For a building owner considering the installation of a green roof, the current detailed assessment process, time and cost of application may act as a deterrent. Through an expedited approval process, with reduced fees and the provision of technical advice, a building owner is able to spend more time and money on sustainable improvements.

In Chicago, such a mechanism is currently being applied to the rehabilitation of Chicago bungalows through the Historic Chicago Bungalow Initiative (HCBI). This program is a collaboration of the City of Chicago Departments of Housing and Environment, Illinois Clean Energy Community Foundation, Illinois Housing Development Authority and the Chicago Architecture Foundation. The program provides an entire framework of financial and technical resources for the rehabilitation of Chicago bungalows including:

- Rehabilitation loans and grants
- Directory of product and service providers
- Technical information and library resources
- Discussion forums
- Information seminars for building owners
- Tax incentives
- Design guidelines
- Case studies
- Newsletters
- Permit assistance (see below)

9.4 Incentives and grant Programs

In support of the program the Chicago Department of Construction and Permits (DCAP) provides permit assistance for rehabilitation works to certified bungalows. This assisted permit process includes:

- The provision of information through the HCBI website
- The provision of example pattern drawings for common projects
- The provision of assistance in the preparation of plans and documents required for building permits through technical DCAP staff. (HCBI, 2007)

References

Ngan Goya, 2004, Green Roof Policies: Tools for Encouraging Sustainable Design", www.gnla.ca, accessed 31 October 2007.

Historic Chicago Bungalow Initiative. http://www.chicagobungalow.org/member/index.shtml, accessed 15 December 2007.

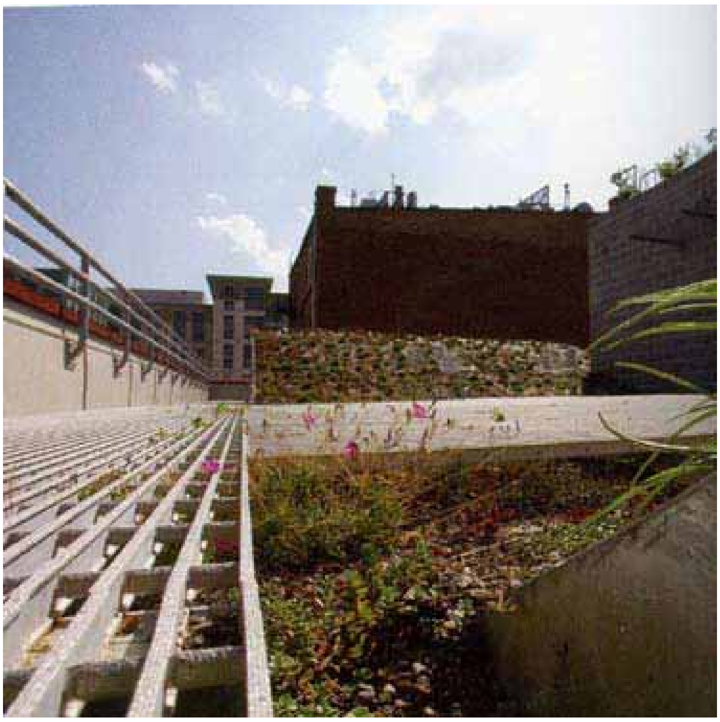
CASE STUDIES

american society of landscape architects

1 2 3 4 5 6 7

type	semi extensive - whilst this roof is meant to be accessed by the inhabitants of the building, it is still extensive. A lightweight, high density foam supports the thin substrate on the hills. A metal grate floor system sits proud of the vegetation below it, to allow for the benefits of green roofs while still having public
construction	a multi layered system - in most multi layered systems, the water proof membrane, root protection board, drainage layer and growing medium are apllied seperately.
extras	Nil

1. The ASLA building. Illustrates how a light weight roof structure can still allow for public access . The vegetation in the background is supported by a light weight high density foam



american society of landscape architects

1 2 3 4 5 6 7

type	semi extensive
construction	a multi layered system
extras	Nil

2. A detail of the metal grate flooring

american society of landscape architects

1 2 3 4 5 6 7

type	semi extensive
construction	a multi layered system
extras	Nil

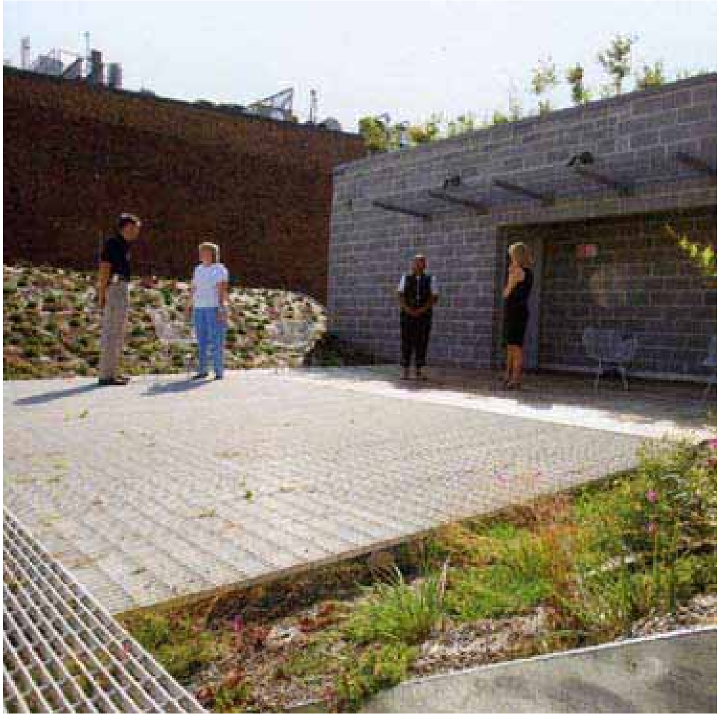
3. People enjoying the ASLA rooftop for lunch

