Chapter 12
Greenroof design, construction and maintenance

12.1 Introduction

Greenroofs reintroduce vegetation on areas previously considered unavoidably impervious. They reduce overall site imperviousness and the resulting stormwater runoff. The vegetative cover on a greenroof can:

- improve air quality
- provide habitats for bird and insects
- help retain higher levels of humidity in city areas
- yield significant structural and cost benefits including reducing the expansion and contraction of roof membranes and insulating buildings against temperature extremes

12.2 Design approach

Typically, as shown in Figure 12-1, the cross section of a greenroof consists of:

- a waterproof membrane
- a root barrier
- an insulation layer (optional)
- a drainage layer
- filter fabric
- the engineered growing medium or soil substrate
- the plant material
- usually some form of a biodegradable wind blanket, such as a jute or coco liner-type mesh, is placed over the new plants to stabilise establishing roots

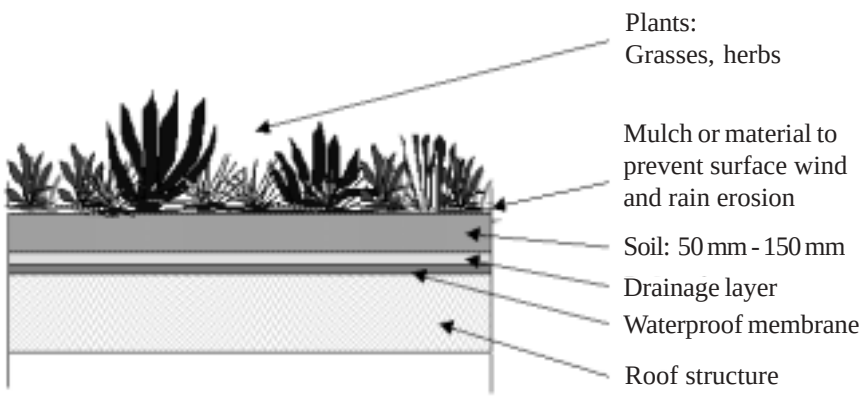
Successful greenroof installation requires an appreciation and consideration of plant biology, hydraulic engineering and architecture. Greenroofs are thoroughly engineered systems which address all the critical aspects of design, including:

- the saturated weight of the system and load bearing capacity of the underlying roof deck
- moisture and root penetration resistance of the waterproofing membrane
- resistance to wind shear, management of drainage
- the suitability of the proposed plant material

Plate 12-1: Example of a green roof

Ideally, even thin systems work optimally with two layers, separated by a geotextile fabric. The lower level is commonly very light-weight granular mineral material (usually a fired clay). Plant roots will

Figure 12-1
Greenroof standard detail



Section Not To Scale

penetrate through the geotextile and concentrate along the bottom of this layer where they find the best conditions for survival (cool temperatures and more consistent moisture). When roots are encouraged to grow higher up in the profile, they are much more vulnerable to the effects of varying temperature and moisture, consequently, if irrigation is used, water is introduced into this granular layer. If the substrate is chosen to have good water retention qualities, this greenroof will support a variety of plants without irrigation.

12.3 Applicability

Greenroofs can be used on a variety of roof types and on any property size, as their installation will not require the use of additional land. In Auckland's temperate climate, greenroofs should not be limited by the ability to establish and maintain vegetative cover.

12.3.1 Roof Slope

Generally the construction effort and cost of greenroofing increase with slope. Minimal slopes slow down water flow, and above 5^{o} or more it is necessary to prevent rapid runoff by increasing the retention capacity of the substrate. Light soils and water retaining substrates make it possible to vegetate sloping roofs up to 30^{o}.

However, roofs with a slope of 20^{o} or more require:

- steps to prevent soil slippage and erosion
- possible additional support with cross battens
- a raised grid structure to secure the plants' growing substrate.

12.3.2 Additional support considerations

The additional load of materials comprising and water held in a greenroof must be taken into account when accommodating the building's structural load. The calculation must be based on its saturated state. Below are some values from March, 1998 brochure from ZinCo International 3/98. These are calculated in accordance with the German National Standard DIN 1055 - Design Load for Buildings and give examples of roof covers and their approximate saturated weights for comparison:

- Normal roofing
- Gravel Surface 90 - 150 kg/m^2
- Paving Slabs 160 - 220 kg/m^2
- Vehicle Surface From 500 kg/m^2
- Greenroof 60 - 150 kg/m^2

For greenroofs with projected live loads of higher than 815 pascals, consultation with a structural engineer is required. Additional soil depths and larger plants will need more structural support, and a greater layer build-up of the greenroof system. Deeper planting beds can be constructed over internal columns and walls to provide a higher overall loading capacity.