american society of landscape architects

1 2 3 4 5 6 7

type	semi extensive
construction	a multi layered system
extras	Nil

4. The two feature waves are lightewight construction.



american society of landscape architects

1 2 3 4 5 6 7

type	semi extensive
construction	a multi layered system
extras	Nil

5. Illustrates how the vegetation runs beneath the metal grate floor structure to maximise the benefits of a green roof.

american society of landscape architects

1 2 3 4 5 6 7

type	semi extensive
construction	a multi layered system
extras	Nil

6. A detail of the metal grate flooring

american society of landscape architects

1 2 3 4 5 6 7

type	semi extensive
construction	a multi layered system
extras	Nil

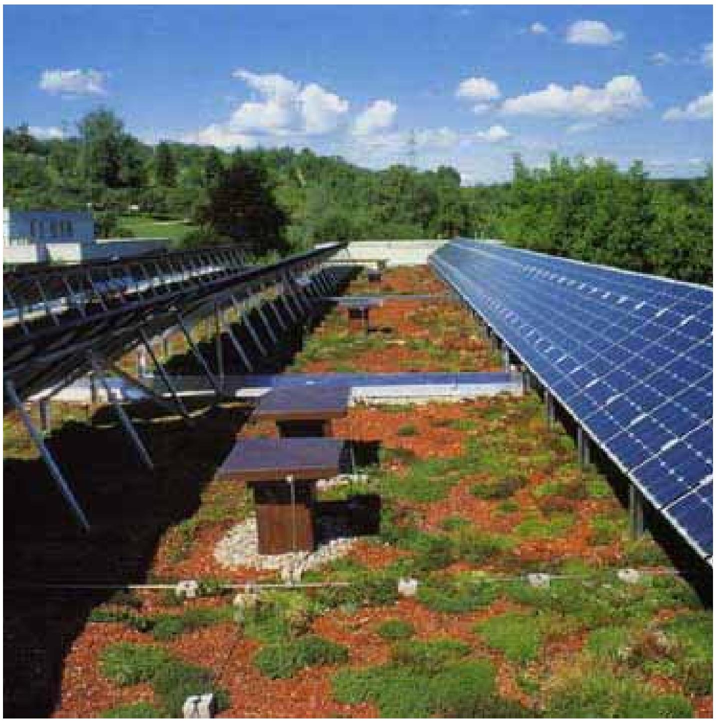
7. The ASLA green roof

primary and secondary school

1 2 3 4

type	extensive
construction	a multi layered system
extras	solar panels

1. This school is set up to teach children about the benefits of using solar panels in conjunction with green roofs.



primary and secondary school

1 2 3 4

type	extensive
construction	a multi layered system
extras	solar panels

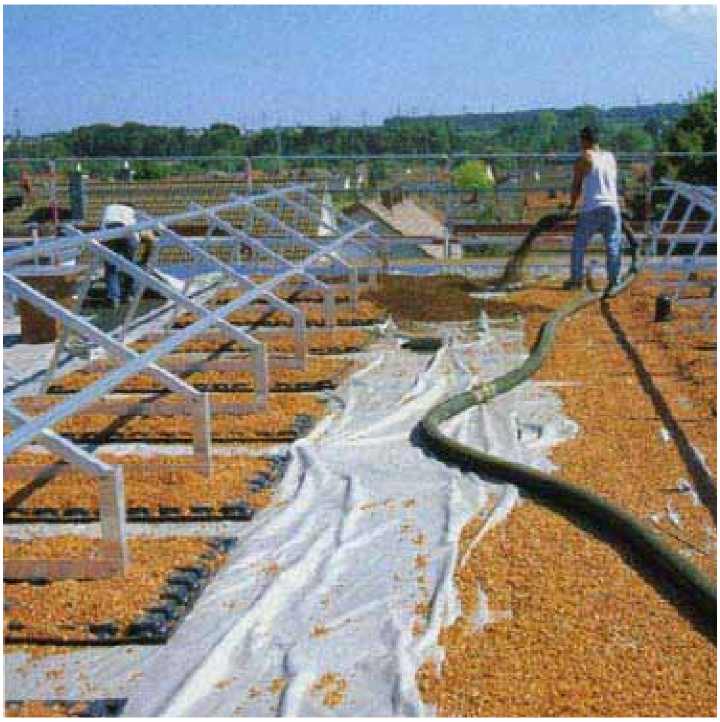
2. Solar panels work more efficiently when installed on a green roof as the ambient temperature is less than what it would be on a standard roof. This sets up optimum conditions for solar panels

primary and secondary school

1 2 3 4

type	extensive
construction	a multi layered system
extras	solar panels

3. The school has green roofs functioning on most of its roof tops



primary and secondary school

1 2 3 4

type	extensive
construction	a multi layered system
extras	solar panels

4. Illustrates how thedrainage layer or substrate may be installed

Beddington Zero Emissions Development

1 2 3 4

type	extensive
construction	a multi layered system
extras	solar panels

1. Beddington Zero Emissions is a low cost residential development which aims to achieve a net zero emissions target. The architects have introduced green roofs and solar panels as part of this no emission strategy

Beddington Zero Emissions Development

1 2 3 4

type	extensive
construction	a multi layered system
extras	solar panels

2. BedZed green roof.

Beddington Zero Emissions Development

1 2 3 4

type	extensive
construction	a multi layered system
extras	solar panels

3. BedZed solar panels

Beddington Zero Emissions Development

1 2 3 4

type	extensive
construction	a multi layered system
extras	solar panels

4. BedZed green roofs with exhausts to expel hot air

Vastra Hamnen - residential

1 2 3

type	extensive
construction	a multi layered system
	solar panels solar hot water
extras	

1. Vastra Hamnen is a residential development in the city of Malmo, Sweden. The development is part of a city wide innitative by the government for development to minimise its impact on the environment

Augustenborg Botanical Gardens

1 2 3 4 5

type	semi extensive intensive
construction	a multi layered system
extras	food production

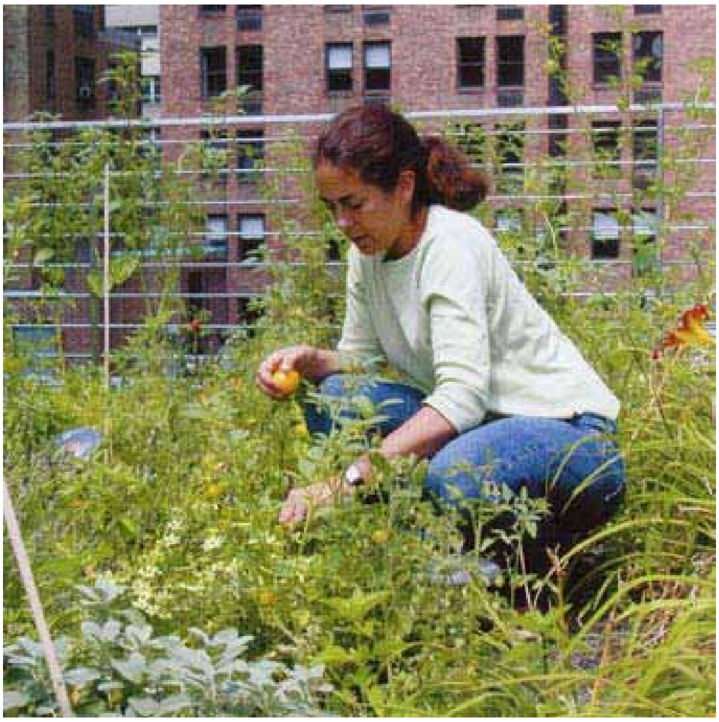
2. Other areas of the Augusternborg Botanical Gardens are purely an extensive green roof

Vastra Hamnen - residential

1 2 3

type	extensive
construction	a multi layered system
extras	solar panels solar hot water

3. Vastra Hamnen green roof



earth pledge - a kitchen garden

1 2 3 4 5

type	intensive
construction	a multi layered system
extras	kitchen garden which produces * eggplant * tomatoes * cucumber * capsicum * herbs

1. Earth Pledge developed a kitchen garden to provide fresh produce for the cafe/restaurant below.

earth pledge - a kitchen garden

1 2 3 4 5

type	intensive
construction	a multi layered system
extras	kitchen garden which produces * eggplant * tomatoes * cucumber * capsicum * herbs

2-5. A selection of some of the fresh produced grown on the top of the Earth Pledge kitchen garden in Manhatten, New York

Augustenborg botanical Gardens

1 2 3 4 5

type	semi extensive intensive
construction	a multi layered system
extras	food production

1. A different solution to a green roof whereby a shallow substrate is applied over the whole roof and deeper garden beds are developed where food produce is grown. People are able to walk between the garden beds on floating timber boards

Augustenborg Botanical Gardens

1 2 3 4 5

type	semi extensive intensive
construction	a multi layered system
extras	food production

2. Other areas of the Augusternborg Botanical Gardens are purely an extensive green roof

Augustenborg Botanical Gardens

1 2 3 4 5

type	semi extensive intensive
construction	a multi layered system
extras	food production

3-5. Augustenborg - different types of vegetation

Centro de Informacion

1 2 3

type	intensive
construction	a multi layered system
extras	food production

1. The Centro de Informacion building grows a variety of food crops as well as native plants to replace those that have been lost due to development

Centro de Informacion

1 2 3

type	intensive
construction	a multi layered system
extras	food production

2. An above surface irrigation system is shown here. This type of system is usually the least effective type of irrigation as water is lost in evaporation. An irrogation system needs to be carefully planned before being installed

Centro de Informacion

1 2 3

type	intensive
construction	a multi layered system
extras	food production

KPMG

1 2 3 4

type	intensive
construction	a multi layered system
extras	wetlands

1. KPMG have installed a wetland to filter the water that the green roof captures.. This water can then be reused fo various purposes.