12.3.3 Cost

The extra capital cost of a greenroof relates directly to the increased loading on the structure. An American report suggests a landscaped rooftop may cost about one third more than the same roof without vegetation. However, taking into account energy savings from insulation and a longer roof lifespan, the cost calculated as an annual figure over the lifetime of the greenroof may only be half that of a conventional roof.

Any costing should include structural, safety, irrigation and maintenance requirements.

12.4 Water quality performance

Wind, insulation and evapotranspiration create the extreme drying conditions on roof tops mean that runoff from a greenroof is often negligible. The vegetation and soil system provides similar treatment to that achieved by other soil filtration systems such as rain gardens, greenroofs provide both water quantity and water quality benefits. Greenroof runoff is accepted as having 75% suspended solids removal.

From a hydrologic standpoint the curve number for a greenroof can be calculated as 61 when considering an overall site curve number in the TP 108 analysis.

12.5 Greenroof components

Development of a greenroof requires careful consideration of each of the following system components:

- waterproof membrane
- insulation layer (optional)
- drainage layer
- filter fabric membrane
- water storage and irrigation
- soil growth medium
- plant material

Plate 12-2: Greenroof in an industrial area

12.5.1 Waterproof membrane system

Greenroof systems contain several layers of protective materials to convey water away from the roof deck.

The waterproofing layer may consist of a liquid-applied membrane or specially designed sheet membrane(s). Some believe the liquid-applied membrane provides a superior waterproofing and easier maintenance (McDonough + Partners, 1999). Because it is applied as a liquid, it must be installed directly on the roofing deck, so any existing roofing must be completely removed. With certain limitations, sheet membranes may be installed over existing roofing, although manufacturers prefer that existing roofing be removed. Many of the oldest greenroofs are waterproofed with mastic asphalt, but bitumen sheets with polyester carriers and SBS modified coatings are becoming more common.

Root resistance is achieved either by a laminated upper layer (usually copper) or by chemical additives in the coating. To ensure drainage capacity, the support to the waterproofing layer should have a slope of at least 1.5% (Hendriks and Hooker, March, 1994). Since plant roots discharge acids, the waterproof membrane must also be able to withstand this.

Correct application of the waterproof membrane is essential to the viability of the greenroof. Quality control is assured through knowledgeable roofing procedures and a water impermeability test immediately following membrane application, with a minimum duration of 24 hours (48 hours preferred).

Design standards that are applicable to waterproofing systems include:

- ASTM C981
- ASTM C898
- ASTM STP 1084
- the Architectural Graphic Standard
- the NRCA Roofing and Waterproofing Manual (RCI's Greenroof Workshop, August 6, 2001)

Water leakage from poor drainage or possible root puncture could lead to interior damage if the correct waterproofing membrane system, root barrier, and drainage layer are not selected. Vulnerable areas where leakage is possible include:

- abutting vertical walls
- roof vent pipes
- outlets
- air conditioning units
- perimeter areas.

A thorough water flood test needs to be conducted for leaks after installation of the waterproofing membrane to ensure quality control, certainly before the other layers are applied.

Plate 12-3: Close up view of varied vegetation on a greenroof

12.5.2 Insulation layer (optional)

The insulation layer is an optional component of a greenroof that prevents

Plate 12-4: Wetland on a roof

the water stored in the system from extracting heat energy from the underlying building. They are generally applied on existing roofs in retrofitting projects that may require an increase in the building's insulation value.

12.5.3 Drainage layer

Every greenroof must have a drainage layer to carry away excess water. On very shallow greenroofs the drainage layer may be combined with the filter layer. Unimpeded drainage is assured in greenroof systems because the drainage layer is applied over the entire roof area. A drainage layer is not always necessary on sloped roofs due to gravitaty drainage, but it is recommended to avoid ponding. The drainage layer can be made of gravel, rockwool or plastic.

Drainage can be used to partition the roof surface into compartments so that in the event of damage to the waterproofing, leaks can be easily found. The drainage layer serves the dual purpose of keeping the soil well aerated and in somes cases also acts as a water retention layer.

Drainage capacity must increase closer to the rainwater outlets, so a separation barrier 500 mm wide of large rounded pebbles should be installed along the eaves and near outlets. These rainwater outlets need to be accessible for seasonal cleaning (Hendriks and Hooker, 1994). Additionally, a shallow layer of gravel or pebbles placed approximately 400mm from the outside perimeter of the roof is recommended, providing additional drainage, fire control and access to the roof for maintenance.