KPMG

1 2 3 4

type	intensive
construction	a multi layered system
extras	wetlands

2. Reeds growing in the wetlands on top of the KPMG carpark

KPMG

1 2 3 4

type	intensive
construction	a multi layered system
extras	wetlands

KPMG

1 2 3 4

type	intensive
construction	a multi layered system
extras	wetlands

Milwaukee Metropolitan Sewerage District

1 2 3

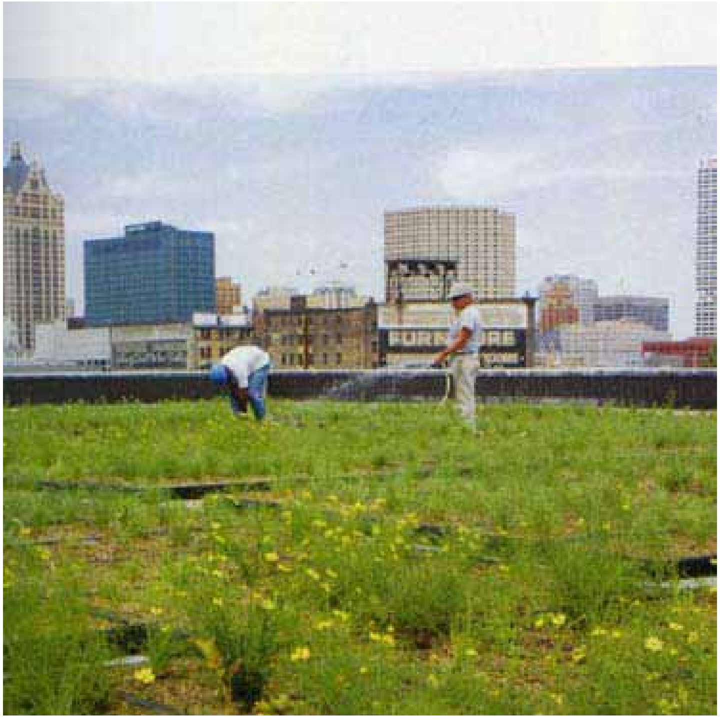
type	extensive
construction	modular system -
extras	Nil

1. A simplistic form of a modular system. This system contains all of the neccessary layers that make up a green roof including water proof membrane, root protection layer, drainage and substrate. Each module is approximately 150mm deep and can be easily manouvred if required.

Milwaukee Metropolitan Sewerage District

1 2 3

type	extensive
construction	modular system
extras	Nil



Milwaukee Metropolitan Sewerage District

1 2 3

type	extensive
construction	modular system
extras	Nil

Geno Haus

1 2 3 4

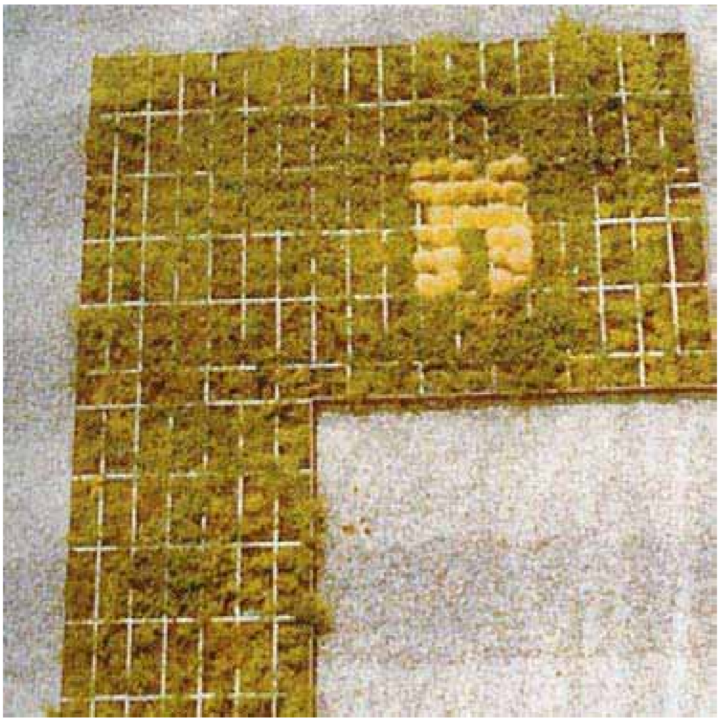
type	extensive
construction	modular system
extras	Nil

1. A simple interlocked modular system which has allowed for the vegetation to grow over each planter box

Geno Haus

1 2 3 4

type	extensive
construction	modular system
extras	Nil



Geno Haus

1 2 3 4

type	extensive
construction	modular system
extras	Nil

Geno Haus

1 2 3 4

type	extensive
construction	modular system
extras	Nil

Ecohouse

1 2 3 4

type	extensive
construction	semi - modular
extras	Nil

Ecohouse

1 2 3 4

type	extensive
construction	semi - modular
extras	Nil

Ecohouse

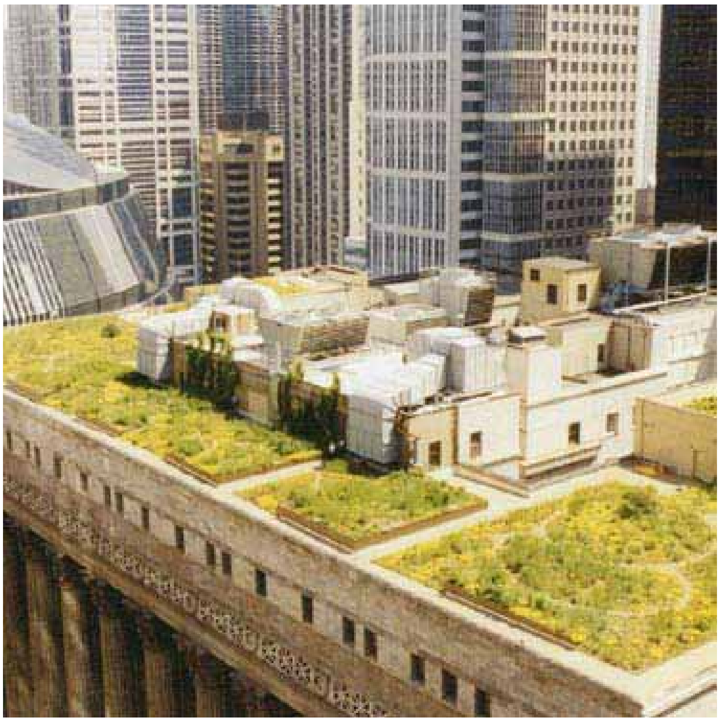
1 2 3 4

type	extensive
construction	semi - modular
extras	Nil

Ecohouse

1 2 3 4

type	extensive
construction	semi modular
extras	Nil



Chicago Town Hall

1

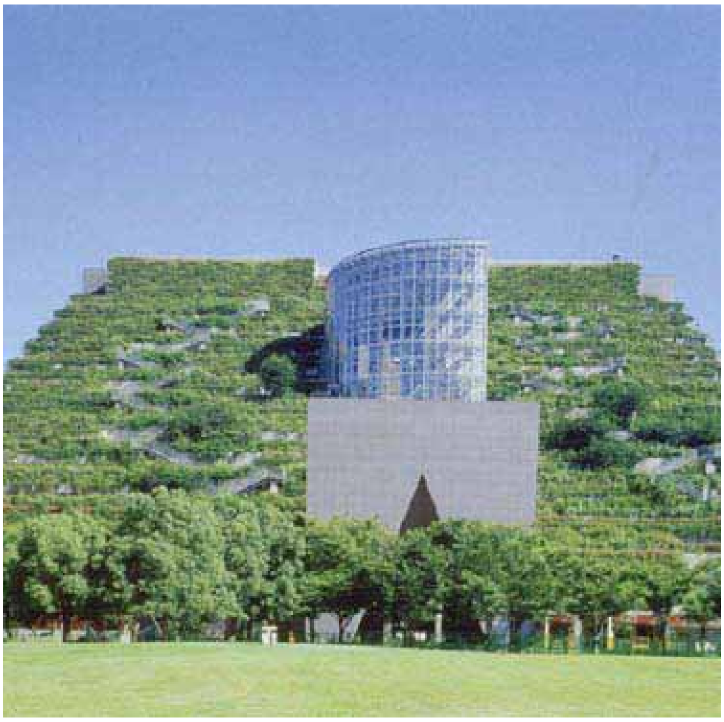
type	semi extensive extensive intensive
construction	a multi layered system
extras	Nil

Chicago Town Hall

type	semi extensive extensive intensive
construction	a multi layered system
extras	Nil

Chicago Town Hall

type	semi extensive extensive intensive
construction	a multi layered system
extras	Nil