12.5.4 Filter fabric membrane

The main function of the filter fabric/membrane is to hold the soil in place and prevent soil particles, plant debris and mulch, from entering and clogging the drainage layer below. Air and water are thus permitted to flow through, while the drainage layer and the actual drains are protected. Careful placement is required with overlaps of at least 100 mm to 160mm wide along vertical edges up to the plant material layer, finished with a strip of self-adhesive bitumen membrane. Typical materials are lightweight water-resistant polyester fiber mats or polypropylene-polyethylene mats (Hendriks and Hooker, 1994). These filter fabrics are the relatively inexpensive typical non-woven, non-biodegradable landscape fabric types found at most garden/home improvement stores.

It is essential to mark the position of the roof outlets before installing the protection layer, so that they can be located easily and the root barrier and protection mat cut accordingly. Protection of the membrane from these components could include 10mm of granular rubber (Hendriks and Hooker, 1994). Reliable detailing at penetration and perimeter areas with durable protection is critical. Any expansion joints which are not extended up through the waterproofing should remain free of plants. They can, for example, be covered by gravel or paving slabs so that they can be easily located and remain accessible at all times.

12.5.5 Water storage and irrigation

Plate 12-5: Greenroof as an aesthetic feature

Greenroofs must be able to store water and not dry out too quickly. If the soil 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. Certainly, the most ecologically correct and economically sustainable systems would require no or little human intervention.

An optional reservoir board layer, available from some companies, can be installed to retain and store small amounts of water. Additionally, either a simple automatic drip irrigation system with a manifold delivering water at the base of the profile can be installed. A more complete (and heavy and costly) irrigation system can be incorporated into any greenroof design.

Base level irrigators introducing water directly to the root zone are favoured for several reasons:

- Roots are encouraged to grow down into the deepest portion of the cover where temperature and moisture conditions are most stable
- a dry surface cover is maintained, discouraging the germination of weed seeds
- water losses due to evaporation are minimised

12.5.6 Soil / growth medium

Because natural soils are heavy, particularly when wet, greenroofs often involve the use of lightwieght soil mixes of high quality compost and recycled materials. These materials need to:

- be water permeable
- be water and air retentive
- be reistent to rot, heat, frost and shrinkage
- have good nutrient status
- provide an excellent rooting medium.

As plants appropriate for greenroofs favour poor soils, substrates that improve soil structure without enriching it are best. While grasses can be grown on lightweight rockwool or growing media as shallow as 10-25cm in depth, it is generally desirable to have as large a volume and depth of media as possible to contribute to wind stability, offset high drying rates and protect the roots from frost damage.

Plant material

Careful and regionally specific vegetative planning is critical to the long term success of any greenroofing project within the Auckland Region. Characteristics of vegetation typically used on greenroofs include:

- shallow root systems
- good regenerative qualities
- resistance to direct radiation, drought, frost and wind
- compatibility with the local range of temperature, humidity, rainfall, and sun/shade exposure
- drought tolerant

Most importantly for the artificial environment of a greenroof, plants need to be reviewed for their tolerance of drought conditions, as most systems are designed to be low maintenance and extensive irrigation is expensive and requires additional design.

The closest natural environment matching conditions found on greenroofs are coastal plant communities, or arid, rocky regions.

12.6 Design procedure

12.6.1 Initial steps

1. Estimate rainfall using TP108 for your site location.
2. Calculate pre- and post- site development curve numbers using a CN of 61 for the roof area.

Stormwater management will still need to be provided for overall site control but the roof area will not require treatment and use of the 61 CN will have a beneficial effect on overall site runoff (peak flow and volume).

12.6.2 Design steps

The following issues need to be addressed in addition to careful consideration of each layer of the greenroof system.

Windproofing

What is the speed and direction of winds blowing across the roof? How do they change daily and with the seasons? Is there a need to provide shelter from the wind?

Shade requirements

How do sun angles change daily and with the seasons as the sun moves across the roof? Where are the cool shaded spots, lightly shaded spots and full sun areas? Is overhead shading necessary?

12.7 Operation and maintenance

Thorough design of a greenroof system should reduce the need for maintenance. Due to the return of organic matter to the soil, additional fertilising is not usually necessary. Mowing and pruning or trimming of plants may sometimes be desirable for aesthetic reasons but correct choice of low growing, or limited size plants should reduce the need for this.

12.8 Case study

Roof area: 400m^2
Roof slope: 10%
Region: Auckland
Two layer profile

Design parameters
Waterproof membrane:
Soil depth: 0.10m
Irrigation required: no
Water storage required: no
Plant type: native grasses, succulents, herbs
Drainage system:
Saturated loading (to be incorporated into roof loading design):

12.9 Bibliography

Web resources:
www.greenroofs.com
www.cmhc-schl.gc.ca/en/imqualf/himu/wacon/wacon_088.cfm
www.Ecoroofs.com
www.portphillp.vic.gov.au
www.construction.ntu.ac.uk