ACROS Fukuoka

1 2 3 4

type	intensive
construction	a multi layered system
extras	Nil

ACROS Fukuoka

1 2 3 4

type	intensive
construction	a multi layered system
extras	Nil

ACROS Fukuoka

1 2 3 4

type	intensive
construction	a multi layered system
extras	Nil

ACROS Fukuoka

1 2 3 4

type	intensive
construction	a multi layered system
extras	Nil

Casa Bautrager

1 2 3

type	intensive
construction	a multi layered system
extras	Nil

Casa Bautrager

1 2 3

type	intensive
construction	a multi layered system
extras	Nil

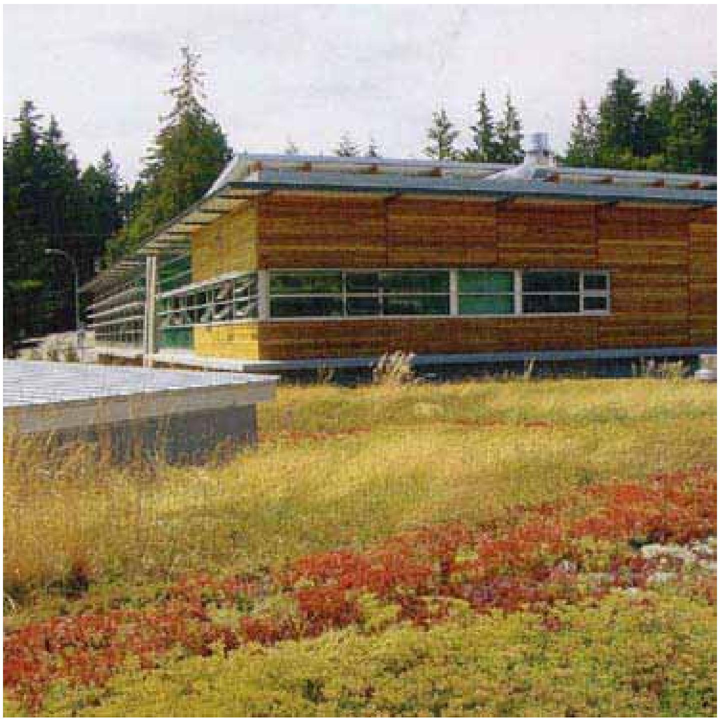
Casa Bautrager

1 2 3

type: intensive

construction: a multi layered system

extras: Nil



Sechelt Justice Service Centre

1 2 3 4

type: extensive

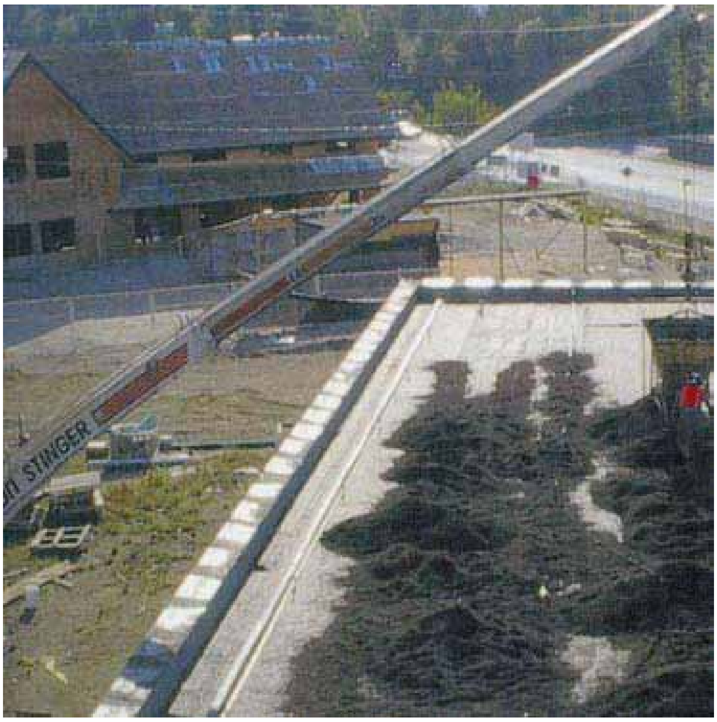
construction: a multi layered system

extras: Nil

Sechelt Justice Service Centre

1 2 3 4

type	extensive
construction	a multi layered system
extras	Nil



Sechelt Justice Service Centre

1 2 3 4

type	extensive
construction	a multi layered system
extras	Nil

Sechelt Justice Service Centre

1 2 3 4

type	extensive
construction	a multi layered system
extras	Nil

Heinz

1 2 3

type	semi extensive
construction	a multi layered system
extras	Nil

Heinz

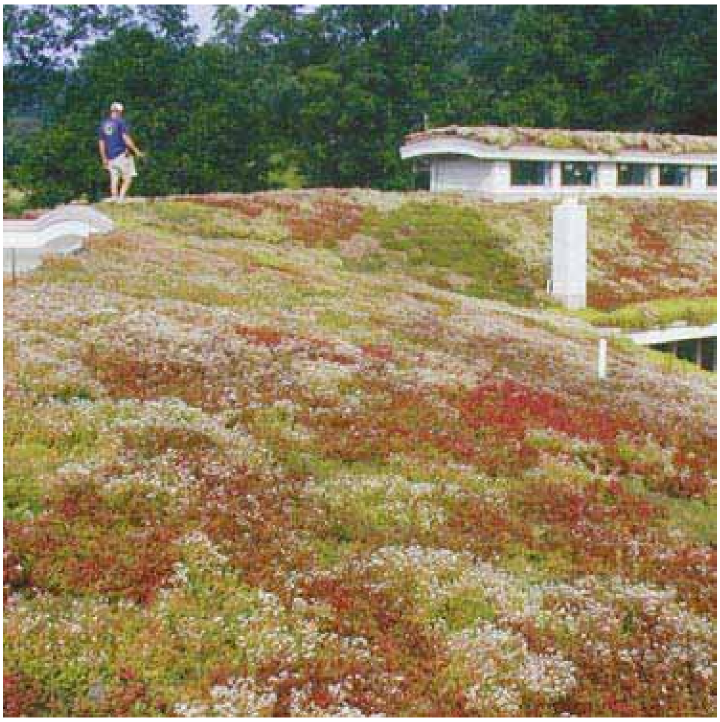
1 2 3

type	semi extensive
construction	a multi layered system
extras	Nil

Heinz

1 2 3

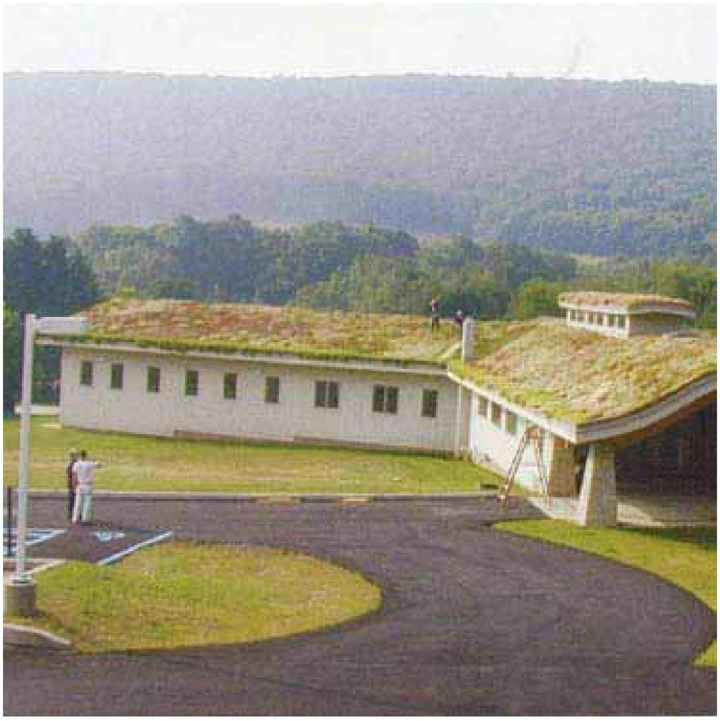
type	extensive
construction	a multi layered system
extras	Nil



Life Expression Chiropractic Centre

1 2

type	extensive
construction	a multi layered system
extras	Nil



Life Expression Chiropractic Centre

1 2

type	extensive
construction	a multi layered system
extras	Nil

Arbroath Abbey Visitor Centre

1

type	extensive
construction	a multi layered system
extras	Nil

St Lukes Science Centre Healing Garden

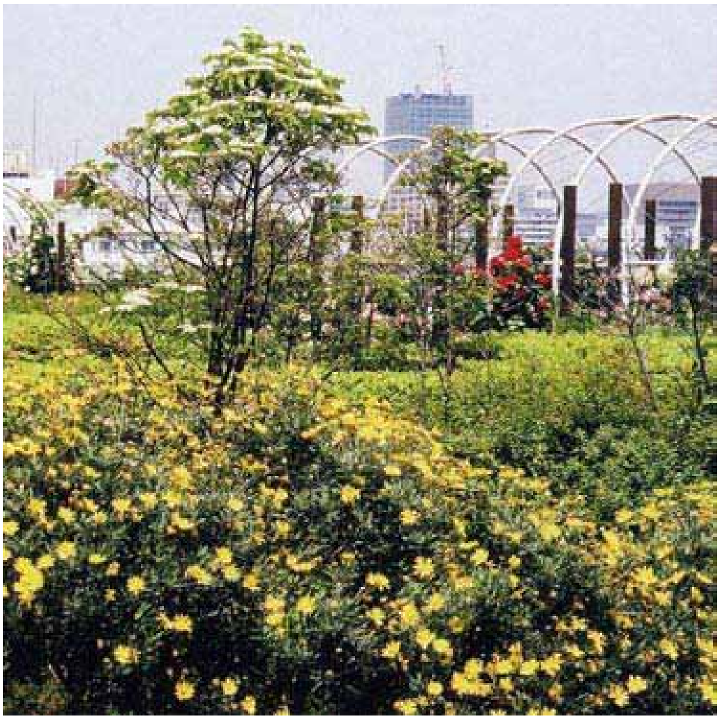
1 2 3 4

type	intensive
construction	a multi layered system
extras	Nil

St Lukes Science Centre Healing Garden

1 2 3 4

type	intensive
construction	a multi layered system
extras	Nil



St Lukes Science Centre Healing Garden

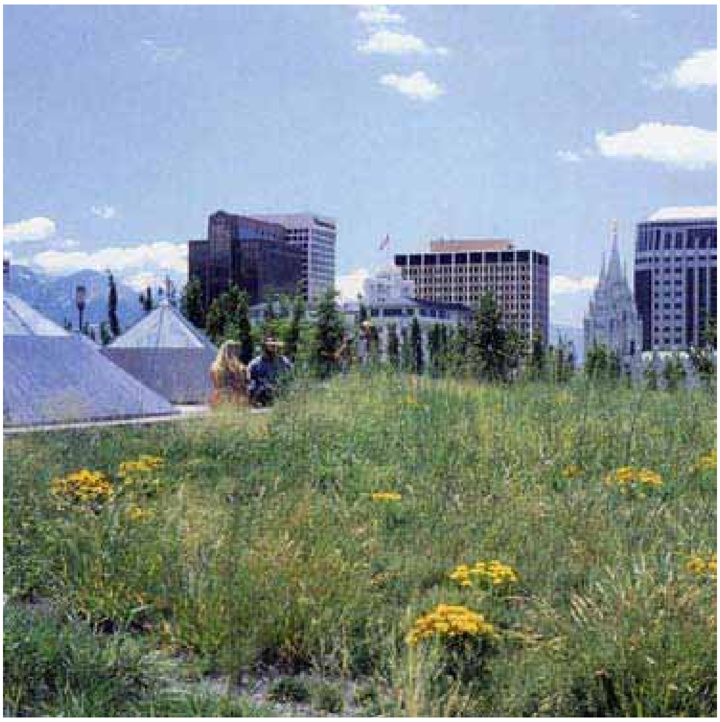
1 2 3 4

type	intensive
construction	a multi layered system
extras	Nil

St Lukes Science Centre Healing Garden

1 2 3 4

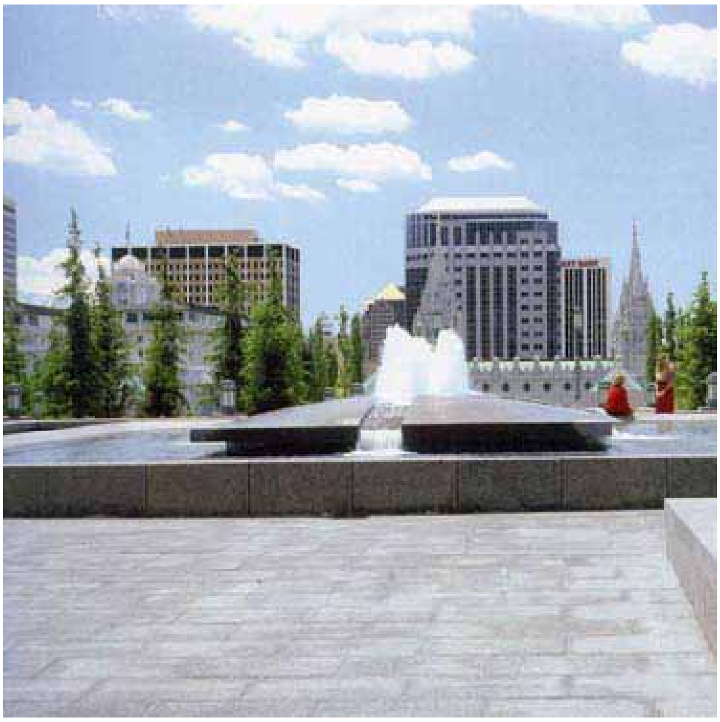
type	intensive
construction	a multi layered system
extras	Nil



Church of Jesus Christ Latter Day Saints

1 2 3 4

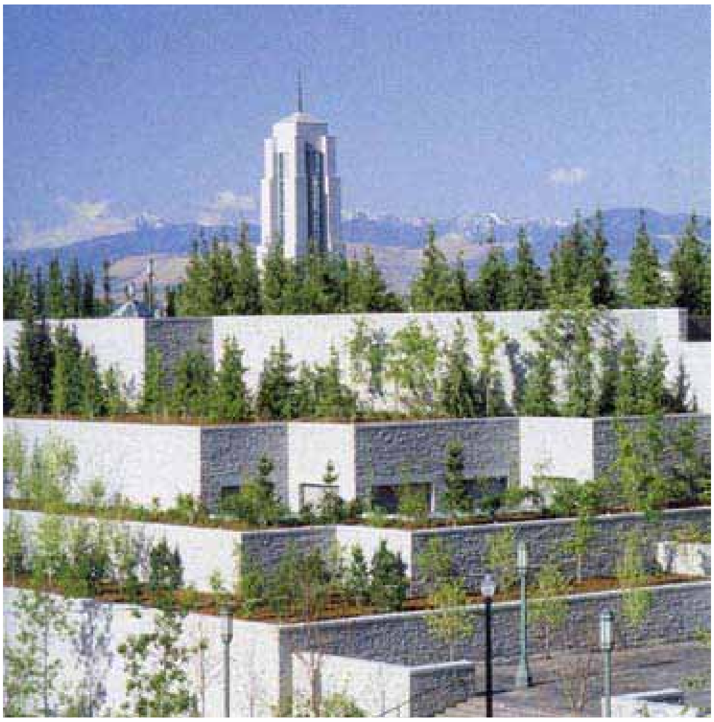
type	intensive
construction	a multi layered system
extras	Nil



Church of Jesus Christ Latter Day Saints

1 2 3 4

type	intensive
construction	a multi layered system
extras	Nil



Church of Jesus Christ Latter Day Saints

1 2 3 4

type	intensive
construction	a multi layered sys-
extras	Nil

Church of Jesus Christ Latter Day Saints

1 2 3 4

type	intensive
construction	a multi layered system
extras	Nil

Roppongi Hills

1 2

type	intensive
construction	a multi layered system
extras	Nil

Roppongi Hills

1 2

type	intensive
construction	a multi layered system
extras	Nil

Orchid Meadow

1 2 3 4

type	semi extensive
construction	a multi layered system
extras	Nil

Orchid Meadow

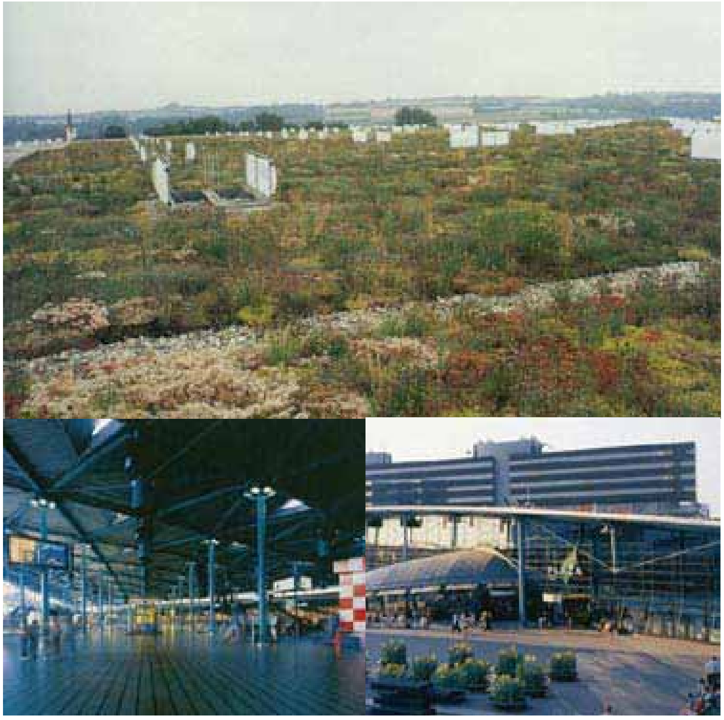
1 2 3 4

type	semi extensive
construction	a multi layered system
extras	Nil

Schiphol Plaza

1 2 3 4

type	extensive
construction	a multi layered system
extras	Nil



Schiphol Plaza

1 2 3 4

type	extensive
construction	a multi layered system
extras	Nil

Conservatorium of Music, Sydney

1

type	intensive
construction	a multi layered system
extras	Nil

M Central

1 2 3 4 5 6 7 8

type intensive

construction a multi layered system

extras Nil

M Central

1 2 3 4 5 6 7 8

type intensive

construction a multi layered system

extras Nil

M Central

1 2 3 4 5 6 7 8

type intensive

construction a multi layered system

extras Nil

M Central

1 2 3 4 5 6 7 8

type intensive

construction a multi layered system

extras Nil

M Central

1 2 3 4 5 6 7 8

type	intensive
construction	a multi layered system
extras	Nil

Freshwater Place

1

type	intensive
construction	a multi layered system
extras	Nil

Charles Sturt University

1

type	extensive
construction	a multi layered system
extras	Nil

Council House 2 (CH2)

1 2

type	intensive
construction	a multi layered system
extras	solar panels wind turbines cooling showers grey water treatment sewer mining

Council House 2 (CH2)

1 2

type	extensive
construction	a multi layered system
extras	solar panels wind turbines cooling showers grey water treatment sewer mining

DPI Marine and Freshwater Resource Institute

1 2

type	extensive
construction	a multi layered system
extras	wetlands

DPI Marine and Freshwater Resource Institute

1 2

type	extensive
construction	a multi layered system
extras	wetlands

30 The Bond

1 2 3

type	semi - extensive
construction	a multi layered system
extras	nil

30 The Bond

1 2 3

type	semi extensive
construction	a multi layered system
extras	nil

30 The Bond

1 2 3

type	semi extensive
construction	a multi layered system
extras	nil

Embarkation place

1 2

type intensive

construction a multi layered system

extras nil

Embarkation place

1 2

type intensive

construction a multi layered system

extras nil